MIT Technology Review

SPECIAL EDITION

10 Breakthrough Technologies p. 7
The Internet of DNA

50 Smartest Companies p. 45
Tesla's Grand Ambitions

Innovators Under 35 p. 66
Visionaries at Work

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Best in Tech 2015

10 Breakthrough Technologies

Some breakthroughs arrive ready to use, some set the stage for innovations to emerge later. Either way, the milestones on this list will be worth watching for years to come.

50 Smartest Companies

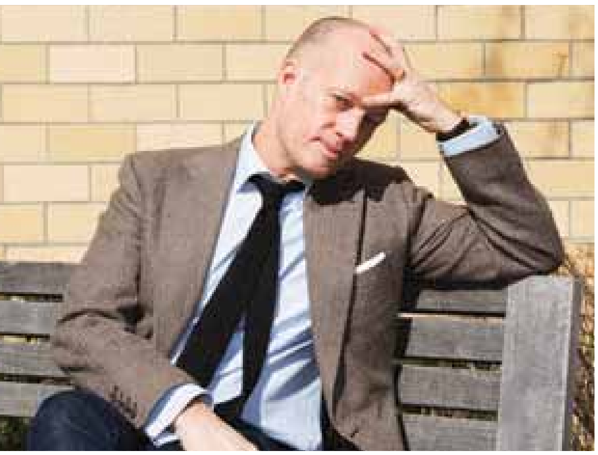
Too many apps, not enough big ideas: the standard complaint about modern enterprises. Wondering where the audacious, innovative, visionary companies are? Just see our list.

Innovators Under 35

Our stories on these young innovators offer a window into the challenges and rewards of creating technologies to address the world's greatest needs.

Cover art by Viktor Hachmang

From the Editor



GUIDO VITTI

Strictly speaking, these pages offer a way to wrap your mind around some of the most important companies, people, and technologies of our time. But what you'll also find is a window into the world itself—for there is no aspect of our world that is not in some way touched by technology.

Here you'll see stories on efforts to economically turn seawater into drinking water, and to get cars to talk to each other in order to reduce congestion and traffic deaths. You'll find new methods of detecting cancer early and getting Internet connectivity to people who've never had it. You'll find ideas for making good use of the unimaginably massive troves of DNA data being produced around the world.

In our young innovators list you'll read about people doing the hard work, contemplation, and painstaking research in fields like robotics, clean energy, Alzheimer's, online security, and space travel. You'll learn not only what they're doing but what inspired them to do it in the first place.

We hope you will be inspired reading about them.

Enjoy,

Jason Pontin
CEO, Editor in Chief, and Publisher
MIT Technology Review

CEO, Editor in Chief, and Publisher
Jason Pontin

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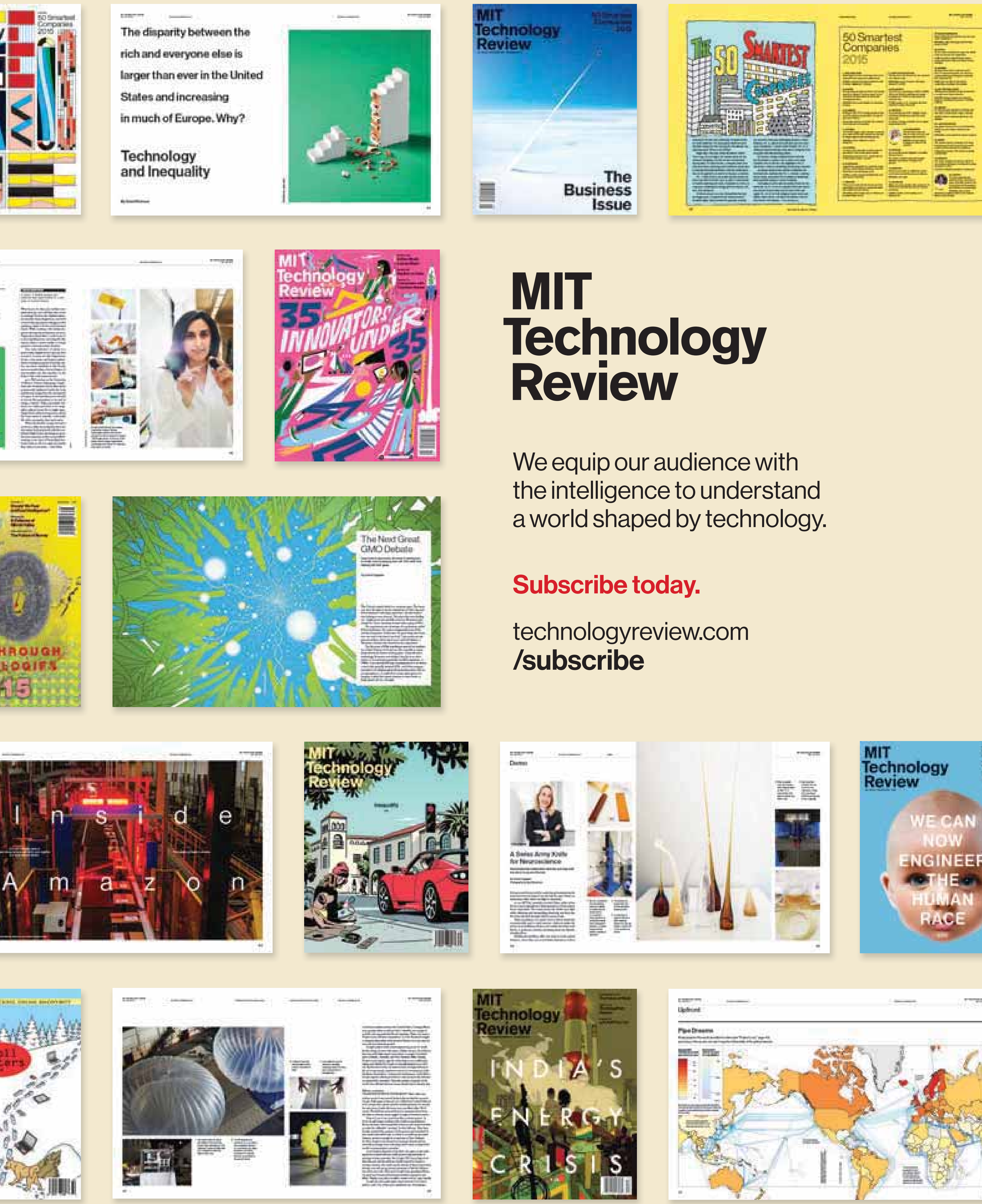
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The disparity between the rich and everyone else is larger than ever in the United States and increasing in much of Europe. Why?
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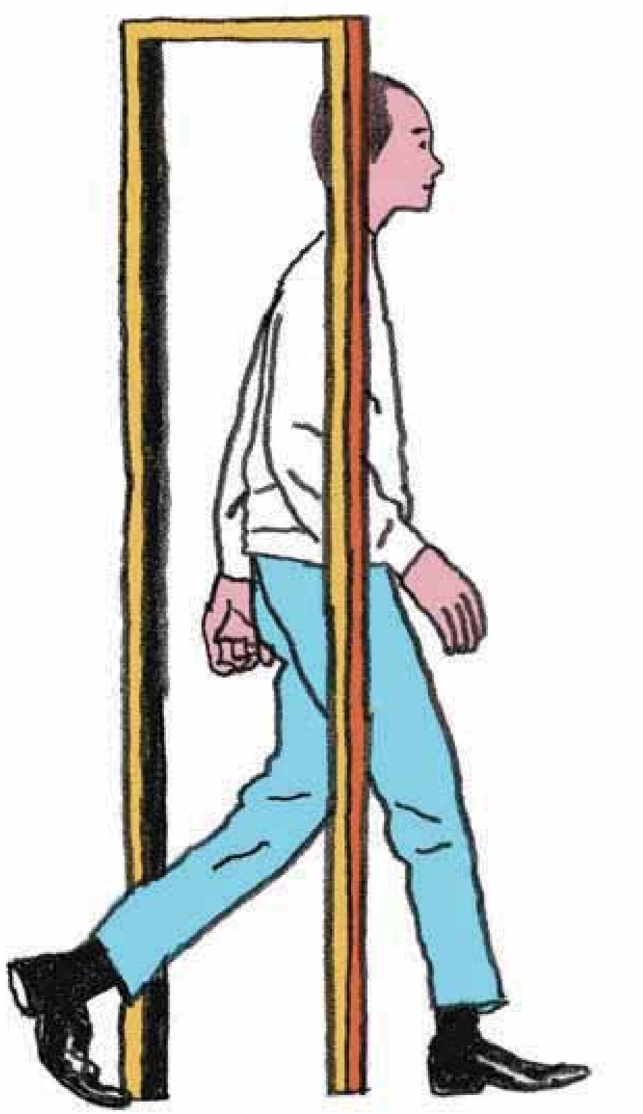
ELLIOTT EARLS

10 Breakthrough Technologies

Not all breakthroughs are created equal. Some arrive more or less as usable things; others mainly set the stage for innovations that emerge later, and we have to estimate when that will be. But we'd bet that every one of the milestones on this list will be worth following in the coming years.

Breakthrough	**Availability**
Magic Leap	1–3 years
Nano-Architecture	3–5 years
Car-to-Car Communication	1–2 years
Project Loon	1–2 years
Liquid Biopsy	now
Megascale Desalination	now
Apple Pay	now
Brain Organoids	now
Supercharged Photosynthesis	10–15 years
Internet of DNA	1–2 years



Magic Leap

A startup is betting more than half a billion dollars that it will dazzle you with its new approach to creating 3-D imagery.

By Rachel Metz

Logically, I know there isn't a hulking four-armed, twisty-horned blue monster clomping in circles in front of me, but it sure as hell looks like it.

I'm sitting behind a workbench in a white-walled room in Dania Beach, Florida, in the office of a secretive startup called Magic Leap. I'm staring wide-eyed through a pair of lenses attached to what looks like metal scaffolding that towers over my head and contains a bunch of electronics and lenses. It's an early prototype of the company's so-called cinematic-reality technology, which makes it possible for me to believe that the muscular beast with the gruff expression and two sets of swinging arms is actually in the room with me, hovering about seven feet in front of my face.

He's not just visible at a set distance. I'm holding a video-game controller that's connected to the demo station, and at the press of a button I can make the monster smaller or larger, move him right or left, bring him closer, or push him farther away.

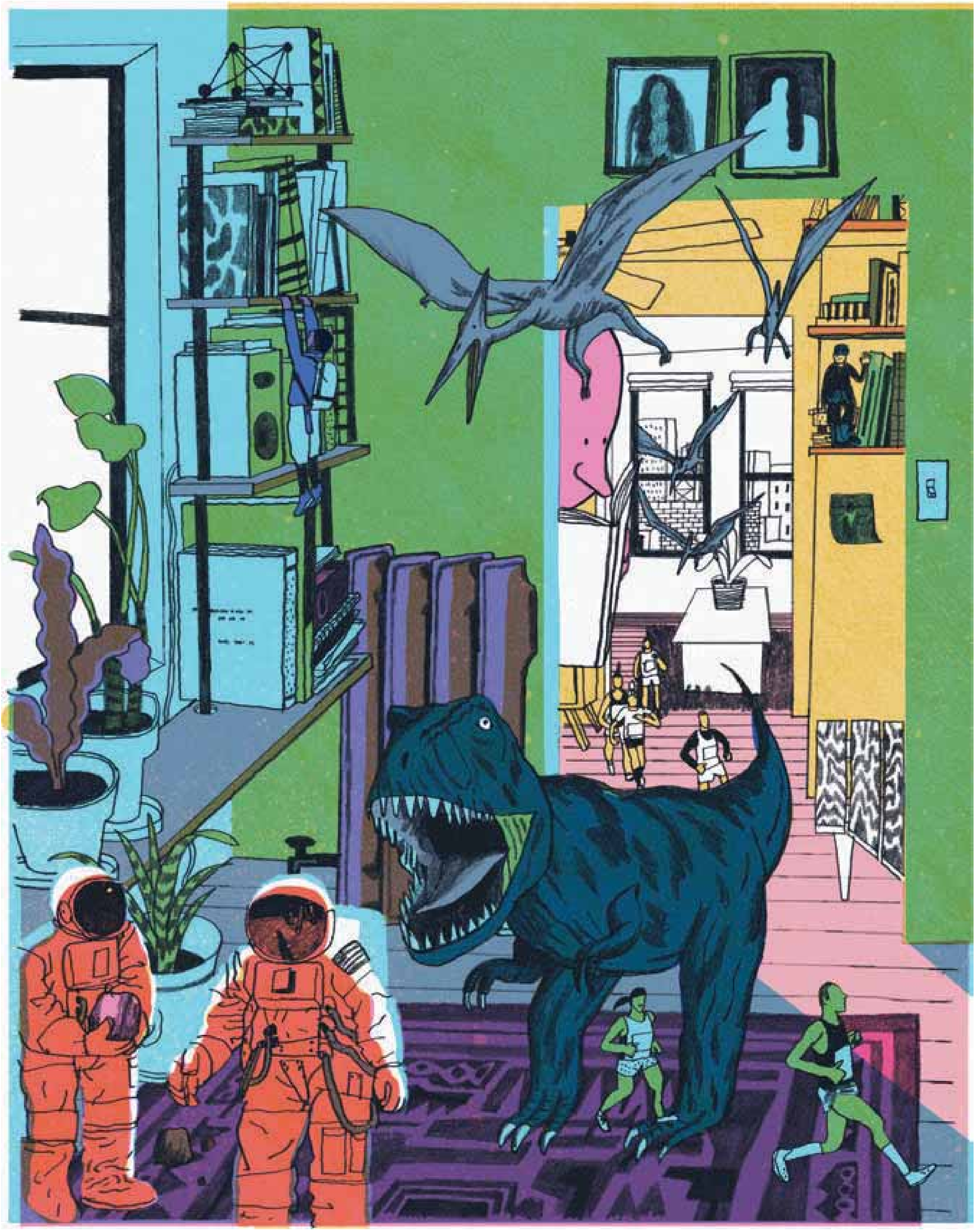
Of course, I bring him as near as possible; I want to see how real he looks up close. Now he's about 30 inches from my

Breakthrough
A device that can make virtual objects appear in real life.

Why It Matters
The technology could open new opportunities for the film, gaming, travel, and telecommunications industries.

Key Players
- Magic Leap
- Microsoft

JOSH COCHRAN



A video by the musician St. Vincent floats on a virtual screen in a break area in Magic Leap's headquarters.

eyeballs and, though I've made him pocket-sized, looks about as authentic as a monster could—he seems to have rough skin, muscular limbs, and deep-set beady eyes. I extend my hand to give him a base to walk on, and I swear I feel a tingling in my palm in expectation of his little feet pressing into it. When, a split second later, my brain remembers that this is just an impressively convincing 3-D image displayed in the real space in front of me, all I can do is grin.

Virtual- and augmented-reality technologies used in movies, smartphone apps, and gadgets tend to underdeliver on overhyped promises with images that look crappy. Typically that's because stereoscopic 3-D, the most commonly used method, is essentially tricking your eyes instead of working with the way you normally see things. It produces a sense of depth by showing each eye a separate image of the same object at a different angle. But since that forces you to look simultaneously at a flat screen in the distance and images that appear to be moving in front of you, it can make you dizzy and lead to headaches and nausea.

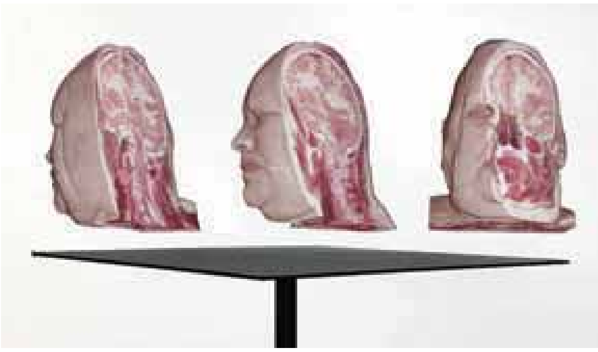
To be sure, stereoscopic 3-D has recently started getting better. The best system you can currently buy comes from Oculus VR, which Facebook purchased last spring for $2 billion; the $199 Gear VR, which was built in collaboration with Samsung and is aimed at software developers, lets you slide a Samsung smartphone into a headset to play games and watch videos.

But while Oculus wants to transport you to a virtual world for fun and games, Magic Leap wants to bring the fun and games to the world you're already in. And in order for its fantasy monsters to appear on your desk alongside real pencils, Magic Leap had to come up with an alternative to stereoscopic 3-D—something that doesn't disrupt the way you normally see things. Essentially, it has developed an itty-bitty projector that shines light into your eyes—light that blends in extremely well with the light you're receiving from the real world.

As I see crisply rendered images of monsters, robots, and cadaver heads in Magic Leap's offices, I can envision someday having a video chat with faraway family members who look as if they're actually sitting in my living room while, on their end, I appear to be sitting in theirs. Or walking around New York City with a virtual tour guide, the sides of buildings overlaid with images that reveal how the structures looked in the past. Or watching movies where the characters appear to be right in front of me, letting me follow them around as the plot unfolds. But no one really knows what Magic Leap might be best for. If the company can make its technology not only cool but comfortable and easy to use, people will surely dream up amazing applications.

Abovitz says he and his employees are trying to “blow away” their inner 11-year-olds.

COURTESY OF MAGIC LEAP



Top: In a demonstration of a medical or educational application, a cadaver head can be dissected one slice at a time. Bottom: A fake robot appears to stand on a real hand.

That's no doubt why Google took the lead in an astonishingly large $542 million investment round in Magic Leap in October 2014. Whatever it is cooking up has a good chance of being one of the next big things in computing, and Google would be crazy to risk missing out. The investment looked especially prescient in January, when Microsoft revealed plans to release a sleek-looking headset this year. HoloLens, which lets you interact with holograms, sounds as if it's very similar to what Magic Leap is working on.

Behind the magic

Magic Leap won't say when it will release a product or how much the thing will cost, beyond that the price will be within the range of today's consumer mobile devices. When I press founder and CEO Rony Abovitz about such details, he'll only smile and say, "It's not far away."

He's sitting behind the desk in his office, which is just down the road from the Fort Lauderdale–Hollywood airport. The shelves are lined with toys and View-Masters—the plastic gadgets that let you look at pictures in 3-D. Abovitz, 44, is a bear of a guy with a kind smile, and when I meet him he's dressed in black Nikes, a long-sleeved shirt, and slacks, his graying curly hair topped with a yarmulke. He's thoughtful and composed, which I find somewhat surprising given that the only time I had seen him before was in a video of his talk at a TEDx event in 2012 in Sarasota, Florida. It featured two people dressed as furry creatures called "Shaggles," Abovitz walking on stage dressed as an astronaut, and unintelligible rock music. Though the talk, called "The Synthesis of Imagination," came off as performance art (perhaps even a mockery of a TED talk), he swears there is a coherent message embedded in it; figure it out, he says, and he'll give you a yo-yo.

By day, Abovitz is a technology entrepreneur with a background in biomedical engineering. He previously founded Mako Surgical, a company in Fort Lauderdale that makes a robotic arm equipped with haptic technology, which imparts a sense of touch so that orthopedic surgeons have the sensation of actually working on bones as they trigger the robot's actions. Mako was sold to a medical technology company, Stryker, for nearly $1.7 billion in 2013. By night, Abovitz likes to rock out. He sings and plays guitar and bass in a pop-rock band called Sparkydog & Friends. And as he tells it, Magic Leap has its origins in both the robotic-surgery company and his life as a musician.

Combining virtual reality with the physical world appealed to Abovitz even at Mako. Although the robotic-arm technology could give surgeons the sensation of touching their instruments to bones, Abovitz also wanted to let them see virtual

The Forerunners—and the Competition

1838: Sir Charles Wheatstone invents the first stereoscope, which uses two angled mirrors to reflect a separate image into each eye. It gives viewers the sense that they're seeing one image in three dimensions.

1922: A silent 3-D film, *The Power of Love*, is released; viewers wear glasses with two different-colored lenses—red and green—to watch it.

1961: Philco employees build the first known head-mounted display, called Headsight, which features a helmet outfitted with a cathode-ray tube and magnetic head-position tracking.

1962: Morton Heilig receives a patent for the Sensorama, a big, boxy machine that shows short 3-D films on a small, one-person display, combined with sensations like smell and wind to make the experience immersive.

1985: Jaron Lanier, who is credited with coining the term "virtual reality," founds VPL Research. It sells such products as the Data Glove, which lets people use their hands to interact with a virtual environment, and the EyePhone, a head-mounted display.

1990: Boeing scientists Thomas Caudell and David Mizell build a wearable, see-through display that can superimpose lines on a board—aimed at making it easier for workers to assemble bundles of wires on boards that will then be installed on an airplane.

2010: Quest Visual releases Word Lens, an application that makes it possible to point a smartphone camera at a sign written in Spanish and have it appear in English on the screen.

2012: Palmer Luckey raises $2.4 million on the crowdfunding site Kickstarter for his stereoscopic 3-D virtual-reality gaming headset, Oculus Rift. Two years later, Facebook will buy Oculus for $2 billion.

2015: Months after Google invests in Magic Leap, Microsoft shows off the HoloLens, which also uses a technology other than stereoscopic 3-D to make virtual objects appear to be integrated with the real world. It plans to release the gadget in early 2016.

bones as they went about this work. Over and over, he says, he tried out head-mounted displays made by different companies, but he was disappointed with them all. "They were all just complete crap," he says. "You'd put it on and it would give you a headache and it was awful, and I was wondering, 'Why is this so bad?'"

At the same time, Abovitz also wanted to take Sparkydog & Friends on a virtual tour. In U2's 1987 video for "Where the Streets Have No Name," the group, in a nod to an earlier move by the Beatles, plays an impromptu show on the roof of a Los Angeles liquor store. Abovitz yearned for his band to be able to do that, but virtually, and on a thousand rooftops at once.

About four years ago, he started mulling the problem over with John Graham Macnamara, a high school friend who had dropped out of Caltech's theoretical physics program. They became captivated by the idea of displaying moving holograms like the one in *Star Wars*. Holograms—3-D images that can be viewed from many angles—are made by accurately re-creating light fields, the patterns made when light rays bounce off an object. But Abovitz figured it would cost a lot and take lots of time to project even low-resolution holographic images. At one point, he remembers muttering, "There is no display that can actually work."

The next morning, though, he awoke with an idea: why bother with the painstaking steps needed to send a hologram out into a room for multiple people to see at once? Why not, instead, essentially make a hologram that only *you* see, doing it in a way that is natural for the eyes and brain to perceive, unlike stereoscopic 3-D? "We're spending half a billion dollars–plus to effectively make nothing happen to you, physiologically," Abovitz says.

The solution he and Macnamara and the rest of Magic Leap's team have come up with is still largely under wraps, and on the record they avoid discussing how the technology works except in vague terms, citing concerns about competition. But it's safe to say Magic Leap has a tiny projector that shines light onto a transparent lens, which deflects the light onto the retina. That pattern of light blends in so well with the light you're receiving from the real world that to your visual cortex, artificial objects are nearly indistinguishable from actual objects.

If the company can get this to work in a head-mounted display, showing images near the eyes and consistently refocusing them to keep everything looking sharp, it will make 3-D images much more comfortable to view, says Gordon Wetzstein, an assistant professor of electrical engineering at Stanford who researches computational imaging and displays. "If they do what people suspect they do," Wetzstein says, "it will be amazing."

From virtual to reality

Magic Leap is working feverishly to get to that point. Since building its first prototype in 2011, the company has continued to shrink its technology down.

Already it works on something smaller than the unwieldy scaffolding I used. In another demonstration, using hardware on a cart, I can poke at a tiny flying steampunk robot, a character from a first-person-shooter game called Dr. Grordbort's Invaders that Magic Leap is making with Weta Workshop, which created many of the special effects in the *Hobbit* movies. The robot can follow my finger around with surprising accuracy, right between the cubicles in Magic Leap's office.

To judge from a look I get at a design prototype—a realistic-looking piece of hardware that's completely nonfunctional—the company appears to be aiming to fit its technology into a chunky pair of sports sunglasses wired to a square pack that fits into your pocket. A somewhat similar image in a patent application Magic Leap filed in January suggests as much, too. The company won't say for sure, though; Abovitz confirms that the headset will be a glasses-like wearable device, but I have to twist his arm to get him to agree to use even that hazy phrasing on the record.

It's clear that getting the technology into that small form will be very hard. The smallest demo hardware I've seen at Magic Leap can't yet match the experience of the bigger demo units. It includes a projector, built into a black wire, that's smaller than a grain of rice and channels light toward a single see-through lens. Peering through the lens, I spy a crude green version of the same four-armed monster that earlier seemed to stomp around on my palm. In addition to improving the resolution of smaller units, Magic Leap will have to cram in sensors and software that will track your eyes and fingers, so you can control and interact with its virtual creatures—which themselves will have to incorporate real-life objects into whatever they appear to be doing.

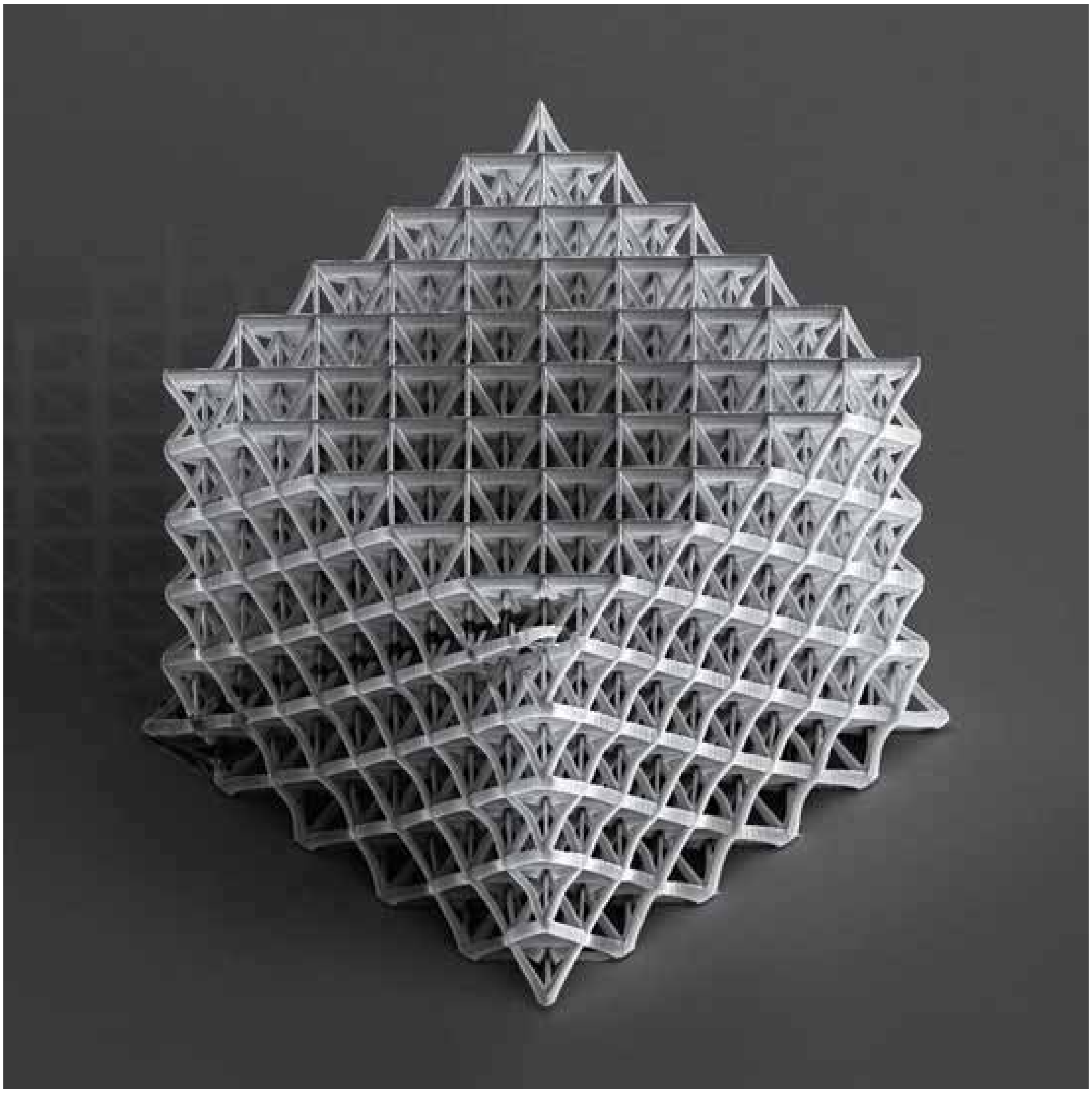
That's where last year's half-billion dollars of investment come in. Magic Leap is hiring like crazy. It's looking for software engineers for everything from eye tracking and iris recognition to the branch of artificial intelligence known as deep learning. It needs optical engineers, game designers, and other people who will dream up virtual objects to display. To give you a sense of where their minds might go, I saw ray guns and magic wands lying around the office. As its chief futurist, Magic Leap has hired the science fiction author Neal Stephenson, whose 1992 novel *Snow Crash* imagined a virtual world called the Metaverse.

The excitement of such quick growth is palpable at Magic Leap's brightly decorated headquarters, where staid office trappings are punctuated by red high-backed love seats and yellow chairs. Employees energetically describe the games, sensors, and ray guns they're working on.

With the massive investment last year, interest in the company has intensified. Abovitz says, "We went from 'Does anyone care about this?' to 'Okay, people do care.'" Now he and the team are feeling the weight of these expectations. He says, "The inner 11-year-old—we want to blow that away."

Abovitz was enigmatic in his brief appearance on a TEDx stage in 2012. "A few awkward steps for me; a magic leap for mankind," he said from inside his spacesuit.

COURTESY OF TEDX



This ceramic cube, about 50 micrometers on each side, is light because it is mostly air.

Nano-Architecture

A Caltech scientist creates tiny lattices with enormous potential.

By Katherine Bourzac

Breakthrough
Materials whose structures can be precisely tailored so they are strong yet flexible and extremely light.

Why It Matters
Lighter structural materials would be more energy-efficient and versatile.

Key Players
- Julia Greer, Caltech
- William Carter, HRL Laboratories
- Nicholas Fang, MIT
- Christopher Spadaccini, Lawrence Livermore National Laboratory

To visit the lab of Caltech materials scientist Julia Greer is to enter a realm where the ordinary rules of physical stuff don't seem to apply. Greer designs and builds nanomaterials that behave in ways surprising to those of us who spend our days in a world where strong materials like ceramic and steel tend to be heavy, while lightweight ones are weak. When Greer controls architecture at the nanoscale, the rules change.

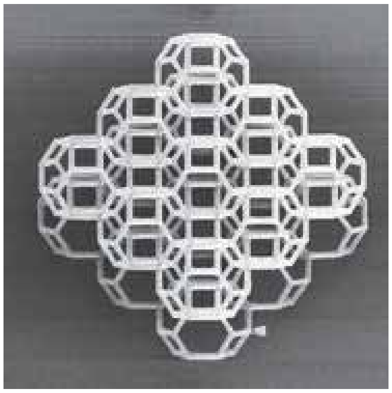
Conventional ceramics are strong, heavy, and (as anyone who has dropped a plate knows) brittle, prone to shattering. But last year Greer created a ceramic that is one of the strongest and lightest substances ever made. It's also not brittle. In a video Greer made, a cube of the material shudders a bit as a lab apparatus presses down hard on it, then collapses. When the pressure is removed, it rises back up "like a wounded soldier," she says. "It's unreal, isn't it?" Greer often rushes to meetings around campus on Rollerblades and talks so fast that she demands focused listening. Peering into this beautiful, otherworldly nanolattice on her computer screen, she slows down for a while.

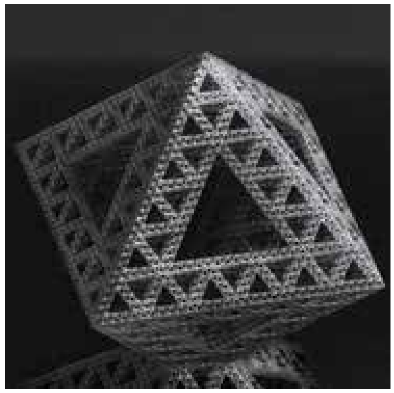
If materials like Greer's could be produced in large quantities, they could replace composites and other materials used in a wide range of applications, because they'd be just as strong at a fraction of the weight. Another possibility is to greatly increase the energy density of batteries—the amount of power they can hold at a given size. To do that, researchers have been trying to develop electrodes that are lighter than the ones used in today's batteries but can store more energy. However, promising electrode materials such as silicon are prone to cracking under strain. An electrode made by coating a metal nanolattice with silicon could have crack-resistant toughness in its very structure.

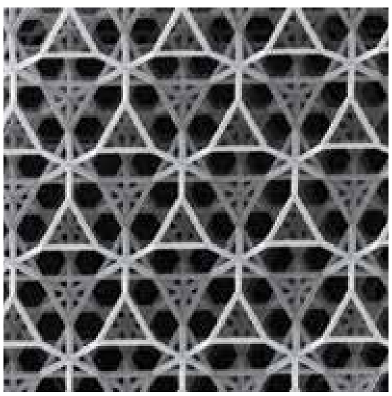
Greer in her Caltech lab, holding a model of the atomic structure of a metal.

Top right: These discs are used to store nanoscale lattices. Bottom right: A scanning electron microscope has an arm that can compress and bend nanostructures.

Photographs by Anais & Dax







Fine-tuning materials' architecture at the nanoscale yields distinctive patterns—and unusual properties.

COURTESY OF JULIA R. GREER

The key to creating such wondrous materials is an arsenal of specialized machines—some of which Greer has rebuilt to suit her purposes—that make it possible to precisely control structure at the nanoscale over relatively large areas. Greer jogs down two floors of stairs to the basement lab where she keeps these precision instruments to isolate them from vibrations. One machine, found behind two heavy black curtains, is a sort of 3-D printer that uses flashes of laser light to very slowly build intricate polymer scaffolds. A student of Greer's coats the polymer with metals, ceramics, or other materials and then shaves off the sides, making it possible to etch away the polymer inside. The result is a little block of material made up of nanoscale trusses crisscrossed like the struts in the Eiffel Tower—but each strut's walls are only about 10 nanometers thick.

Without Greer's method, building something like this is impossible. She shows me a sample that came about from an earlier collaboration with researchers at HRL Laboratories in Malibu, California, who are producing materials with larger, microscale trusses. It's made out of nickel and looks somewhat like a metal scouring sponge. When she lets it drift onto my palm, I can barely feel it touch down, and the subversion of expectations is confusing. This metal is, literally, lighter than a feather. It could make for ultralight thermal insulation—an application her HRL colleagues are pursuing.

The featherweight nickel shows the promise of architectural control in making new materials with weird properties. But it's also a reminder of how far Greer has to go in scaling up her methods: so far, she can't make enough of the nanostructured materials to cover your palm.

Greer is determined to use her nanofabrication methods for a variety of materials, and a long list of collaborators are interested in their unusual properties. She can space the nanoscale walls in light-emitting materials or thermal insulation to precisely control the flow of light or heat. She's working with two battery makers to use her nanostructures to study electrochemistry. And she is teaming with biologists to see whether the nanostructured ceramic could serve as a scaffold for growing bones—such as the tiny ones in the ear whose degeneration is one cause of deafness.

In hopes of making such applications feasible, she is working to speed up the high-resolution laser-printing process. Greer has a six-millimeter-square fleck of the nanostructured ceramic she made last year. It is about as thick as a sheet of paper but took about a week to make.

"For us to do scientific experiments, we don't need a large amount," she says. "The question now is: how do you scale this?" ■

Car-to-Car Communication

A simple wireless technology promises to make driving much safer.

By Will Knight

Breakthrough
Cars that can talk to each other to avoid crashes.

Why It Matters
More than a million people are killed on roads worldwide every year.

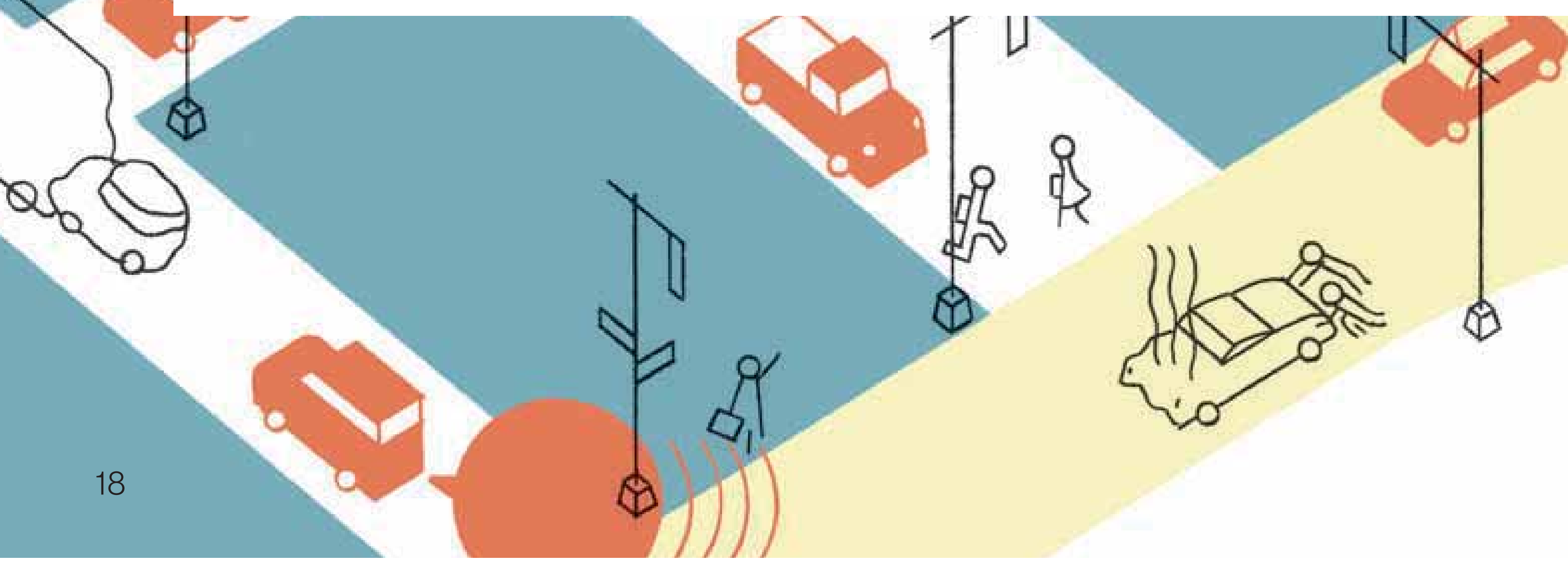
Key Players
- General Motors
- University of Michigan
- National Highway Traffic Safety Administration

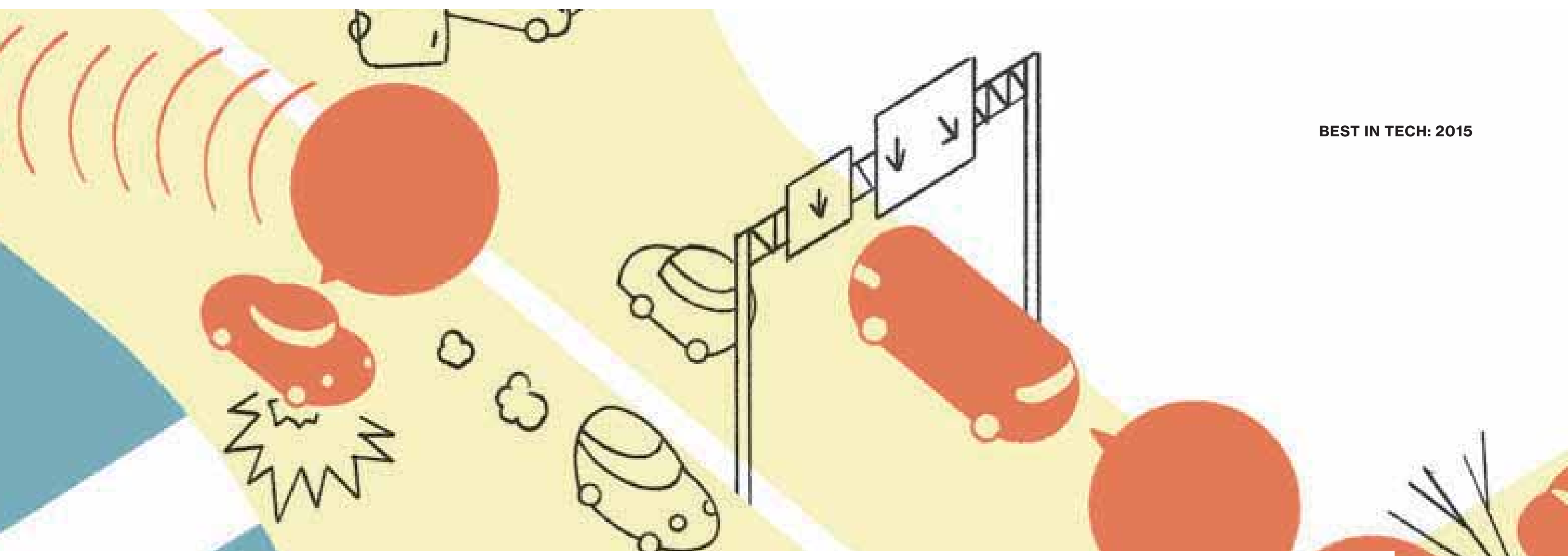
Hariharan Krishnan hardly looks like a street racer. With thin-rimmed glasses and a neat mustache, he reminds me of a math teacher. And yet on a sunny day in September 2014, he was speeding, seemingly recklessly, around the parking lot at General Motors' research center in Warren, Michigan, in a Cadillac DTS.

I was in the passenger seat as Krishnan wheeled around a corner and hit the gas. A moment later a light flashed on the dashboard, there was a beeping sound, and our seats started buzzing furiously. Krishnan slammed on the brakes, and we lurched to a stop just as another car whizzed past from the left, its approach having been obscured by a large hedge. "You can see I was completely blinded," he said calmly.

The technology that warned of the impending collision will start appearing in cars in just a couple of years. Called car-to-car or vehicle-to-vehicle communication, it lets cars broadcast their position, speed, steering-wheel position, brake status, and other data to other vehicles within a few hundred meters. The other cars can use such information to build a detailed picture of what's unfolding around them, revealing trouble that even the most careful and alert driver, or the best sensor system, would miss or fail to anticipate.

Already many cars have instruments that use radar or ultrasound to detect obstacles or vehicles. But the range





of these sensors is limited to a few car lengths, and they cannot see past the nearest obstruction.

Car-to-car communication should also have a bigger impact than the advanced vehicle automation technologies that have been more widely heralded. Though self-driving cars could eventually improve safety, they remain imperfect and unproven, with sensors and software too easily bamboozled by poor weather, unexpected obstacles or circumstances, or complex city driving. Simply networking cars together wirelessly is likely to have a far bigger and more immediate effect on road safety.

Creating a car-to-car network is still a complex challenge. The computers aboard each car process the various readings being broadcast by other vehicles 10 times every second, each time calculating the chance of an impending collision. Transmitters use a dedicated portion of wireless spectrum as well as a new wireless standard, 802.11p, to authenticate each message.

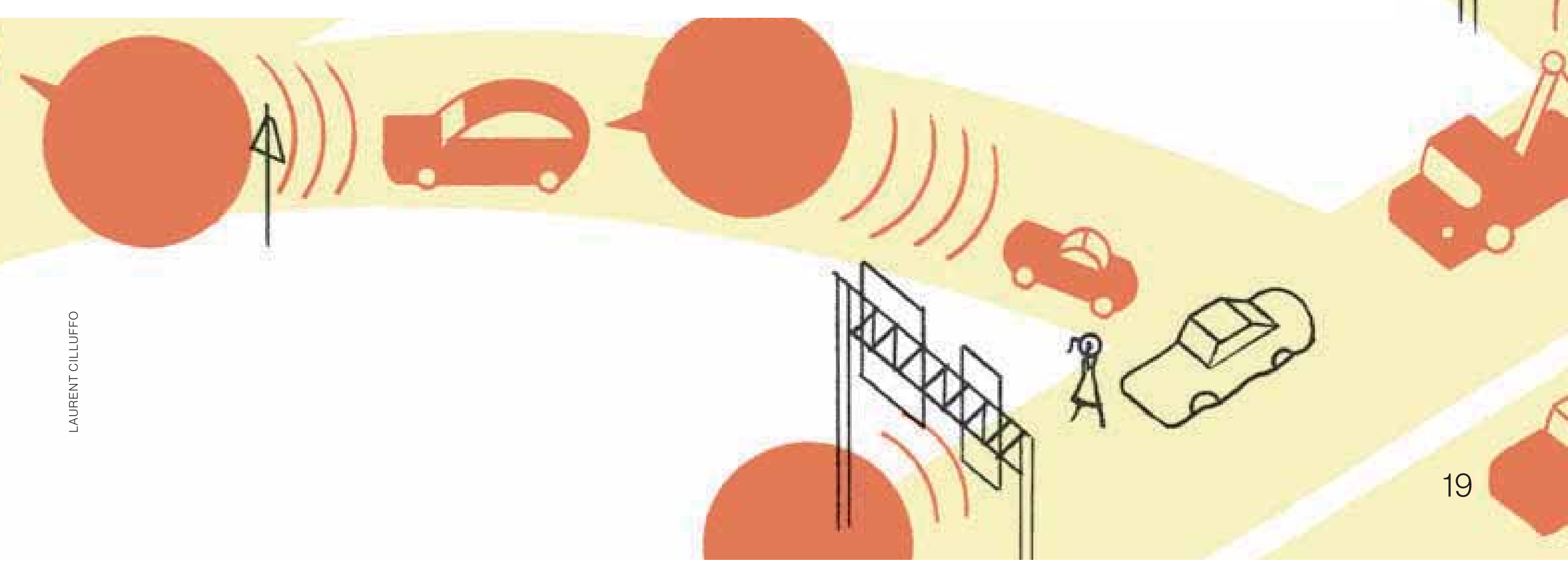
Krishnan took me through several other car-to-car safety scenarios in the company's parking lot. When he started slowly pulling into a parking spot occupied by another car, a simple alert sounded. When he attempted a risky overtaking maneuver, a warning light flashed and a voice announced: "Oncoming vehicle!"

More than five million crashes occur on U.S. roads alone every year, and more than 30,000 of those are fatal. The prospect of preventing many such accidents will provide significant impetus for networking technology.

Just an hour's drive west of Warren, the town of Ann Arbor, Michigan, has done much to show how valuable car-to-car communication could be. There, between 2012 and 2014, the National Highway Traffic Safety Administration and the University of Michigan equipped nearly 3,000 cars with experimental transmitters. After studying communication records for those vehicles, NHTSA researchers concluded that the technology could prevent more than half a million accidents and more than a thousand fatalities in the United States every year. The technology stands to revolutionize the way we drive, says John Maddox, a program director at the University of Michigan's Transportation Research Institute.

Shortly after the Ann Arbor trial ended, the U.S. Department of Transportation announced that it would start drafting rules that could eventually mandate the use of car-to-car communication in new cars. The technology is also being tested in Europe and Japan.

There will, of course, also be a few obstacles to navigate. GM has committed to using car-to-car communication in a 2017-model Cadillac. Those first Cadillacs will have few cars to talk to, and that will limit the value of the technology. It could still be more than a decade before vehicles that talk to each other are commonplace.



LAURENT CILLUFFO

Project Loon

Billions of people could get online for the first time thanks to helium balloons that Google will soon send over many places cell towers don't reach.

By Tom Simonite

Photographs by RC Rivera

You climb 170 steps up a series of dusty wooden ladders to reach the top of Hangar Two at Moffett Federal Airfield near Mountain View, California. The vast, dimly lit shed was built in 1942 to house airships during a war that saw the U.S. grow into a technological superpower. A perch high in the rafters is the best way to appreciate the strangeness of something in the works at Google—a part of the latest incarnation of American technical dominance.

On the floor far below are Google employees who look tiny as they tend to a pair of balloons, 15 meters across, that resemble giant white pumpkins. Google has launched hundreds of these balloons into the sky, lofted by helium. At this moment, a couple of dozen float over the Southern Hemisphere at an altitude of around 20 kilometers, in the rarely visited stratosphere—nearly twice the height of commercial airplanes. Each balloon supports a boxy gondola stuffed with solar-powered electronics. They make a radio link to a telecommunications network on the ground and beam down high-speed cellular Internet coverage to smartphones and other devices. It's known as Project Loon, a name chosen for its association with both flight and insanity.

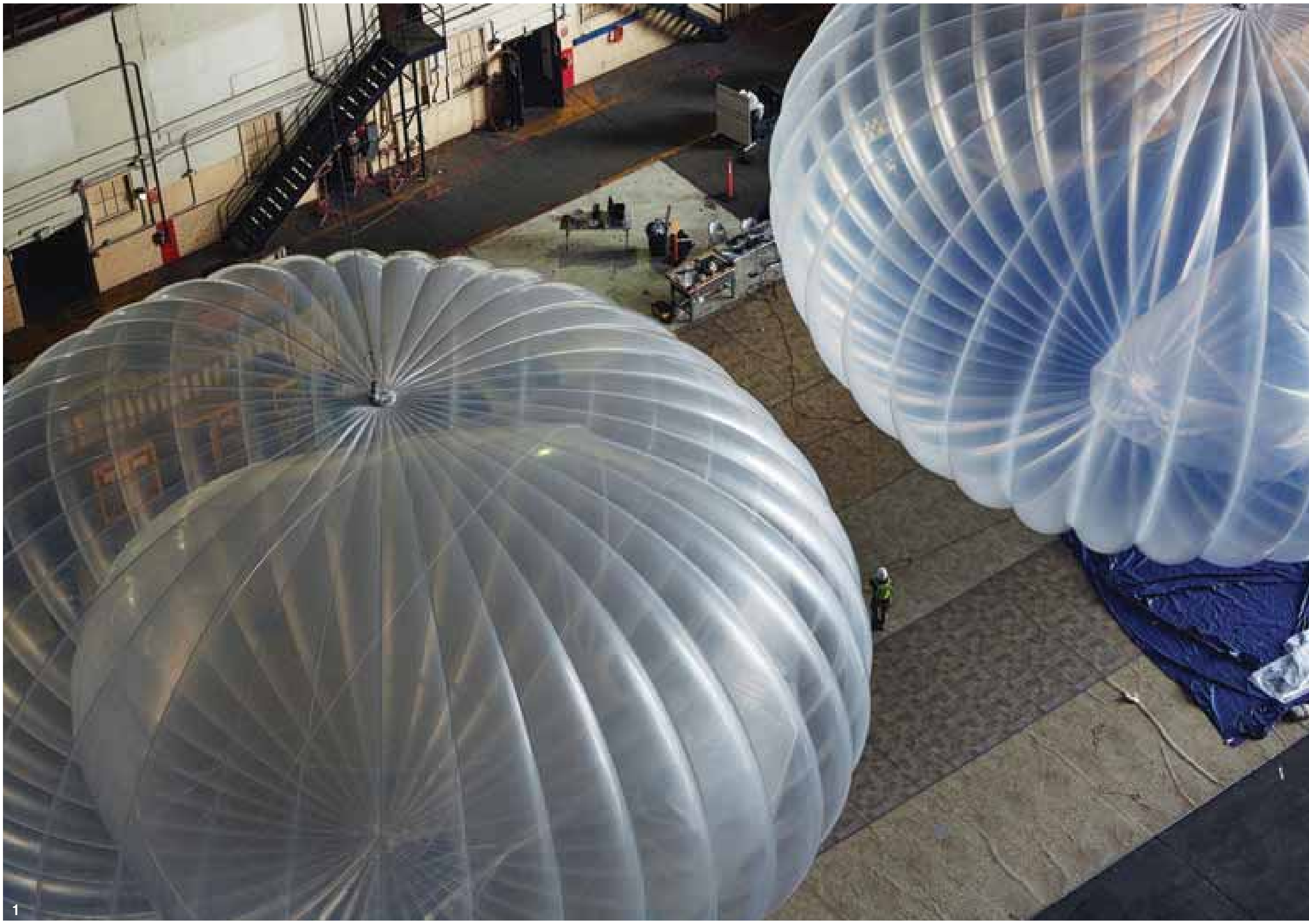
Google says these balloons can deliver widespread economic and social benefits by bringing Internet access to the 60 percent of the world's people who don't have it. Many of those 4.3 billion people live in rural places where telecommunications companies haven't found it worthwhile to build cell towers or other infrastructure. After working for three years and flying balloons for more than three million kilometers, Google says Loon balloons are almost ready to step in.

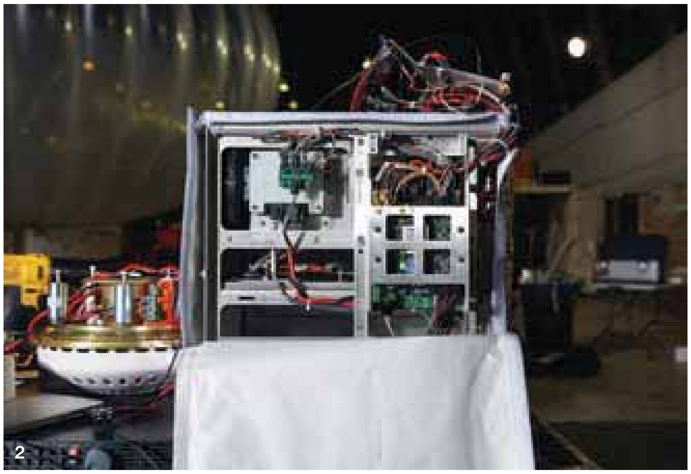
It is odd for a large public company to build out infrastructure aimed at helping the world's poorest people. But in addition to Google's professed desires to help the world, the economics of ad-supported Web businesses give the company other reasons to think big. It's hard to find new customers

Breakthrough
A reliable and cost-effective way to beam Internet service from the sky to places lacking it.

Why It Matters
Internet access could expand educational and economic opportunities for the 4.3 billion people who are offline.

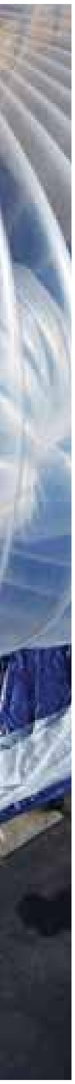
Key Players
- Google
- Facebook





1 The helium balloons above are inflated to the size they reach in the stratosphere. The "ballonets" inside are filled with air or emptied to make the balloon fall or rise.

2 The 15-kilogram box carried by a Loon balloon has computers that act on commands from flight engineers, as well as equipment to transmit Internet connectivity to the ground below.



3 A balloon that was intentionally burst in a test is checked for flaws.

4 Loon balloons can be landed by carefully releasing helium, but they pack a parachute for emergencies.

in Internet markets such as the United States. Getting billions more people online would provide a valuable new supply of eyeballs and personal data for ad targeting. That's one reason Project Loon will have competition: in 2014 Facebook bought a company that makes solar-powered drones so it can start its own airborne Internet project.

Google's planet-scale social-engineering project is much further along. In tests with major cellular carriers, the balloons have provided high-speed connections to people in isolated parts of Brazil, Australia, and New Zealand. Mike Cassidy, Project Loon's leader, says the technology is now sufficiently cheap and reliable for Google to start planning how to roll it out. By the end of 2015, he wants to have enough balloons in the air to test nearly continuous service in several parts of the Southern Hemisphere. Commercial deployment would follow: Google expects cellular providers to rent access to the balloons to expand their networks. Then the number of people in the world who still lack Internet access should start to shrink, fast.

Balloon revolution

"HARMLESS SCIENCE EXPERIMENT." That's what was written on the boxes carried by the balloons that the secretive Google X lab began to launch over California's Central Valley in 2012, along with a phone number and the promise of a reward for safe return. Inside the boxes was a modified office Wi-Fi router. The balloons were made by two seamsters hired from the fashion industry, from supplies bought at hardware stores.

Project Loon is now much less like a science project. In 2013, Google began working with a balloon manufacturer, Raven Aerostar, which expanded a factory and opened another to make the inflatable "envelope" for the balloons. That June, Google revealed the existence of the project and described its first small-scale field trials, in which Loon balloons provided Internet service to people in a rural area of New Zealand. In 2014, Project Loon focused on turning a functional but unwieldy prototype into technology that's ready to expand the world's communication networks.

Loon's leaders planned to buy their own space on the radio spectrum so their balloons could operate independently of existing wireless networks. But Google CEO Larry Page nixed that idea and said the balloons should instead be leased to wireless carriers, who could use the chunks of the airwaves they already own and put up ground antennas to link the balloons into their networks. That saved Google from spending billions on spectrum licenses and turned potential competitors into allies. "Nearly every telco we talk to wants to do it," says Cassidy.

Google has also made major improvements to its stratospheric craft. One of the most significant was developing a way to accurately pilot balloons across thousands of miles without any form of propulsion. The stratosphere, which typically is used only by weather balloons and spy planes, is safely above clouds, storms, and commercial flights. But it has strong winds, sometimes exceeding 300 kilometers per hour. Providing reliable wireless service means being able to guarantee that there will always be a balloon within 40 kilometers.

Google solved that aviation problem by turning it into a computer problem. Winds blow in different directions and at different speeds in different layers of the stratosphere. Loon balloons exploit that by changing altitude. As a smaller balloon inside the main one inflates or deflates, they can rise or fall to seek out the winds that will send them where Google wants them to go. It's all directed by software in a Google data center that incorporates wind forecasts from the U.S. National Oceanic and Atmospheric Administration into a simulation of stratospheric airflow. "The idea is to find a way through the maze of the winds," says Johan Mathe, a software engineer working on Loon's navigation system. A fleet of balloons can be coördinated that way to ensure there is always one over any particular area.

The first version of this system sent new commands to Loon balloons once a day. It could find a way for a balloon launched over New Zealand, for example, to dawdle over land until prevailing winds pushed it east and over the Pacific Ocean. Then it would have the balloon ride the fastest winds possible for the 9,000-kilometer trip east to Chile. But that system could only get balloons within hundreds of kilometers of their intended target. For tests of Internet service in New Zealand and elsewhere, the company had to cheat, launching

Project Loon aims to change the economics of Internet access.

Loon balloons nearby to make sure they would be overhead. In late 2014, Google upgraded its balloon navigation system to give balloons fresh orders as frequently as every 15 minutes. They can now be steered with impressive accuracy over intercontinental distances. In early 2015, a balloon traveled 10,000 kilometers and got within 500 meters of its desired cell tower.

Google has also had to figure out how to make the balloons sturdier, so they can spend more time in the stratosphere. The longer they stay up, the lower the cost of operating the network. However, weight considerations mean a balloon's envelope must be delicate. Made from polyethylene plastic with the feel of a heavy-weight trash bag, the material is easily pierced with a fingertip, and a stray grain of grit in the factory can make a pinprick-size hole that will bring a balloon back to earth after less than two weeks.

Preventing those leaks is the work of a squad inside Project Loon that has doggedly chased down every possible cause and come up with preventive measures. These researchers have studied balloons retrieved from the stratosphere, pored over video footage of others inflated to bursting on the ground, and developed a "leak sniffer" to find tiny holes by detecting helium. The leak squad's findings have led to changes in the design of the balloon envelope, fluffier socks for factory workers who must step on the envelopes during production, and new machines to automate some manufacturing steps. Altogether, Google has introduced the first major changes the balloon industry has seen in decades, says Mahesh Krishnaswamy, who oversees manufacturing for Project Loon and previously worked on Apple's manufacturing operations. Those changes have paid off. In the summer of 2013, Loon balloons lasted only eight days before having to be brought down, says Krishnaswamy. Today balloons last on average over 100 days, with most exceeding that time in flight; a handful last as long as 130 days.

Google has also made many improvements to the design of the Loon balloons' payloads and electronics. But it still has problems left to solve. For example, Google needs to perfect a way of making radio or laser connections between balloons, so that they can pass data along in an aerial chain to connect areas far from any ground station.

But Cassidy says Project Loon's technology is already at a point where stratospheric Internet service can be tested at a global scale. In 2015 his goal was to evaluate "quasi-continuous" service along a thin ribbon around the Southern Hemisphere. That ribbon is mostly ocean but would require a fleet of more than 100 Loon balloons circling the globe, says Cassidy. "Maybe 90 percent of the time," he says, "people in that ring will have at least one balloon overhead and be able to use it."

Good signals

"It was just for some minutes, but it was wonderful," says Silvana Pereira, a school principal in a rural area of northeastern Brazil. She's thinking back to an unusual geography class in which pupils at Linoca Gayoso Castelo Branco School could use the Internet thanks to a Loon balloon drifting, invisibly, high overhead. Internet service is nonexistent in the area, but that day's lesson on Portugal was enhanced by Wikipedia and

5 Among the upgrades Google is testing for its balloons (seen here from the rafters): using hydrogen, which is cheaper than helium, and having a motor move their solar panels to track the sun.

online maps. "They were so involved that the 45 minutes of a regular class wouldn't be enough to satisfy their demand for knowledge," says Pereira.

Her school is only around 100 kilometers from a metro area of more than one million people, but its location is too poor and sparsely populated for Brazil's wireless carriers to invest in Internet infrastructure. Google's goal is for Project Loon to change those economics. It should be possible to operate one Loon balloon for just hundreds of dollars per day, Cassidy says, and each one should be able to serve a few thousand connections at any time. The company won't reveal how much it is spending to set all this up, or even how many people work on the project.

Cassidy is also confident that his balloons will be able to hold their own against Internet delivered by drones (both Google and Facebook are working on that) or satellites (an idea being pursued by SpaceX CEO Elon Musk). Those projects are less far along than Loon, and it's expensive to build and power drones or launch satellites. "For quite some time, balloons will have a big cost advantage," Cassidy says. (Google might be hedging its bets with more than just drones: it recently joined with Fidelity Investments to make a $1 billion investment in SpaceX.)

Technology is not the only thing keeping 4.3 billion people offline, though. For example, policies in India mandate that telecom companies provide coverage to poor as well as rich areas, but the government hasn't enforced the rules, says Sunil Abraham, executive director of the Centre for Internet and Society, a think tank in Bangalore. He is also wary of Project Loon because of the way Google and other Western Internet companies have operated in developing countries in recent years. They have cut deals with telecoms in India and other countries to make it free to access their websites, disadvantaging local competitors. "Anyone coming with deep pockets and new technology I would welcome," he says, but he adds that governments should fix up their patchy regulatory regimes first to ensure that everyone—not just Google and its partners—really does benefit.

Those working on Project Loon are confident the public good will be served. They seem as motivated by a desire to make people's lives better as by Loon's outlandish technology. Cassidy's voice wavers with emotion when he thinks back to seeing the delight of Pereira's pupils during their Internet-enabled geography lesson. "This is a way of changing the world," he says.

The Liquid Biopsy

Fast DNA-sequencing machines are leading to simple blood tests for cancer.

By Michael Standaert

Everything about China is big, including its cancer problem. In some wealthier cities, like Beijing, cancer is now believed to be the most frequent killer. Air pollution, high rates of smoking, and notorious "cancer villages" scarred by industrial pollution are increasing death rates around the country. Liver cancer in particular is four times as prevalent as it is in the West, in part because one in 14 people in China carry hepatitis B, which puts them at risk. Of all the people worldwide who die of cancer each year, some 27 percent are Chinese.

In December 2014, I traveled by metro from Shenzhen to Hong Kong. I'd arranged to meet Dennis Lo, a doctor who has worked for nearly 20 years on a technique called the "liquid biopsy," which is meant to detect liver and other cancers very early—even before symptoms arise—by sequencing the DNA in a few drops of a person's blood.

Lo appeared fastidiously dressed as usual in a sharp blazer, a habit that called to mind formal dinners at the University of Oxford, where he studied in the 1980s. He is well known for having been the first to show that a fetus sheds bits of its DNA into the bloodstream of its mother. That finding, first made in 1997, has in recent years led to a much safer, simpler screening test for Down syndrome. By now more than one million pregnant women have been tested.

Today Lo is competing with labs around the world to repeat that scientific and commercial success by developing cancer screening tests based on a simple blood draw. That's possible because dying cancer cells also shed DNA into a person's blood. Early on, the amount is vanishingly small—and obscured by the healthy DNA that also

JAVIER JAÉN

circulates. That makes it difficult to measure. But Lo says the objective is simple: an annual blood test that finds cancer while it's curable.

Cancers detected at an advanced stage, when they are spreading, remain largely untreatable. In the United States, early detection is behind medicine's most notable successes in applying technology to cut deaths from common cancers. Half of the steep decline in deaths from colorectal cancer is due to screening exams like colonoscopies.

Lo's hospital is involved in two of the largest studies anywhere to prove that DNA analysis can also act as a screening test. The researchers are following a thousand people with hepatitis B to see if the DNA test can spot liver tumors before an ultrasound can. An even larger study is on nasopharyngeal carcinoma, a cancer that starts in the upper part of the throat. It's rare elsewhere in the world, but in south China men have a one in 60 chance of contracting it in their lifetimes.

This cancer appears to be linked to eating salted fish, as well as to a genetic susceptibility among Chinese and to infection by the Epstein-Barr virus, the germ that causes mononucleosis. The role of the virus, says Lo, creates a special situation. The test he developed searches for easy-to-spot viral DNA that dying cancer cells release into a person's plasma.

The study involves 20,000 healthy middle-aged men recruited in Hong Kong, and it's halfway done. Among the first 10,000 men screened, the researchers picked up 17 cases of cancer—13 of those at stage I, the earliest kind. Nearly all these men have now beaten the cancer with radiation treatment. The typical survival rate is less than 70 percent if patients seek out a doctor only when they have the most advanced symptoms, like a mass in the neck. "They would normally be just walking on the street not knowing that there was a time bomb waiting to go off, and now we have alarmed them," says Lo. As he sees it, every man in south China could be screened. One private hospital in Hong Kong has started offering the test already. "We believe it will save lives," he says.

Lo's lab is now locked in a technology race with scientists at other institutions, including Johns Hopkins University, to see if these ideas can turn into a general-purpose test for nearly any cancer, not only those involving a virus. The approach relies on gene-sequencing machines, which rapidly decode millions of short fragments of DNA that are loose in the bloodstream. The results are compared with the reference map of the human genome. Researchers can then spot the specific patterns of rearranged DNA that are telltale signs of a tumor.

Lo showed me several older sequencing machines during a tour of his laboratory, located at the Chinese University of Hong Kong. He says that the next generation of DNA sequencers, some no larger than a cell phone, could allow routine screening for cancer to become less expensive and far more widely used. For the time being, the cost of the DNA test being tried out on people at risk for liver cancer is still too high for routine use. Lo notes that the fetal tests were similarly expensive at first but that prices have since declined to as little as $800. That's led to much wider use. "The same thing should happen [with cancer]," he says.

Building on the foundations put in place by doctors like Lo, commercial interest in liquid biopsies has recently started to explode. Eric Topol, a professor of genomics at the Scripps Research Institute, predicted this January that the technology, applied to cancer and other diseases, will become the "stethoscope for the next 200 years." Jay Flatley, CEO of Illumina, the San Diego company that builds fast gene-sequencing machines, told investors this year that the market for such tests could be worth at least $40 billion. Calling the technology "perhaps the most exciting breakthrough" in cancer diagnostics, he said his company would begin offering researchers a liquid-biopsy test kit to facilitate the search for signs of cancer.

In addition to screening for cancer, liquid biopsies could be a way to help people already fighting the disease. Doctors can pick a drug according to the specific DNA mutation driving a cancer forward. Tests to identify the mutation are sometimes done on tissue taken from a tumor, but a noninvasive blood test would be appropriate in more cases. Lo told me that 40 percent of Chinese lung cancer patients have a mutation in one gene, *EGFR*, that would make them eligible for new targeted drugs.

Cancer comes in many types, and Lo says that for each, researchers must methodically make their case that liquid biopsies can really save lives. He believes he's close with nasopharyngeal cancer. "If you can screen and prognosticate in very common cancer types, that is the time when it will go mainstream," he says.

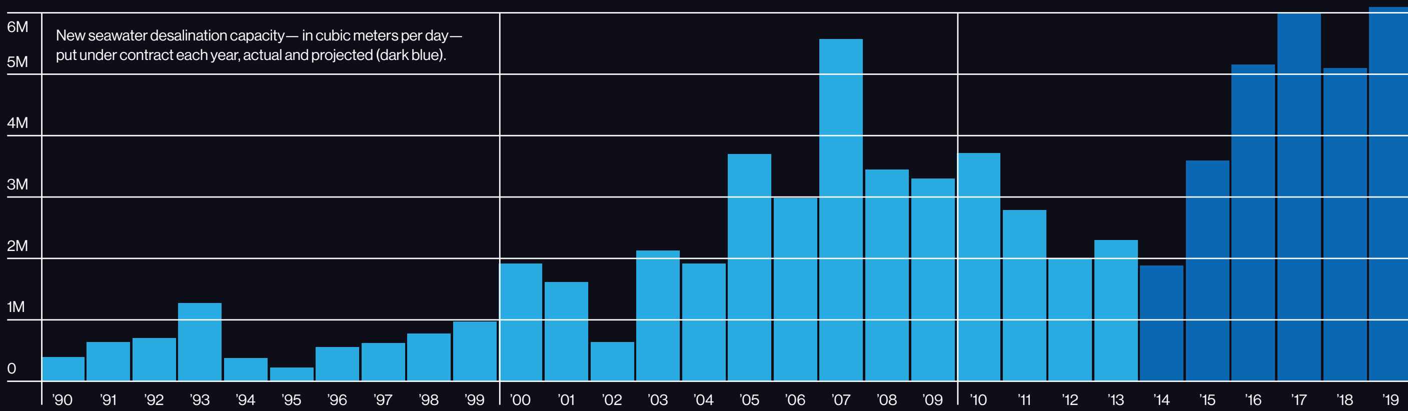
Breakthrough
A blood test to catch cancer early.

Why It Matters
Cancer kills some eight million people a year around the world.

Key Players
- Dennis Lo, Chinese University of Hong Kong
- Illumina
- Bert Vogelstein, Johns Hopkins

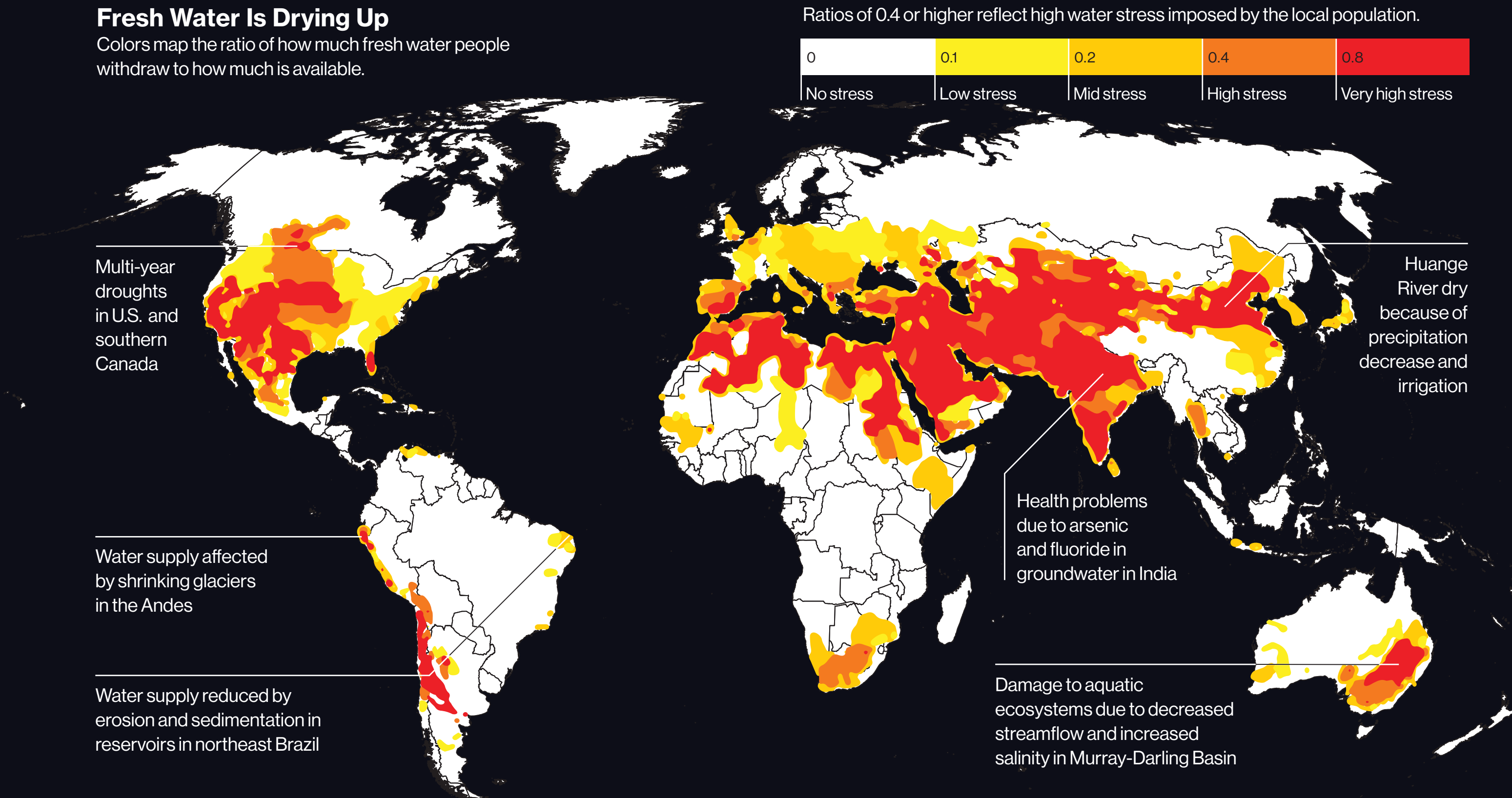
High Tide for Seawater Desalination

The world is experiencing a huge wave of seawater desalination projects.



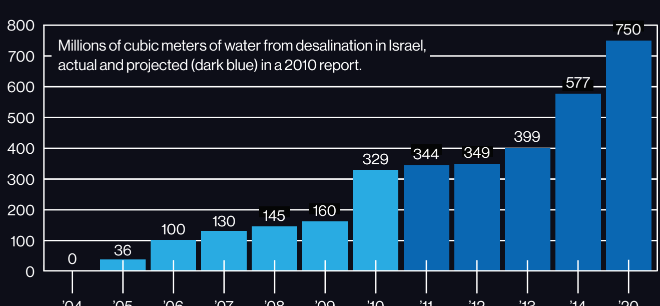
Fresh Water Is Drying Up

Colors map the ratio of how much fresh water people withdraw to how much is available.



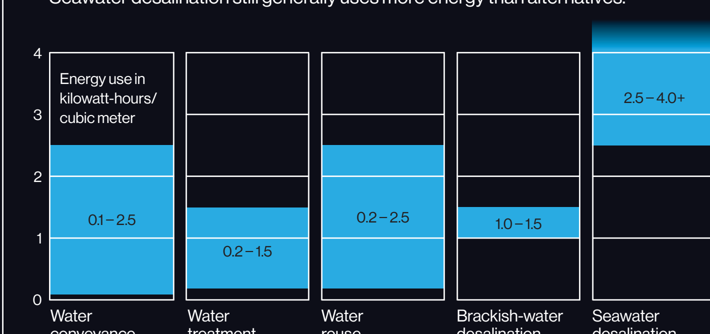
Israel's Turn to the Sea

Desalination will be providing 50 percent of drinkable water in Israel by 2016.



Water Supplies and Energy: No Free Drink

Seawater desalination still generally uses more energy than alternatives.



Megascale Desalination

The world's largest and cheapest reverse-osmosis desalination plant is up and running in Israel.

By David Talbot

Breakthrough
Demonstrating that seawater desalination can cost-effectively provide a substantial portion of a nation's water supply.

Why It Matters
The world's supplies of fresh water are inadequate to meet the needs of a growing population.

Key Players
- IDE Technologies
- Poseidon Water
- Desalitech
- Evoqua

On a Mediterranean beach 10 miles south of Tel Aviv, Israel, a vast new industrial facility hums around the clock. It is the world's largest modern seawater desalination plant, providing 20 percent of the water consumed by the country's households. Built for the Israeli government by Israel Desalination Enterprises, or IDE Technologies, at a cost of around $500 million, it uses a conventional desalination technology called reverse osmosis (RO). Thanks to a series of engineering and materials advances, however, it produces clean water from the sea cheaply and at a scale never before achieved.

Worldwide, some 700 million people don't have access to enough clean water. In 10 years the number is expected to explode to 1.8 billion. In many places, squeezing fresh water from the ocean might be the only viable way to increase the supply.

The new plant in Israel, called Sorek, was finished in late 2013 but is just now ramping up to its full capacity; it will produce 627,000 cubic meters of water daily, providing evidence that such large desalination facilities are practical. Indeed, desalinated seawater is now a mainstay of the Israeli water supply. Whereas in 2004 the country relied entirely on groundwater and rain, it now has four seawater desalination plants running; Sorek is the largest. Those plants account for 40 percent of Israel's water supply. By 2016, when additional plants will be running, some 50 percent of the country's water is expected to come from desalination.

The traditional criticism of reverse-osmosis technology is that it costs too much. The process uses a great deal of energy to force salt water against polymer membranes that have pores small enough to let fresh water through while holding salt ions back. However, Sorek will profitably sell water to the Israeli water authority for 58 U.S. cents per cubic meter (1,000 liters, or about what one person in Israel uses per week), which is a lower price than today's conventional desalination plants can manage. What's more, its energy consumption is among the lowest in the world for large-scale desalination plants.

The Sorek plant incorporates a number of engineering improvements that make it more efficient than previous RO facilities. It is the first large desalination plant to use pressure tubes that are 16 inches in diameter rather than eight inches. The payoff is that it needs only a fourth as much piping and other hardware, slashing costs. The plant also has highly efficient pumps and energy recovery devices. "This is indeed the cheapest water from seawater desalination produced in the world," says Raphael Semiat, a chemical engineer and desalination expert at the Israel Institute of Technology, or Technion, in Haifa. "We don't have to fight over water, like we did in the past."

Australia, Singapore, and several countries in the Persian Gulf are already heavy users of seawater desalination, and California is also starting to embrace the technology (see "Desalination Out of Desperation," January/February 2015). Smaller-scale RO technologies that are energy-efficient and relatively cheap could also be deployed widely in regions with particularly acute water problems—even far from the sea, where brackish underground water could be tapped.

Earlier in development are advanced membranes made of atom-thick sheets of carbon, which hold the promise of further cutting the energy needs of desalination plants. ■

ILLUSTRATION BY LUKE SHUMAN; DATA ON CAPACITY FROM GWI DESALDATA/IDA; MAP DATA FROM ALCAMO ET AL. (2003), IPCC; DATA ON ISRAEL FROM ISRAEL WATER AUTHORITY; DATA ON ENERGY USE FROM UNITED NATIONS

Apple Pay

A clever combination of technologies makes it faster and more secure to buy things with a wave of your phone.

By Robert D. Hof

SIMON LANDREIN

When Apple Pay was announced in September 2014, Osama Bedier was unimpressed. A longtime PayPal executive who now runs a payment startup called Poynt, Bedier had spent more than two years leading Google's mobile wallet service, which lets people use their phones to pay for things at checkout counters. It used some of the same technologies as Apple Pay and failed to catch on widely. So despite Apple Pay's appealing promise—safe payment with just the press of a thumb on your iPhone—there was good reason to be skeptical of its chances, too.

Yet when Apple Pay launched just a few weeks later, Bedier was a convert. Poynt makes a new kind of payment terminal—one that retailers can use to accept Apple Pay—and the advent of the service helped send the company's orders soaring. "Now merchants have people walking in saying, 'Why can't I use Apple Pay?'" he says at Poynt's Palo Alto headquarters, whose lobby displays a 100-year-old National cash register, testament to the long history of payment technologies. Originally Bedier expected Poynt to sell 20,000 payment terminals in 2015, but after the launch of Apple Pay, he scrambled to find a new manufacturer in

Breakthrough
A service that makes it practical to use your smartphone as a wallet in everyday situations.

Why It Matters
Credit card fraud damages the economy by raising the costs of goods and services.

Key Players
- Apple
- Visa
- MasterCard
- Google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Taiwan that could handle far greater demand. "Apple Pay will touch off a rush to mobile payment," he says.

Momentum for mobile payment technologies was building even before Apple Pay debuted. Some 17 percent of all smartphone users reported making a point-of-sale payment with their phone in 2013, up from 6 percent in 2012, according to a U.S. Federal Reserve survey. In-person mobile payments in the United States more than doubled in 2014, to $3.7 billion, according to Forrester Research. Meanwhile, as services such as Uber and stores like Starbucks allow people to pay via mobile app, transactions that once brought out the wallet are disappearing into the phone, where they are faster and should be more secure. You can use your existing credit card accounts, but you never have to pull out the physical cards. "We know after people tap their phone to pay two or three times, they don't go back to their old behavior," says Ed McLaughlin, MasterCard's executive in charge of new payment technologies.

None of the individual technologies is novel, but Apple turned them into a service that is demonstrably easier than any other.

But even if Apple didn't invent mobile payments, it has significantly enhanced them. Just as Apple made it far easier to use a computer, listen to music, and communicate on the go, Apple Pay is all about doing the same for buying goods and services, online and off. Each financial innovation from the invention of money to the credit card reduced friction in commercial exchange and accelerated the pace of commerce. Apple Pay does that too: it marks the end of scrawling a signature, producing a driver's license, and other hassles that came with earlier forms of payment. It's also smoother than mobile services that came before it. Apple Pay works automatically when your phone is held up to the checkout terminal, with no need to open an app as you must to use Google Wallet or PayPal. Pressing your thumb to the phone eliminates the need to use a PIN, speeding the transaction. This is true no matter whether you're booking a room on Airbnb or buying sandwiches at Subway. It fuses the virtual and physical worlds of commerce in a way that no other payment system has done.

That doesn't mean most of us will be ditching our wallets and waving phones in every store right away—far from it. The $3.7 billion worth of mobile payments made in U.S. stores last year was just a drop in the $4 trillion bucket of consumer retail spending. Beyond that, an additional $12 trillion was spent on services. Apple Pay itself faces a raft of challenges, too, and not just from rival wallets offered by Google, PayPal, retailers, and wireless carriers. Currently only people with the new iPhone 6 can use Apple Pay in stores. It's officially available only in the United States for now, but 98 percent of U.S. stores lack the right checkout terminals to accept it. Finally, Apple Pay is far from replacing some of the things in a physical wallet—in particular, popular store rewards cards. Starbucks's app, which is a combination store locator, rewards card, and payment engine all in one, still accounts for the majority of all mobile payments in retail stores.

Still, Apple has done a lot of things right, suggesting that Apple Pay will turn out to be a milestone. Even if it is only a moderate success for Apple, it seems certain to be a driver of mobile payments in general. None of the individual technologies in it is novel, but the extent of Apple's control over both the software and the hardware in the iPhone—which exceeds what Google can do for Google Wallet even on Android phones—allowed it to combine those technologies into a service demonstrably easier to use than any other.

As a result, Apple is now cementing standards for the payment industry. Merchants have been debating whether bar codes or the radio technology near-field communication (NFC), for instance, should be the method that a phone uses to relay payment information when you wave it at a checkout terminal. Apple's choice to build NFC into iPhones means many stores will feel compelled to get terminals with NFC support if they want to maximize their appeal to millions of iPhone owners.

Likewise, Apple Pay is setting the pace in payment security, outdoing credit cards with multiple layers of protection (see "Tighter Security," next page). The phone doesn't store real card numbers, and even the merchant doesn't see them, let alone keep them in the databases that hackers routinely plunder. Each transaction generates a unique code that can be used only once. The capper: the payment is triggered with

Tighter Security

When you swipe a credit card at the checkout counter or buy something with your card online, you give the merchant your card number so the store can ask for approval from your card provider. The stores often keep those card numbers on their servers, where they repeatedly have been easy prey for criminals.

Apple Pay eliminates that exposure of your card number. When you sign up, you can use your phone's camera to take a picture of your card. Apple confirms the card with your bank, but then it deletes the photo, and the card number isn't stored on the phone or by Apple. Instead, Apple Pay creates an encrypted string of data called a device account number that stands in for your card. It gets stored on the phone in a special chip known as the Secure Element. The device account number can't be accessed by any applications on the phone other than Apple Pay. When it's time to buy something, the Secure Element coughs up the device account number and combines it with data about the transaction to create a unique code for that sale. A payment processor such as Visa or MasterCard is able to recognize the device account number and the unique code, and it uses them to approve or reject the transaction. The merchant never sees your actual card number.

Apple didn't invent this technology, and other payment services that use the wireless standard known as near-field communication also make use of secure elements. But Apple Pay goes a step further by combining these technologies with the iPhone's Touch ID fingerprint sensor, which is used to unlock the phone. That means you don't have to bother entering a PIN to confirm the transaction, but someone who steals your phone would be out of luck.

Touch ID, which responds only to the owner's fingerprint. This level of fraud protection is one reason banks representing 90 percent of U.S. consumer payments support Apple Pay, says Avin Arumugam, head of next-generation payment products at JP Morgan Chase.

Most of all, Apple's timing is impeccable. Card networks set an October 2015 deadline for merchants to upgrade to terminals that can take credit cards with embedded chips for security—after that date, the merchants who don't upgrade will have to eat fraudulent charges. Most of those terminals they'll need to install will have NFC built in. Although that upgrade cycle will take years to reach most stores, Apple Pay could speed it up, says Keith Rabois, a former executive at PayPal and Square and an investor in several payment startups. "Apple Pay removes most of the barriers to adoption of mobile payment," he says.

Already, Apple Pay has taken off more quickly than Google Wallet or any other mobile payment system to date. "The time was ripe for Apple," says Jason Buechel, chief information officer at Whole Foods Market, where almost 2 percent of store sales were coming in through Apple Pay by mid-January. McDonald's said Apple Pay was accounting for half its mobile-phone transactions, and Walgreens's mobile payments doubled after Apple Pay debuted. Some 60 percent of customers used it on multiple days in November 2014, using it three times as frequently as new PayPal customers used that system in the same time period, according to a study by the brokerage firm Investment Technology Group.

Apple stands to gain big if Apple Pay's momentum continues. Not from the 0.15 percent of each transaction that it charges card-issuing banks: those fees would bring in only $2.5 billion by 2017 even if the new system got an unexpectedly large 30 percent share of U.S. credit and debit card expenditures, according to one estimate by investor Carl Icahn. That's a tiny fraction of Apple's fiscal 2014 revenue of $183 billion. The bigger impact will be ensuring the iPhone's appeal. Once you're using Apple Pay every day, in addition to other Apple services like iCloud and iTunes, you may think thrice before switching to an Android.

For all the focus on Apple Pay in retail stores, its biggest opportunity in the next few years will probably be greasing payments for countless apps and services. When you take a ride with Uber, the payment happens almost invisibly, without friction. Rabois suggests that Apple Pay could bring that level of ease to thousands of on-demand services in transportation, food delivery, and more. Once people get used to making app payments with a touch, they'll start expecting to do the same everywhere else they can.

Brain Organoids

A new method for growing human brain cells could unlock the mysteries of dementia, mental illness, and other neurological disorders.

By Russ Juskalian

Photographs by Regina Huegli

Madeline Lancaster figured out a way to keep neurons growing in a dish until they develop characteristics of living human brains.

Breakthrough
Three-dimensional clusters of living neurons that can be grown in a lab from human stem cells.

Why It Matters
Researchers need new ways of understanding brain disorders and testing possible treatments.

Key Players
- Madeline Lancaster and Jürgen Knoblich, Institute of Molecular Biotechnology
- Rudolph Tanzi and Doo Yeon Kim, Massachusetts General Hospital

As Madeline Lancaster lifts a clear plastic dish into the light, roughly a dozen clumps of tissue the size of small baroque pearls bob in a peach-colored liquid. These are cerebral organoids, which possess certain features of a human brain in the first trimester of development—including lobes of cortex. The bundles of human tissue are not exactly "brains growing in a dish," as they're sometimes called. But they do open a new window into how neurons grow and function, and they could change our understanding of everything from basic brain activities to the causes of schizophrenia and autism.

Before it grows in one of Lancaster's dishes, a brain organoid begins as a single skin cell taken from an adult. With the right biochemical prodding, that cell can be turned into an induced pluripotent stem cell (the kind that can mature into one of several types of cells) and then into a neuron. This makes it possible to do things that were impossible before. Now scientists can directly see how networks of living human brain cells develop and function, and how they're affected by various drug compounds or genetic modifications. And because these mini-brains can be grown from a specific person's cells, organoids could serve as unprecedentedly accurate models for a wide range of diseases. What goes wrong, for example, in neurons derived directly from someone with Alzheimer's disease?

The prospect of finding answers to such questions is leading pharmaceutical companies and academic researchers to seek collaborations with Lancaster and Jürgen Knoblich, whose lab at the Institute of Molecular Biotechnology (IMBA) in Vienna, Austria, is where Lancaster developed the organoids as a postdoc. The first of these collaborations was an investigation of microcephaly, a disorder characterized by small brain size, with Andrew Jackson of the University of

1 Lancaster holds up organoids in a dish.

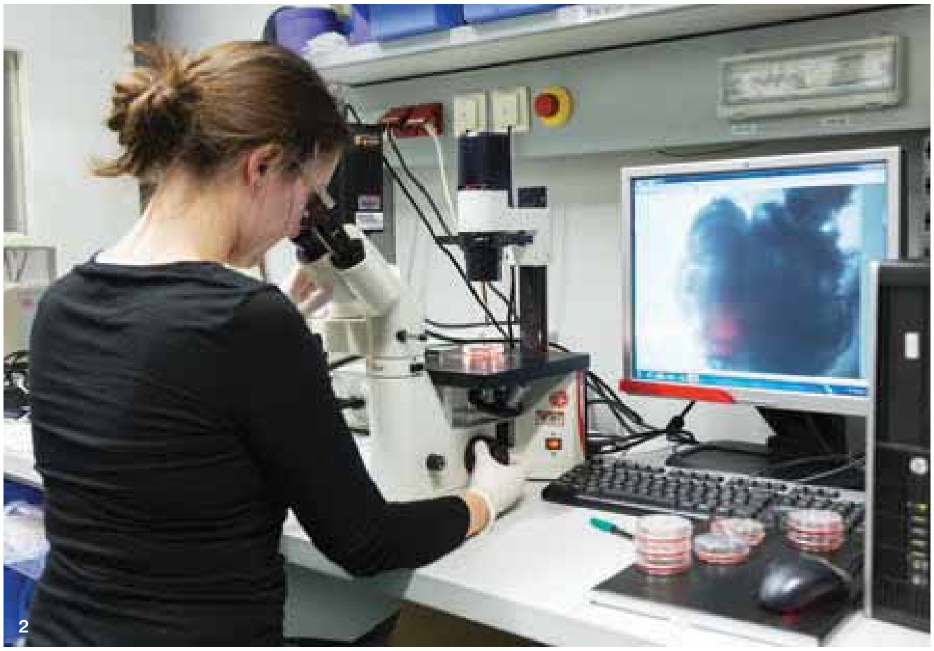
Edinburgh. Using cells derived from a patient with microcephaly, the team cultured organoids that shared characteristics with the patient's brain. Then the researchers replaced a defective protein associated with the disorder and were able to culture organoids that appeared partially cured.

This is just the beginning, says Lancaster. Researchers such as Rudolph Jaenisch at MIT and Guo-li Ming at Johns Hopkins are beginning to use brain organoids to investigate autism, schizophrenia, and epilepsy. What makes cerebral organoids particularly useful is that their growth mirrors aspects of human brain development. The cells divide, take on the characteristics of, say, the cerebellum, cluster together in layers, and start to look like the discrete three-dimensional structures of a brain. If something goes wrong along the way—which is observable as the organoids grow—scientists can look for potential causes, mechanisms, and even drug treatments.

The breakthrough in creating these organoids happened as part of a side project. Other researchers had grown neurons in a dish before, and like them, Lancaster started by using a flat plate to "play" with neural stem cells—the kind that form into neurons and other cells in the nervous system. Sometimes, she says, "I'd get neural stem cells that wouldn't really stay in 2-D, and they would kind of fall off the plate and they'd make 3-D clumps—and rather than ignoring them or throwing them away, I thought, 'Those are cool—let's see what happens if I let them keep growing.'" But there was a major challenge: how to keep the tissue at the center of the organoids fed without the benefit of veins. Lancaster's solution was to encapsulate each organoid in a matrix known to nurture cells, put a dozen of these blobs in a nutritious bath, and shake or spin it all to keep the organoids awash in cellular food.

Since publishing her method, Lancaster has pushed the brain tissue to further levels of complexity with neurons at later stages of development. The number of possible applications grows with each advance. Most tantalizing to Lancaster herself is the prospect that cerebral organoids might solve the deepest of mysteries: what happens in our brains to set us apart from other animals? "I'm mainly interested," she says, "in figuring out what it is that makes us human."

Organoids could be far more useful than animals in many experiments.



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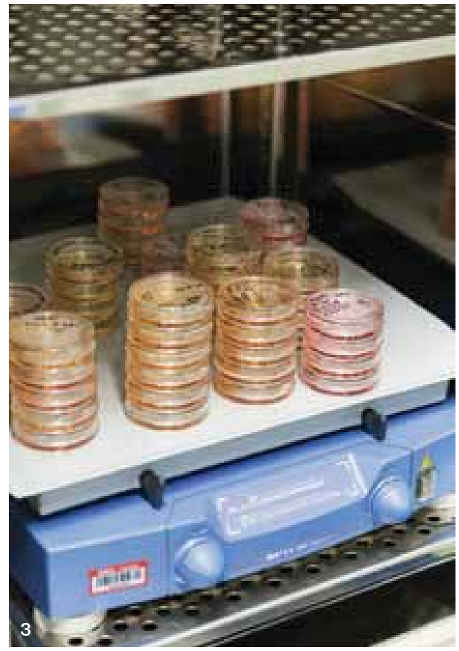

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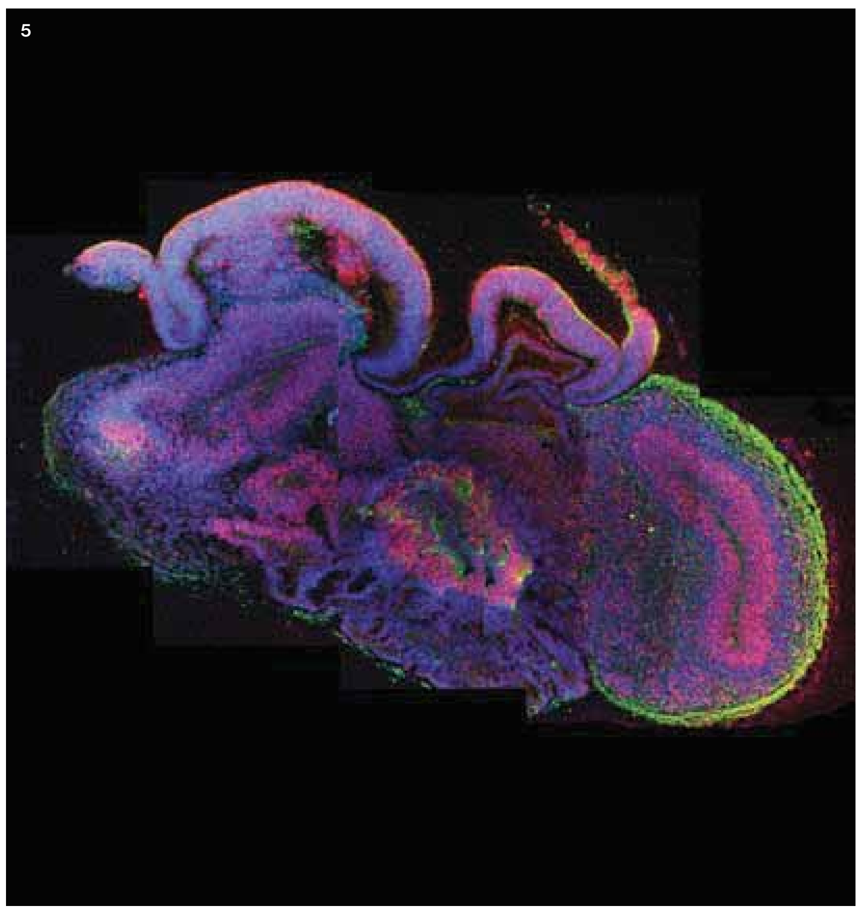


2 Magdalena Renner, a graduate student in the lab, examines organoids under a microscope.

3 A variety of organoids are kept alive on a shaker plate in an incubator.

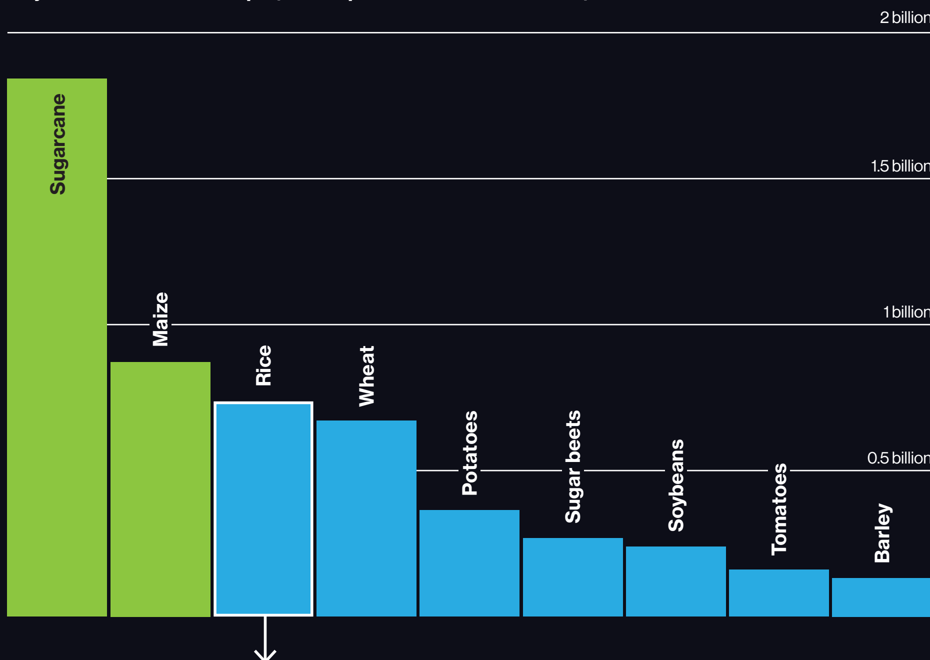
4 Organoids cut into very thin sections have been put on slides for examination.

5 A stained section of an organoid is seen in close-up.

Photosynthesis Boost

The world's highest-production crops use a super-efficient form of photosynthesis. It's known as C4 photosynthesis because the first step is the formation of a four-carbon molecule. C3 photosynthesis, found in most plant species, starts with a three-carbon molecule.

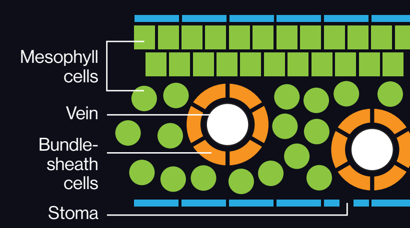
Major C4 and C3 crops (annual production in metric tons)



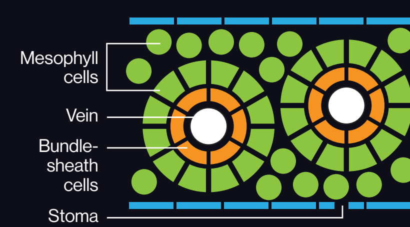
Carbon Concentrators

In C4 plants, a wreathlike arrangement of cells (lower image) helps concentrate carbon dioxide. A ring of mesophyll cells (green) captures the carbon dioxide, which is conveyed to an inner ring of bundle-sheath cells (orange). The arrangement is known as the Kranz anatomy, after the German word for wreath.

C3



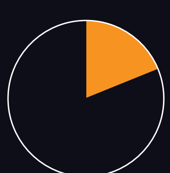
C4



Rice Matters

Farmers are struggling to meet growing demand for rice, the staple for half of the world's population.

Rice provides 19% of global dietary energy



Plateauing yields

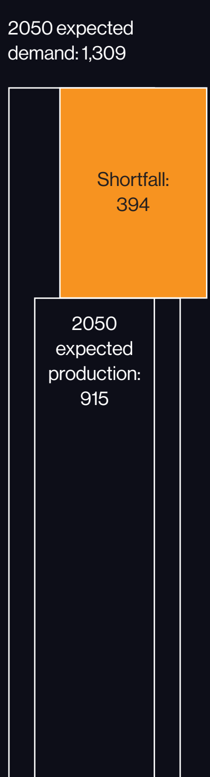
1990

Last year that average rice yields increased in California

33%

Percentage of rice-producing regions where yields have plateaued

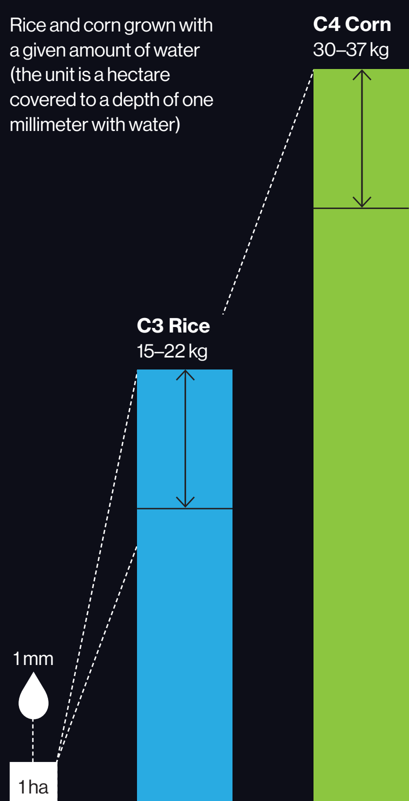
Projected shortfall in rice production (in millions of tons)



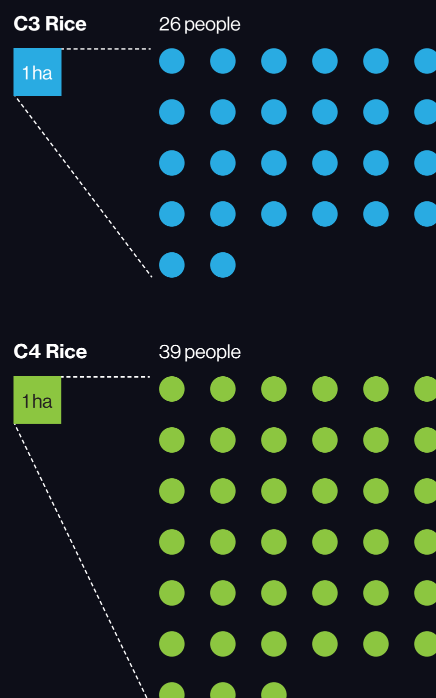
Efficient Farming

A unit of water goes further with C4 crops, producing far more food. In China, planting C4 rice could feed 50 percent more people per hectare.

Rice and corn grown with a given amount of water (the unit is a hectare covered to a depth of one millimeter with water)



People fed yearly in China by one harvest from one hectare of C3 vs. C4 rice



Supercharged Photosynthesis

Advanced genetic tools could help boost crop yields and feed billions more people.

By Kevin Bullis

Breakthrough
Engineering rice plants to extract energy from sunlight far more efficiently than they do now.

Why It Matters
Crop yields aren't increasing fast enough to keep up with demand from a growing population.

Key Players
- Paul Quick, International Rice Research Institute
- Daniel Voytas, University of Minnesota
- Julian Hibberd, University of Cambridge
- Susanne von Caemmerer, Australian National University

ILLUSTRATION BY LUKE SHUMAN / SOURCES: FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS; CORNELL UNIVERSITY; INTERNATIONAL RICE RESEARCH INSTITUTE; PATRICIO GRASSINI, ET AL., NATURE COMMUNICATIONS; DEEPAK RAY ET AL., PLOSONE

In December 2014, geneticists announced that they'd engineered rice plants to carry out photosynthesis in a more efficient way—much as corn and many fast-growing weeds do. The advance, by a team of researchers in the Philippines and the United Kingdom, removes a big obstacle from scientists' efforts to dramatically increase the production of rice and, potentially, wheat. It comes at a time when yields of those two crops, which together feed nearly 40 percent of the world, are dangerously leveling off, making it increasingly difficult to meet rapidly growing food demand.

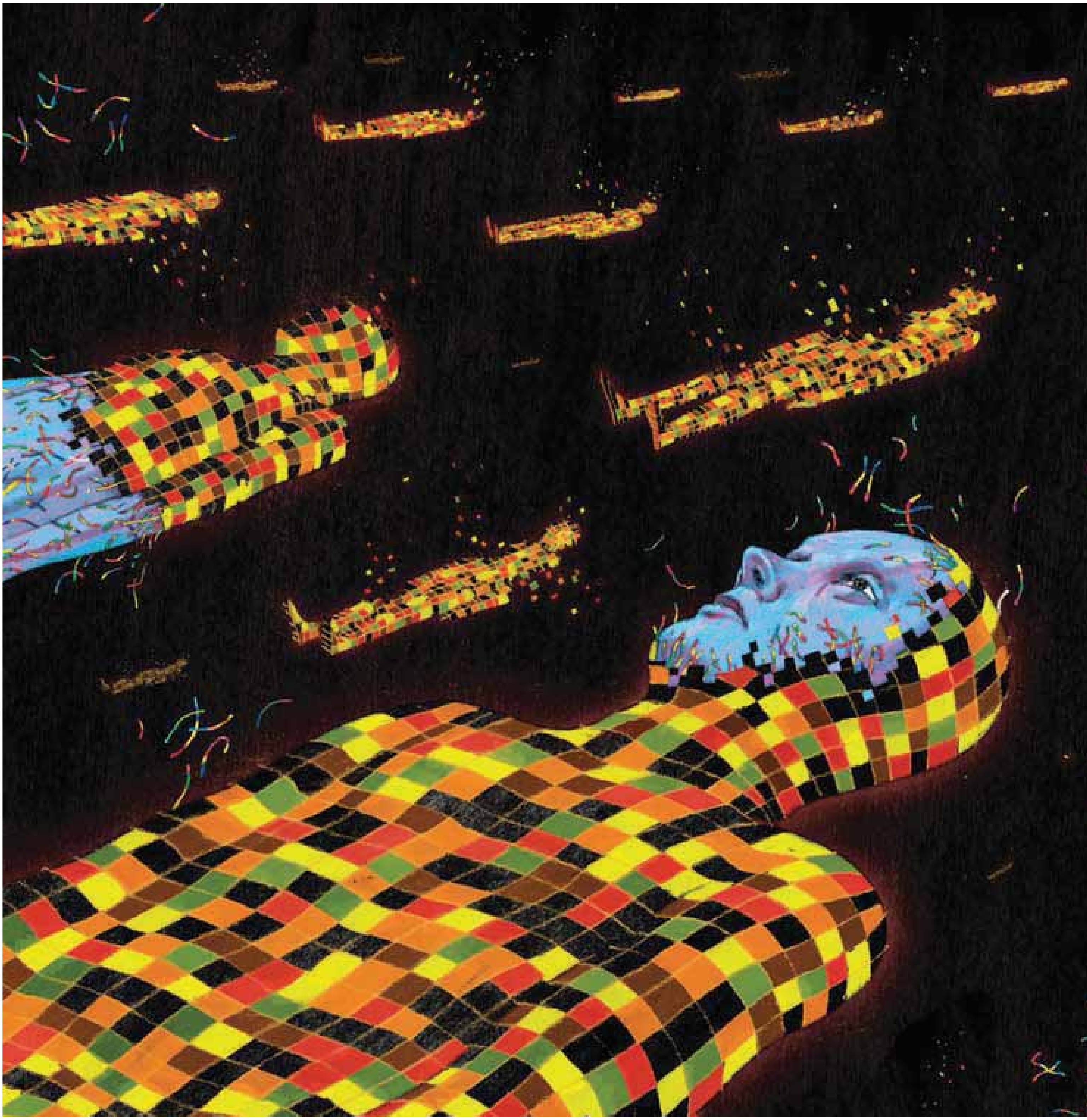
The supercharged process, called C4 photosynthesis, boosts plants' growth by capturing carbon dioxide and concentrating it in specialized cells in the leaves. That allows the photosynthetic process to operate much more efficiently. It's the reason corn and sugarcane grow so productively; if C4 rice ever comes about, it will tower over conventional rice within a few weeks of planting. Researchers calculate that engineering C4 photosynthesis into rice and wheat could increase yields per hectare by roughly 50 percent; alternatively, it would be possible to use far less water and fertilizer to produce the same amount of food.

The 2014 results, achieved by Paul Quick at the International Rice Research Institute (IRRI) in the Philippines and Julian Hibberd, a professor at the University of Cambridge in the U.K., introduced five key C4 photosynthesis genes into a rice plant and showed that the plant can capture carbon dioxide via the same mechanism seen in plants with the supercharged form of photosynthesis. "It's the first time we've seen evidence of the C4 cycle in rice, so it's very exciting," says Thomas Brutnell, a researcher at the Danforth Plant Science Center in St. Louis. Brutnell is part of the C4 Rice Consortium headed by IRRI, which has funding from the Bill & Melinda Gates Foundation, but was not directly involved in the most recent breakthrough.

Despite the genetic changes, the altered rice plants still rely primarily on their usual form of photosynthesis. To get them to switch over completely, researchers need to engineer the plants to produce specialized cells in a precise arrangement: one set of cells to capture the carbon dioxide, surrounding another set of cells that concentrate it. That's the distinctive wreath anatomy found in the leaves of C4 plants. However, scientists still don't know all the genes involved in producing these cells and suspect that they could number in the dozens.

New genome editing methods that allow scientists to precisely modify parts of plant genomes could help solve the problem. Using conventional breeding to manipulate more than one or two genes is a "nightmare," Brutnell says, let alone trying to engineer a plant with dozens of gene changes. Genome editing could make it possible to change a large number of genes easily. Says Brutnell: "Now we have the toolbox to go after this."

It can be a decade or more before even simple crop modifications reach farmers, let alone changes as complex as reëngineering how plants carry out photosynthesis. But once scientists solve the C4 puzzle in a plant such as rice, they hope, the method can be extended to dramatically increase production of many other crops, including wheat, potatoes, tomatoes, apples, and soybeans.



DADU SHIN

Internet of DNA

A global network of millions of genomes could be medicine's next great advance.

By Antonio Regalado

Noah is a six-year-old suffering from a disorder without a name. This year, his physicians will begin sending his genetic information across the Internet to see if there's anyone, anywhere, in the world like him.

A match could make a difference. Noah is developmentally delayed, uses a walker, speaks only a few words. And he's getting sicker. MRIs show that his cerebellum is shrinking. His DNA was analyzed by medical geneticists at the Children's Hospital of Eastern Ontario. Somewhere in the millions of As, Gs, Cs, and Ts is a misspelling, and maybe the clue to a treatment. But unless they find a second child with the same symptoms, and a similar DNA error, his doctors can't zero in on which mistake in Noah's genes is the crucial one.

In January 2015, programmers in Toronto began testing a system for trading genetic information with other hospitals. These facilities, in locations including Miami, Baltimore, and Cambridge, U.K., also treat children with so-called Mendelian disorders, which are caused by a rare mutation in a single gene. The system, called MatchMaker Exchange, represents something new: a way to automate the comparison of DNA from sick people around the world.

One of the people behind this project is David Haussler, a bioinformatics expert based at the University of California, Santa Cruz. The problem Haussler is grappling with now is that genome sequencing is largely detached from our greatest tool for sharing information: the Internet. That's unfortunate because more than 200,000 people have already had their genomes sequenced, a number certain to rise into the millions in years ahead. The next era of medicine depends on

Breakthrough
Technical standards that let DNA databases communicate.

Why It Matters
Your medical treatment could benefit from the experiences of millions of others.

Key Players
- Global Alliance for Genomics and Health
- Google
- Personal Genome Project

large-scale comparisons of these genomes, a task for which he thinks scientists are poorly prepared. "I can use my credit card anywhere in the world, but biomedical data just isn't on the Internet," he says. "It's all incomplete and locked down." Genomes often get moved around in hard drives and delivered by FedEx trucks.

Haussler is a founder and one of the technical leaders of the Global Alliance for Genomics and Health, a nonprofit organization formed in 2013 that compares itself to the W3C,

The unfolding calamity in genomics is that a great deal of life-saving information, though already collected, is inaccessible.

the standards organization devoted to making sure the Web functions correctly. Also known by its unwieldy acronym, GA4GH, it's gained a large membership, including major technology companies like Google. Its products so far include protocols, application programming interfaces (APIs), and improved file formats for moving DNA around the Web. But the real problems it is solving are mostly not technical. Instead, they are sociological: scientists are reluctant to share genetic data, and because of privacy rules, it's considered legally risky to put people's genomes on the Internet.

But pressure is building to use technology to study many, many genomes at once and begin to compare that genetic information with medical records. That is because scientists think they'll need to sort through a million genomes or more to solve cases—like Noah's—that could involve a single rogue DNA letter, or to make discoveries about the genetics of common diseases that involve a complex combination of genes. No single academic center currently has access to information that extensive, or the financial means to assemble it.

Haussler and others at the alliance are betting that part of the solution is a peer-to-peer computer network that can unite widely dispersed data. Their standards, for instance, would permit a researcher to send queries to other hospitals, which could choose what level of information they were willing to share and with whom. This control could ease privacy concerns. Adding a new level of complexity, the APIs could also call on databases to perform calculations—say, to reanalyze the genomes they store—and return answers.

The day I met Haussler, he was wearing a faded Hawaiian shirt and taking meetings on a plastic lawn chair by a hotel pool in San Diego. Both of us were there to attend one of the world's largest annual gatherings of geneticists. He told me he was worried that genomics was drifting away from the open approach that had made the genome project so powerful. If people's DNA data is made more widely accessible, Haussler hopes, medicine may benefit from the same kind of "network effect" that's propelled so many commercial aspects of the Web. The alternative is that this vital information will end up marooned in something like the disastrous hodgepodge of hospital record systems in the United States, few of which can share information.

One argument for quick action is that the amount of genome data is exploding. The largest labs can now sequence human genomes to a high polish at the pace of two per hour. (The first genome took about 13 years.) Back-of-the-envelope calculations suggest that fast machines for DNA sequencing will be capable of producing 85 petabytes of data this year worldwide, twice that much in 2019, and so on. For comparison, all the master copies of movies held by Netflix take up 2.6 petabytes of storage.

"This is a technical question," says Adam Berrey, CEO of Curoverse, a Boston startup that is using the alliance's standards in developing open-source software for hospitals. "You have what will be exabytes of data around the world that nobody wants to move. So how do you query it all together, at once? The answer is instead of moving the data around, you move the questions around. No industry does that. It's an insanely hard problem, but it has the potential to be transformative to human life."

Today scientists are broadly engaged in what is, in effect, a project to document every variation in every human gene and determine what the consequences of those differences are. Individual human beings differ at about three million DNA positions, or one in every 1,000 genetic letters. Most of these differences don't matter, but the rest explain many things that do: heartbreaking disorders like Noah's, for example, or a higher than average chance of developing glaucoma.

So imagine that in the near future, you had the bad luck to develop cancer. A doctor might order DNA tests on your tumor, knowing that every cancer is propelled by specific mutations. If it were feasible to look up the experience of everyone else who shared your tumor's particular mutations, as well as what drugs those people took and how long they lived, that doctor might have a good idea of how to treat you. The unfolding calamity in genomics is that a great deal of this life-saving information, though already collected, is inaccessible. "The limiting factor is not the technology," says David Shaywitz, chief medical officer of DNAnexus, a bioinformatics company that hosts several large collections of gene data. "It's whether people are willing."

In summer 2014 Haussler's alliance launched a basic search engine for DNA, which it calls Beacon. Currently, Beacon searches through about 20 databases of human genomes that were previously made public and have implemented the alliance's protocols. Beacon offers only yes-or-no answers to a single type of question. You can ask, for instance, "Do any of your genomes have a T at position 1,520,301 on chromosome 1?" "It's really just the most basic question there is: have you ever seen this variant?" says Haussler. "Because if you did see something new, you might want to know, is this the first patient in the world that has this?" Beacon is already able to access the DNA of thousands of people, including hundreds of genomes put online by Google.

One of the cofounders of the Global Alliance is David Altshuler, who is now head of science at Vertex Pharmaceuticals but until recently was deputy chief of the MIT-Harvard Broad Institute, one of the largest academic DNA-sequencing centers in the United States. The day I visited Altshuler in his Broad office, his whiteboard was covered with diagrams showing genetic inheritance in families, as well the word "Napster" written in large blue letters—a reference to the famously disruptive music-sharing service of the 1990s.

Altshuler has his own reasons for wanting to connect massive amounts of genetic data. As an academic researcher, he hunted for the genetic causes of common diseases like diabetes. That work was carried out by comparing the DNA of afflicted and unafflicted people, trying to spot the differences that come up most often. After burning through countless research grants this way, geneticists realized there would be no easy answers, no common "diabetes genes" or "depression genes." It turns out that common diseases aren't caused by single, smoking-gun defects. Instead, a person's risk, scientists have learned, is determined by a combination of hundreds, if not tens of thousands, of rare variations in the DNA code.

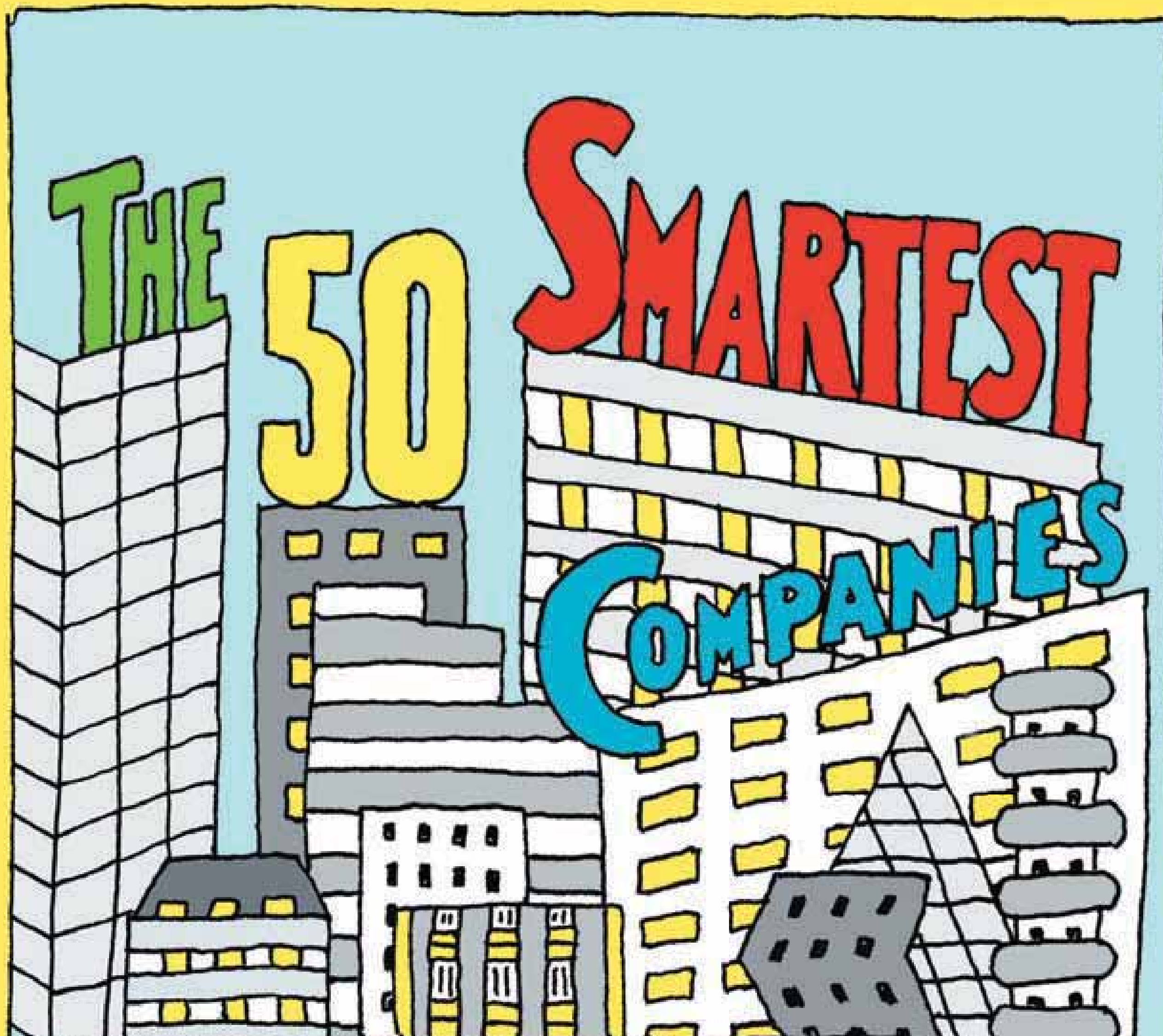
That's created a huge statistical headache. In July 2014, in a report listing 300 authors, Broad looked at the genes of 36,989 people with schizophrenia. Even though schizophrenia is highly heritable, the 108 gene regions identified by the scientists explained only a small percentage of a person's risk for the disease. Altshuler believes that big gene studies are still a good way to "crack" these illnesses, but he thinks it will probably take millions of genomes to do it.

The way the math works out, sharing data no longer looks optional, whether researchers are trying to unravel the causes of common diseases or ultra-rare ones. "There's going to be an enormous change in how science is done, and it's only because the signal-to-noise ratio necessitates it," says Arthur Toga, a researcher who leads a consortium studying the science of Alzheimer's at the University of Southern California. "You can't get your result with just 10,000 patients—you are going to need more. Scientists will share now because they have to."

Privacy, of course, is an obstacle to sharing. People's DNA data is protected because it can identify them, like a fingerprint—and their medical records are private too. Some countries don't permit personal information to be exported for research. But Haussler thinks a peer-to-peer network can sidestep some of these worries, since the data won't move and access to it can be gated. More than half of Europeans and Americans say they're comfortable with the idea of sharing their genomes, and some researchers believe patient consent forms should be dynamic, a bit like Facebook's privacy controls, letting individuals decide what they'll share and with whom—and then change their minds. "Our members want to be the ones to decide, but they aren't that worried about privacy. They're sick," says Sharon Terry, head of the Genetic Alliance, a large patient advocacy organization.

The risk of not getting data sharing right is that the genome revolution could sputter. Some researchers say they are seeing signs that it's happening already. Kym Boycott, head of the research team that sequenced Noah's genome, says that when the group adopted sequencing as a research tool in 2010, it met with immediate success. Over two years, between 2011 and 2013, a network of Canadian geneticists uncovered the precise molecular causes of 146 conditions, solving 55 percent of their undiagnosed cases.

But the success rate appears to be tailing off, says Boycott. Now it's the tougher cases like Noah's that are left, and they are getting solved only half as often as the others. "We don't have two patients with the same thing anymore. That's why we need the exchange," she says. "We need more patients and systematic sharing to get the [success rate] back up." In late January, when I asked if MatchMaker Exchange had yielded any matches yet, she demurred, saying that it could be a matter of weeks before the software was fully operational. As for Noah, she said, "We are still waiting to sort him out. It's important for this little guy."



Sometimes we hear that technology companies have lost their ambition. Too many great minds are pouring their energy into the next app for the affluent, the argument goes. Where is the daring?

Right here. This year, when the editors of *MIT Technology Review* began our annual search for the smartest companies, we did not have trouble finding big ideas. To make the list, a company must have truly innovative technology and a business model that is both practical and ambitious, with the result that it has set the agenda in its field over the past year.

No. 1, Tesla Motors, has added another audacious idea to go with its electric cars. In April 2014, it announced it would be spinning off a line of batteries in service of a big goal: remaking the energy grid for industry, utilities, and residences.

Of all the sectors we cover, biomedicine had the biggest year. Companies have turned research breakthroughs, many powered by genomic analysis, into products that treat challenging diseases. Gilead Sciences, No. 15, sells the first pill that can cure most cases of hepatitis C. Bristol-Myers Squibb, No. 26, is selling an immunotherapy drug that is saving the lives of people with skin and lung cancer.

By contrast, energy companies have been far less innovative, it seems to us, so that sector plays a smaller role on this list. One highlight is No. 6, SunEdison, which is electrifying developing countries.

As always, many newer, private companies can be found here, starting with No. 5, Counsyl, a startup whose cheap, automated DNA analysis is expanding from prenatal testing to cancer screening.

A few giants return after an absence from the list: Microsoft, at No. 48 for its wearable HoloLens device that blends virtual reality and the real world, and Apple, No. 16, for its well-designed smart watch and digital-wallet service. All share one feature: they are innovations with impact. *—Nanette Byrnes*

Illustration by Seymour Chwast

50 Smartest Companies 2015

1. TESLA MOTORS
Extending its battery technology from cars to residential and commercial applications.

***$5 billion**: projected investment required to build its battery "gigafactory" in Nevada*

2. XIAOMI
Fast-growing smartphone vendor is maturing beyond its original "cut-price Apple" model with ideas like flash sales over its mobile messaging platform.

***$45 billion**: most recent valuation for the private company*

3. ILLUMINA
Shifting its fast DNA-reading machines from research applications primarily to hospitals and cancer clinics.

***90 percent**: proportion of all DNA data estimated to be produced on its machines*

4. ALIBABA
The world's largest online retailer, it conducts more than half its daily transactions through its Alipay digital wallet/banking service.

***$25 billion**: amount raised in its record-setting IPO*

5. COUNSYL
Its cheap DNA tests help would-be parents plan ahead. Now it sells cancer screens.

***3.6 percent**: proportion of U.S. couples that use its tests before trying to conceive*

6. SUNEDISON
Aggressively expanding its renewable energy products and building a business to provide electricity to the developing world.

***1.1 billion**: number of people worldwide who don't have access to electricity*

7. TENCENT
China's most-used Internet service portal is expanding by investing in companies inside and outside its home market.

***549 million**: active monthly users on WeChat and its related Weixin service*

8. JUNO THERAPEUTICS
Testing cancer treatments that use a person's own immune cells.

***$265 million**: amount it raised in the largest biotech IPO of 2014*

9. SOLARCITY
The factory it is planning to build in Buffalo will be the Western Hemisphere's largest manufacturer of silicon solar panels, the company says.

***177,000**: number of U.S. customers who lease SolarCity's rooftop solar panels*

10. NETFLIX
It's producing innovative original content and inking distribution deals with cable companies.

***31**: number of Emmy nominations for its original programming in 2014*

(p.56)

11. OVASCIENCE
The first baby conceived with the help of its stem-cell treatment has been born.

***$25,000**: maximum amount it charges IVF clinics for the treatment*

12. GOOGLE
Its Loon balloons are designed to broaden Internet access.

***30**: number of balloons launched from New Zealand's South Island in Google's 2013 pilot test*

13. AMAZON
Robots now used in its fulfillment centers could make the facilities far more efficient.

***$89 billion**: 2014 sales*

14. ALIVECOR
Maker of a heart monitor that connects to an iPhone and automatically detects irregular heartbeats.

***2 million**: number of ECG readings on its devices so far*

15. GILEAD SCIENCES
Began selling the first pill that can cure most cases of hepatitis C.

***$3.6 billion**: sales of the drug in the first three months of 2015*

16. APPLE
Its new smart watch and its Apple Pay digital wallet set the pace for competitors.

***1 million**: number of Apple Watches ordered the day they went on sale, according to outside estimates*

17. VOXEL8
Having created what it calls the world's first 3-D electronics printer, the startup is commercializing promising new materials like conductive ink.

***5,000**: factor by which its inks improve conductivity, according to the company*

18. IDE TECHNOLOGIES
Offering more affordable water desalination at a scale never before achieved.

***300,000**: number of people to be served by the plant it is building with partners in Carlsbad, California*

19. AMGEN
Its Icelandic gene database is yielding clues that help it decide which drugs to develop.

***10,000**: number of sequenced genomes in the database*

20. AQUION ENERGY
Has gained customers for its novel batteries, which can store surplus wind and solar energy.

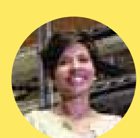
***$129 million**: money raised from Aquion's investors*

21. BAIDU
The Chinese Internet company's new deep-learning research lab has produced notable results in facial and speech recognition.

***70 percent**: increase in 2014 research spending, to $1.125 billion*

22. SPACEX
The rocket company has made progress on the technical challenge of landing and reusing unmanned rockets.

***9**: number of missions completed in the last year*



(p.48)

23. SAKTI3
Uses new materials and manufacturing techniques to make solid-state batteries that store twice as much energy as rival lithium-ion technologies.

***$15 million**: size of recent investment by appliance maker Dyson (General Motors is also a backer)*

24. FREESCALE SEMICONDUCTOR
Pioneering technology to be used in advanced computer vision systems for cars.

***$12 billion**: Freescale's value in a proposed acquisition by a Dutch semiconductor maker*

25. UNIVERSAL ROBOTS
Its user-friendly, relatively cheap robots have found a strong market. In May, Teradyne agreed to buy the company for $285 million.

***70 percent**: increase in revenue from 2013 to 2014*

26. BRISTOL-MYERS SQUIBB
Took a lead in cancer immunotherapy with Opdivo, a life-saving drug for skin and lung cancer.

***$12,500**: monthly cost of the drug*

27. TELADOC
Though some doctors' organizations oppose the idea of remote medicine and are trying to limit the practice, this fast-growing telemedicine company is nearing an IPO.

***10 million**: number of U.S. members in its remote-consultation service*

28. NVIDIA
Its chips are crucial for cutting-edge technologies like deep learning and driverless cars.

***7,000**: number of patents it holds*

29. FACEBOOK
Big ad revenue is being invested in improvements to apps like Messenger and in its new agreement to directly host work by leading news organizations.

***1.44 billion**: number of monthly active users worldwide in the first quarter of 2015*

30. ALNYLAM
It is turning around the prospects for RNA interference, a promising type of gene therapy that has been challenging to use.

***6**: number of the company's drugs in human testing*

31. RETHINK ROBOTICS
Although sales have been soft for its easy-to-train Baxter robot, the company's newest model, Sawyer, is impressively precise and fast.

***$114 million**: funding raised*

32. PHILIPS
The giant of LED lighting has made the efficient technology even more affordable.

***$5**: retail price of two bulbs that will last for a decade*

33. CELLECTIS
Its Calyxt division uses quick gene editing to create crops that might not need regulation as GMOs.

***1 year**: time it took to create a genetically engineered potato that should be healthier to eat when fried*

34. BLUEBIRD BIO
Its gene therapies may cure, not just treat, diseases like sickle-cell anemia.

***9**: number of patients treated so far in studies*

35. THYSSENKRUPP
Reinvented the elevator with magnetic levitation technology, resulting in a system that can transport more people and move horizontally.

***6.4 billion euros**: company's global elevator sales in 2014*

36. SLACK
Its workplace communications app is taking off.

***300 million**: number of messages sent via Slack each month*

37. LINE
The Japanese company runs a hugely popular messaging and free calling app that actually generates revenue.

***181 million**: number of monthly active users*

38. IMPROBABLE
Using computer science to simulate richer virtual worlds, with applications in gaming and virtual reality.

***$20 million**: Improbable's funding from Andreessen Horowitz this year*

39. ENLITIC
Its deep-learning technology automatically spots tumors in medical scans.

***$1.7 billion**: total estimated value of the market for medical image analysis software*

40. COINBASE
Helps companies including PayPal, Dell, and Expedia take Bitcoin payments without having to hold onto the cryptocurrency.

***2.9 million**: number of Bitcoin accounts registered with Coinbase*

41. HACON
Its popular travel planning apps in Europe combine information on taxis, car rental, bike sharing, and public transportation systems.

***40 million**: number of journeys planned on its system every day*

42. 3D SYSTEMS
Moving to dominate the commercialization of 3-D printing by developing a super-fast assembly line.

***50**: factor by which 3D Systems hopes to increase the speed of 3-D printing*

43. GENERALI
This Italian-based insurer will use fitness data from wearables, as well as other health data, to calculate insurance rates for customers who choose to participate.

***60**: number of countries in which the company operates*

44. INTREXON
Developing synthetic biology in multiple fields for health, energy, consumer, and environmental applications.

***$41 million**: amount paid to acquire the maker of a patented transgenic apple*

45. DNANEXUS
Helping researchers and drug companies move genetic data into Amazon's cloud.

***56,000**: number of computer processors the company uses to analyze DNA*

46. IBM
Novel research into artificial intelligence could help the company in its long-term plan to make big data more useful.

***14**: number of hospitals in North America that have signed up to use the Watson AI system to guide cancer therapy*

47. SNAPCHAT
Innovative new formats include "Snapchat Stories," which put videos and photos together to tell a story, and a platform for media organizations that is used by ESPN, CNN, and others.

***1 billion**: number of Snapchat Stories viewed per day*

48. MICROSOFT
Its HoloLens augmented-reality technology reflects the new CEO's turnaround ambitions.

***13 percent**: increase in revenue so far this year*

49. IMPRINT ENERGY
Developing ultrathin, flexible, rechargeable batteries that can be printed cheaply on commonly used industrial screen printers.

***350 micrometers**: width of batteries capable of powering an ultrathin Bluetooth wireless sensor or a wearable device*

50. UBER
It's testing ideas like ride-share services and driver deliveries.

***162,037**: number of active Uber drivers as of December 2014*

Ann Marie Sastry, CEO of Sakti3

Survival in the Battery Business

The advanced battery market has seen many companies stumble in recent years. Startups with promising technologies for storing renewable energy or powering electric cars failed to find customers quickly enough (see "Why We Don't Have Battery Breakthroughs," March/April 2015). But Sakti3, the maker of a novel solid-state battery, got a big boost when the British appliance giant Dyson said it would invest $15 million in the company and incorporate Sakti3's batteries into its products. Because it dispenses with the liquid electrolytes used in most batteries, which can cause chemical reactions that lead to overheating, a solid-state battery doesn't require bulky cooling systems and thus can deliver the same amount of energy in a much smaller package. Given that this could lead to electric cars with longer ranges than the ones available today, Sakti3—one of this year's 50 Smartest Companies—also counts General Motors as an investor. Founder Ann Marie Sastry spoke to *MIT Technology Review*'s senior editor for energy, Richard Martin.

Why would a vacuum cleaner company invest in a battery maker?

Because they need better batteries. What we're doing is building batteries in a very different way, such that we're able to generate very interesting properties. Our prototype systems today provide double the energy density of what's on the market. Even more important is that our technology offers a platform on which to continuously improve.

Why couldn't that happen with today's dominant battery technology?

The liquid-electrolyte systems that have been selected up to this point by manufacturers and the marketplace have been pursued for one principal reason: high energy density. But they have clear limitations in terms of weight, expense, safety, and so on. The continuous improvement in lithium batteries has enabled safe operations [of an electric car, for example] but at a high cost, and provided energy density that's appropriate for some ranges but is not equivalent to an internal-combustion engine. To continue to develop on that platform, as with any manufacturing process, is going to result in marginal gains at best.

At some point in any industrial process you have to ask, "Are we on the right platform?" We needed to eliminate the liquid-electrolyte system while still producing [at] a low cost and enabling out-of-the-gate safety. Our aim is no less than changing the way battery cells are made globally.

So what role might your batteries play in electric cars over the next, say, three years?

The automotive market is enormously important to us. We knew that we would probably have to commercialize first in markets with fewer barriers to entry, and with smaller [batteries]. Over the next three years, the work we are doing in the other markets will build our technology to address the rigorous demands of automotive markets—which is why we actually started the company in the first place.

Why solid-state as opposed to other battery chemistries?

The reason is that we see all the verticals for battery applications increasingly converging around the same needs: for portable systems with low environmental impact, high energy density, and safe, stable operations. Solid-state, if mastered, enables portability of even grid-scale systems, which we think will become increasingly important as renewables make greater incursions into grid power.

Portable systems for grid-scale power? That almost seems like an oxymoron.

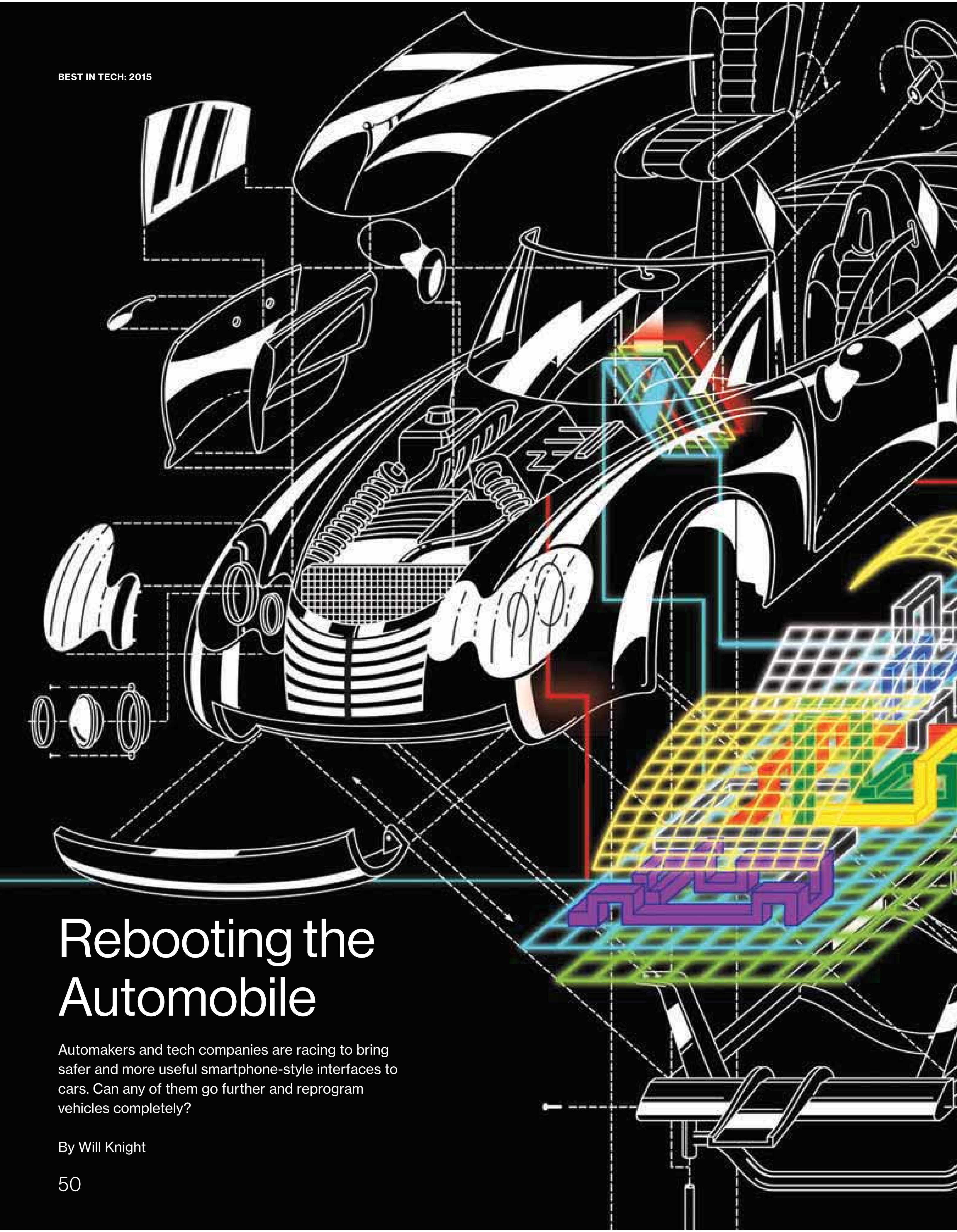
I know! But think about Japan, for instance. People's houses in Japan are really small. If you tried to take a garage and fill it with batteries, that's not really practical. You need a storage system that can address different renewable sources, and the challenge is to produce a system that [can be] exactly optimized to the energy generation technology that is pertinent. Our thinking was that it should be small, agile, and customizable.

We're trying to follow what's been successful in technology advances in general: there are no mainframes anymore—everyone has agile, high-performance laptops. Energy storage shares many of the same principles.

How have you stayed afloat while other battery startups fell by the wayside?

We focused with great intensity on making the technology work on a low-cost platform. There are some businesses that pivot and change in response to market shifts, and that's very often a great strategy. We were extremely stubborn—which can also be useful at times.

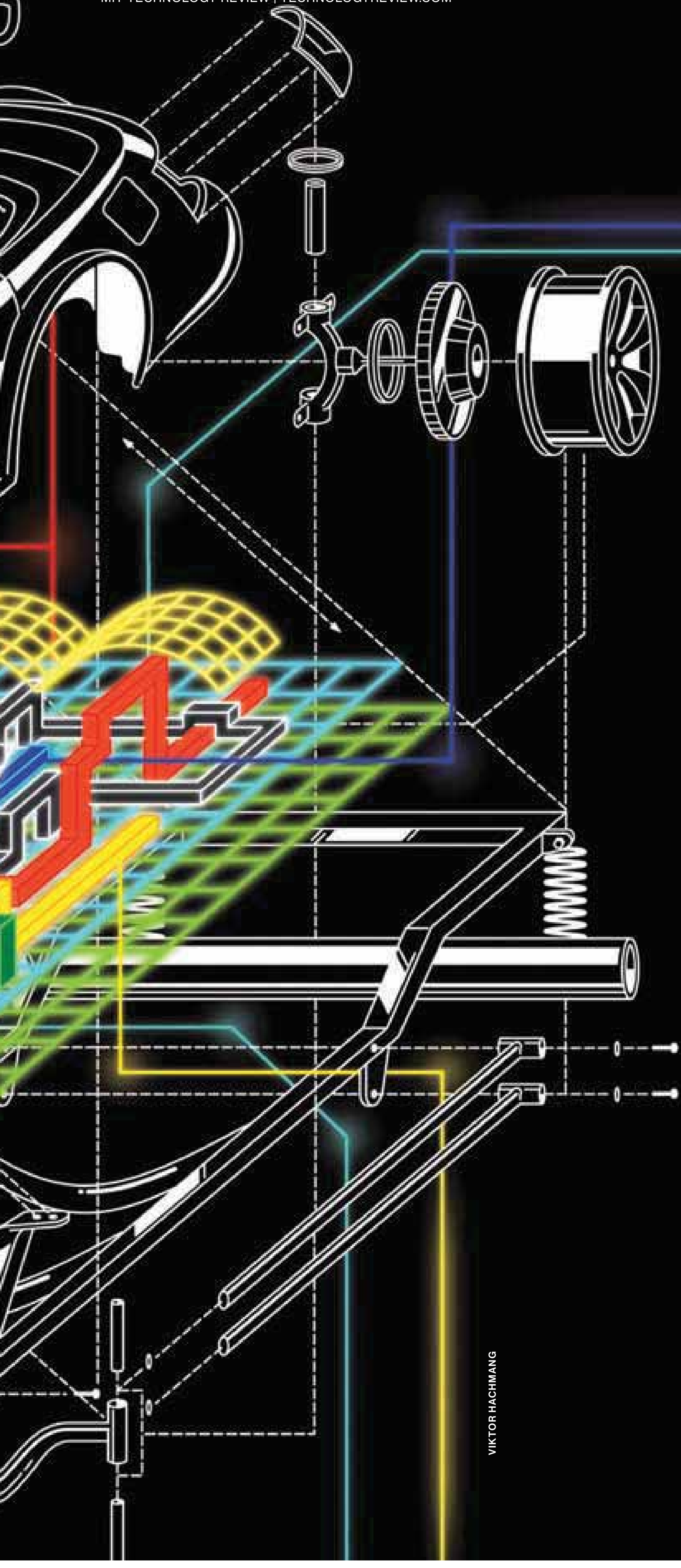
LAURA MCDERMOTT



Rebooting the Automobile

Automakers and tech companies are racing to bring safer and more useful smartphone-style interfaces to cars. Can any of them go further and reprogram vehicles completely?

By Will Knight



VIKTOR HACHMANG

"Where would you like to go?" Siri asked.

It was a sunny, slightly dreamy morning in the heart of Silicon Valley, and I was sitting in the passenger seat of what seemed like a perfectly ordinary new car. There was something strangely Apple-like about it, though. There was no mistaking the apps arranged across the console screen, nor the deadpan voice of Apple's virtual assistant, who, as backseat drivers go, was pretty helpful. Summoned via a button on the steering wheel and asked to find sushi nearby, Siri read off the names of a few restaurants in the area, waited for me to pick one, and then showed the way on a map that appeared on the screen.

The vehicle was, in fact, a Hyundai Sonata. The Apple-like interface was coming from an iPhone connected by a cable. Most carmakers have agreed to support software from Apple called CarPlay, as well as a competing product from Google, called Android Auto, in part to address a troubling trend: according to research from the National Safety Council, a nonprofit group, more than 25 percent of road accidents are a result of a driver's fiddling with a phone. Hyundai's car, which goes on sale this summer, will be one of the first to support CarPlay, and the carmaker had made the Sonata available so I could see how the software works.

CarPlay certainly seemed more intuitive and less distracting than fiddling with a smartphone behind the wheel. Siri felt like a better way to send texts, place calls, or find directions. The system has obvious limitations: if a phone loses the signal or its battery dies, for example, it will stop working fully. And Siri can't always be relied upon to hear you correctly. Still, I would've gladly used CarPlay in the rental car I'd picked up at the San Francisco airport: a 2013 Volkswagen Jetta. There was little inside besides an air-conditioning unit and a radio. The one technological luxury, ironically, was a 30-pin cable for an outdated iPhone. To use my smartphone for navigation, I needed a suction mount, an adapter for charging through the cigarette lighter, and good eyesight. More than once as I drove around, my iPhone came unstuck from the windshield and bounced under the passenger seat.

Android Auto also seemed like a huge improvement. When a Google product manager, Daniel Holle, took me for a ride in another Hyundai Sonata, he plugged his Nexus smartphone into the car and the touch screen was immediately taken over by Google Now, a kind of super-app that provides recommendations based on your location, your Web searches, your Gmail messages, and so on. In our case it was showing directions to a Starbucks because Holle had searched for coffee just before leaving his office. Had a ticket for an upcoming flight been in his in-box, Holle explained, Google Now would've automatically shown directions to the airport. "A big part of why we're doing it is driver safety," he said. "But there's also this huge opportunity for digital experience in the car. This is a smart driving assistant."

CarPlay and Android Auto not only give Apple and Google a foothold in the automobile but may signal the start of a more significant effort by these companies to reinvent the car. If they could tap into the many different computers that control car systems, they could use their software expertise to reimagine functions such as steering or collision avoidance. They could create operating systems for cars.

Google has already built its own self-driving cars, using a combination of advanced sensors, mapping data, and clever navigation and control software. There are indications that Apple is now working on a car too: though the company won't comment on what it terms "rumors and speculation," it is hiring dozens of people with expertise in automotive design, engineering, and strategy. Vans that belong to Apple, fitted with sensors that might be useful for automated driving, have been spotted cruising around California.

After talking to numerous people with knowledge of the car industry, I believe an Apple car is entirely plausible. But it almost doesn't matter. The much bigger opportunity for Apple and Google will be in developing software that will add new capabilities to any car: not just automated driving but also advanced diagnostics and over-the-air software upgrades and repairs. Already, a button at the bottom of the Android Auto interface is meant for future apps that could show vehicle diagnostics. Google expects these apps to be made by carmakers at first, showing more advanced vehicle data than the mysterious engine light that flashes when something goes wrong. Google would like to make use of such car data too, Holle says. Perhaps if Android Auto knew that your engine was overheating, Google Now could plan a trip to a nearby mechanic for you.

At least for now, though, the Google and Apple services essentially can read only basic vehicle data like whether a car is in drive, park, or reverse. Carmakers won't let those companies put their software deeper into the brains of the car, and whether that will change is a crucial question. After all, modern cars depend on computers to run just about everything, from the entertainment console to the engine pistons, and whoever supplies the software for these systems will shape automotive innovation. Instead of letting Apple and Google define their future, carmakers are opening or expanding labs in Silicon Valley in an attempt to fend off the competition and more fully embrace the possibilities offered by software.

The car could be on the verge of its biggest reinvention yet—but can carmakers do it themselves? Or will they give up the keys?

> "It doesn't make sense that the first thing you do is buy a $5 suction cup for your phone."

Cultural shift

Cars are far more computerized than they might seem. Automakers began using integrated circuits to monitor and control basic engine functions in the late 1970s; computerization accelerated in the 1980s as regulations on fuel efficiency and emissions were put in place, requiring even better engine control. In 1982, for instance, computers began taking full control of the automatic transmission in some models.

New cars now have between 50 and 100 computers and run millions of lines of code. An internal network connects these computers, allowing a mechanic or dealer to assess a car's health through a diagnostic port just below the steering wheel. Some carmakers diagnose problems with vehicles remotely, through a wireless link, and it's possible to plug a gadget into your car's diagnostic port to identify engine problems or track driving habits via a smartphone app.

However, until now we haven't seen software make significant use of all these computer systems. There is no common operating system. Given that carmakers are preventing CarPlay or Android Auto from playing that role, it's clear that the auto companies are taking a first crack at it. How successful they are will depend on how ambitious and creative they are. Roughly 10 minutes north of Google's office, I got to see how one of the oldest car companies is beginning to think about this possibility.

Ford opened its research lab in Palo Alto in January 2015. Located one door down from Skype and just around the cor-

Timeline of Automobile Computerization

1966 GM engineers propose using radio relay stations and sensors buried in roads to give drivers directions and traffic updates.

1978 Electronic cruise control is made possible through a Motorola processor.

1981 The engines in all GM models have a Motorola microcomputer that controls the carburetor and fuel injection.

1983 Electronic stability control is introduced in the Toyota Crown.

1987 First touch screen appears, in a Buick Riviera.

1990s Electronics expand into seat motors, instrument panel lighting, and car locks.

1993 A new international standard lets computer systems embedded in cars talk to each other.

1995 The first satellite navigation system is released: GuideStar for the Oldsmobile Eighty Eight.

1996 A system for reading car performance data, known as ODBII, becomes standard on all vehicles.

2007 Blind-spot warning appears on a Volvo S80.

2013 The Infiniti Q50 is the world's first steer-by-wire car.

2013 Tesla's Model S is introduced. It has a 17-inch touch screen, wireless connectivity, and over-the-air upgrades.

1966, 1995: COPYRIGHT 2015 GENERAL MOTORS LLC. USED WITH PERMISSION, GM MEDIA ARCHIVE; 1983: COURTESY OF TOYOTA-CLUB.NET; 1987: COURTESY OF BUICK; 2007: COURTESY OF VOLVO CAR CORPORATION; 2013: COURTESY OF TESLA MOTORS

ner from Hewlett-Packard, it looks like a typical startup space. There are red beanbags, 3-D printers, and rows of empty desks, which the company hopes to fill with more than a hundred engineers. I met a user-interface designer named Casey Feldman. He was perched atop a balance board at a standing desk, working on Ford's latest infotainment system, Sync 3. It runs software Ford has developed, but the automaker is working on ways to hand the screen over to CarPlay or Android Auto if you plug in a smartphone. Feldman was using a box about the size of a mini-fridge, with a touch screen and dashboard controls, to test the software. He showed how Sync 3 displays a simplified interface when the car is traveling at high speed.

Ford's first touch-screen interface, called MyFord Touch, didn't go well. Introduced in 2010, it was plagued by bugs, and customers complained that it was overcomplicated. When Ford dropped from 10th to 20th place in *Consumer Reports*' annual reliability ratings in 2011, MyFord Touch was cited as a key problem. The company ended up sending out more than 250,000 memory sticks containing software fixes for customers to upload to their cars.

Besides running apps like Spotify and Pandora Radio, Sync 3 can connect to a home Wi-Fi network to receive bug fixes and updates for the console software. Ford clearly hopes that drivers will prefer its system to either CarPlay or Android

Auto, and it's doing its best to make it compelling. "It's a cultural shift," says Dragos Maciuca, the lab's technical director. The lab wants to incorporate "some of the Silicon Valley attitudes, but also processes" into the automotive industry, he says. "That is clearly going to be very challenging, but that's why we're here. It doesn't make sense that you buy a car, and the first thing you do is buy a $5 suction cup for your phone."

Ford has been ahead of many automakers in its experimentation. It has come out with a module known as Open XC, which lets people download a wide range of sensor data from their cars and develop apps to aid their driving. A Ford engineer used it to create a shift knob for cars with manual transmission so that the stick lights up or buzzes when it's time to change gears. But Open XC has not taken off widely, and despite Ford's best efforts, the company's overall approach still seems somewhat conservative. Maciuca and others said they were wary of alienating Ford's vast and diverse customer base.

In February 2015, meanwhile, the chip maker Nvidia announced two new products designed to give cars considerably more computing power. One is capable of rendering 3-D graphics on up to three different in-car displays at once. The other can collect and process data from up to 12 cameras around a car, and it features machine-learning software that can help collision-avoidance systems or even automated driving systems recognize certain obstacles on the road. These two systems point to the huge opportunity that advanced automotive sensors and computer systems offer to software makers. "We're arguing now you need supercomputing in the car," Danny Shapiro, senior director of automotive at Nvidia, told me.

If anyone could find a great use for a supercomputer on wheels, it's Chris Gerdes, a professor of mechanical engineering who leads Stanford University's Dynamic Design Lab. Gerdes originally studied robotics as a graduate student, but while pursuing a PhD at Berkeley, he became interested in cars after rebuilding the engine of an old Chevy Cavalier. He drove me to the lab from his office in an incredibly messy Subaru Legacy.

Inside the lab, students were working away on several projects spread across large open spaces: a lightweight, solar-powered car; a Ford Fusion covered in sensors; and a hand-built two-person vehicle resembling a dune buggy. Gerdes pointed to the Fusion. After Ford gave his students a custom software interface, they found it relatively easy to get the car to drive itself. Indeed, the ability to manipulate a car through software explains why many cars can already park themselves and automatically stay within a lane and maintain a safe distance from the vehicle ahead. In the coming years, several carmakers will introduce vehicles capable of driving themselves on highways for long periods. "There are so many things you can do now to innovate that don't necessarily require that you bend sheet metal," Gerdes said as we walked around. "The car is a platform for all sorts of things, and many of those things can be tried in software."

The dune-buggy-like car takes programmability to the extreme. Virtually every component is controlled by an actuator connected to a computer. This means that software can configure each wheel to behave in a way that makes an ordinary road feel as if it were covered with ice. Or, using data from sensors fitted to the front of the car, it can be configured to help a novice motorist react like a race-car driver. The idea is to explore how computers could make driving safer and more efficient without taking control away from the driver completely.

In fact, one small carmaker—headquartered in Silicon Valley—shows how transformational an aggressive approach to software innovation could be.

Drive safely

Tesla Motors, based in Palo Alto, has built what's probably the world's most computerized consumer car. The Model S, an

Operating Systems for Cars

	CarPlay	Android Auto	QNX	Windows E.A.	Tesla OS	Open XC
Made by	Apple	Google	BlackBerry	Windows	Tesla	Ford
Where it runs	iPhone	Android device	Embedded	Embedded	Embedded	Open XC device
Supported by	Most manufacturers	Most manufacturers	Audi, Porsche, Toyota, Honda, Ford, General Motors	Ford, Nissan, Kia, Fiat	Tesla	Ford

electric sedan released in 2012, has a 17-inch touch-screen display, a 3G cellular connection, and even a Web browser. The touch screen shows entertainment apps, a map with nearby charging stations, and details about the car's battery. But it can also be used to customize all sorts of vehicle settings, including those governing the suspension and the acceleration mode (depending on the model, it goes from "normal" to "sport" or from "sport" to "insane").

Every few months, Tesla owners receive a software update that adds new functions to their vehicle. Since the Model S was released, these have included more detailed maps, better acceleration, a hill-start mode that stops the car from rolling backwards, and a blind-spot warning (providing a car has the right sensors). Tesla's CEO, Elon Musk, has said a software patch released this summer would add automated highway driving to suitably equipped models.

These software updates can do more than just add new bells and whistles. Toward the end of 2013, the company faced a safety scare when several Model S cars caught fire after running over debris that ruptured their battery packs. Tesla engineers believed the fires to be rare events, and they knew of a simple fix, but it meant raising the suspension on every Model S on the road. Instead of requiring owners to bring their cars to a mechanic, Tesla released a patch over the airwaves that adjusted the suspension to keep the Model S elevated at higher speeds, greatly reducing the chance of further accidents. (In case customers wanted even more peace of mind, the company also offered a titanium shield that mechanics could install.)

Tesla's efforts show how making cars more fully programmable can add value well after they roll out of the showroom. But software-defined vehicles could also become a juicy target for troublemakers.

In 2013, at the DEF CON conference in Las Vegas, two computer-security experts, Charlie Miller and Chris Valasek, showed that they could hijack the internal network of a 2010 Toyota Prius and remotely control critical features, including steering and braking. "No one really knows a lot about car security, or what it's all about, because there hasn't been a lot of research," Miller told me. "It's possible, if you went out and bought a 2013, they've done huge improvements—we don't know. That's one of the scary things about it."

A few real-world incidents point to why car security might become a problem. In February 2010, dozens of cars around Texas suddenly refused to start and also, inexplicably, began sounding their horns. The cars had been fitted with devices that let the company that leased them, the Texas Auto Center, track them and then disable and recover them should the driver fail to make payments. Unfortunately, a disgruntled employee with access to the company's system was using those gadgets to cause havoc.

I asked Gerdes whether concerns over reliability and security could slow the computerization of cars. He said that didn't have to be the case. "The key question is, 'How fast can you move safely?'" he says. "The bet that many Silicon Valley companies are making—and that many car companies are making with their Valley offices—is that there are ways to move faster and still be safe."

Ultimately, the opportunities may well outweigh such concerns. Tesla's efforts point to how significant software innovation could turn out to be for carmakers. Tesla is even experimenting with connecting the forthcoming autopilot system to the car's calendar, for example. The car could automatically pull up outside the front door just in time for the owner to drive to an upcoming appointment.

One of the cars at Stanford's Dynamic Design Lab.

STEPHEN RUSSELL, STANFORD UNIVERSITY DYNAMIC DESIGN LAB

Perhaps this also explains why Apple and Google are now dabbling in vehicle hardware: so they can fully own some people's driving time even before carmakers decide to open up more aspects of their vehicles. "Clearly Apple and Google would love to be the ones who have the operating system for these future cars," Gerdes says.

As I drove back to the San Francisco airport, my VW Jetta felt more low-tech than ever. The ride was fairly peaceful, with the Santa Cruz Mountains looming in the distance. Even so, after so much driving, I would've been glad had Siri offered to take over.

Will Knight is MIT Technology Review*'s senior editor for AI.*

Michelle Dipp, CEO of OvaScience

Slowing the Biological Clock

For years researchers believed that women were born with all the eggs they would ever have. That—and the fact that the quality of the eggs diminishes when a woman reaches her 40s—meant infertility was inevitable past a certain age. But in 2004, Jonathan Tilly and other researchers at Massachusetts General Hospital showed that ovaries also contain egg precursor cells, which might, in theory, mature into new eggs or boost the health of existing ones. Now OvaScience, which Tilly cofounded—a member of this year's 50 Smartest Companies list—is developing treatments for infertile couples. In its first commercially available approach, energy-producing mitochondria are transferred from egg precursor cells into mature eggs to rejuvenate them. These eggs are then used for in vitro fertilization. In May, the first baby was born to parents who tried this approach. OvaScience CEO Michelle Dipp spoke with *MIT Technology Review* contributing editor Amanda Schaffer.

What need does OvaScience's technology address that regular in vitro fertilization does not?

One in six couples worldwide struggles with infertility, and unfortunately, the standard of care, which is IVF, often fails. Our goal is to address the root cause of infertility and the reason treatment fails, which is frequently unhealthy eggs. We now know that women have egg precursor cells in the outer lining of our ovaries. We are developing several treatments that use these precursor cells. In one treatment, which is now on the market, we add mitochondria to eggs. In another approach, which is still experimental, we move egg precursor cells to the middle of the ovary so that they grow into eggs during IVF. In a third treatment [also experimental], we take the precursor cells and grow them into eggs outside the body.

Should these treatments change the way we think about the biological clock?

As a woman gets older, she still has these fresh, young, healthy egg precursor cells. These cells don't seem to age with time, because they're in an area that lacks a good blood supply, so they lie dormant. I do think that discovery should change our assumptions about fertility and aging.

So how late in life could a woman get pregnant?

It ends up being a doctor-patient conversation about what age they do IVF, and most clinics have certain ways to think about what their age cutoff is. Usually around the time of menopause, it becomes a lot more challenging. Women have to use other hormones in addition to IVF to get pregnant.

Do you see a limit on how many people could benefit from this technology?

More women are waiting to start families. When you look at emerging markets, like in Latin America and the Middle East, more women are going to college, more of them are seeking advanced degrees, more of them are traveling to other countries to get those advanced degrees. They're prioritizing other things. [Because they're older when they try to have children] there's an increase in infertility as well as in IVF rates, and the demand is expected to be even greater in the future. The global market is projected to reach over $20 billion by 2020.

This treatment is expensive—$15,000 on top of the cost of IVF. Won't cost place an important limit on patient access?

It already does with IVF. Many more couples are infertile than seek treatment, because it is paid for out of pocket. [But] a number of doctors offer IVF pro bono in countries where it is hard for patients to gain access.

Your first treatment is not available in the United States. Is the future of the company mainly in other countries?

That's certainly what the market has always dictated in the past. The growth rate of IVF in Europe is about 10 percent. There is no growth in the U.S. That said, the goal is to bring our treatments to women everywhere, and that includes the U.S. But I'm afraid I can't comment on what we would need to do to win regulatory approval here.

How strong is the evidence that your treatment works, considering the absence of randomized controlled trials?

New data show that women who failed previous IVF treatment and then used our approach increased their chance of having a child. We're really excited about that. Because these women had tried IVF already, they served as their own controls.

Fertility treatments are not drugs. Drugs are of course analyzed by a randomized controlled trial, but these are surgical procedures.

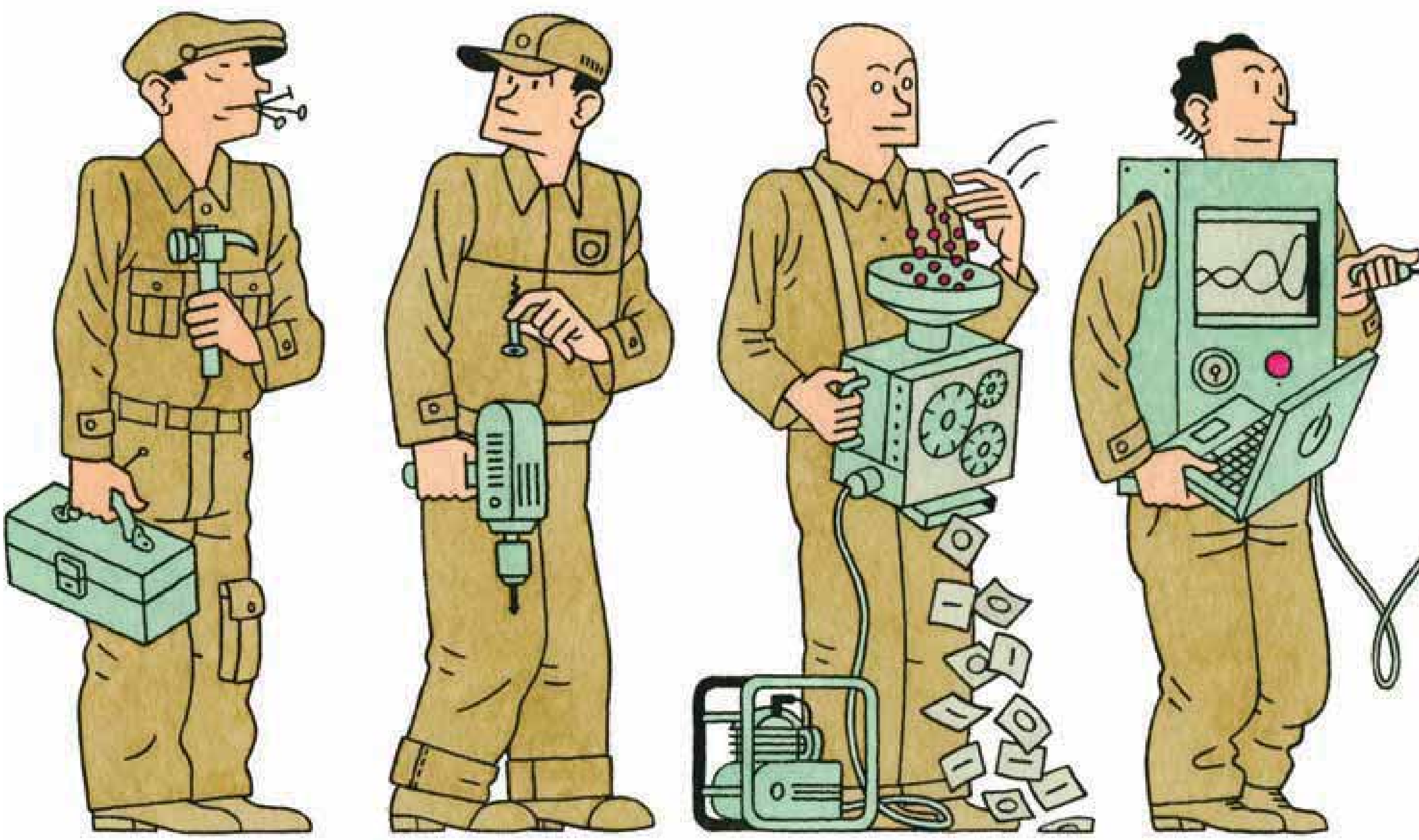
LEONARD GRECO

Who Will Own the Robots?

We're in the midst of a jobs crisis, and rapid advances in AI and other technologies may be one culprit. How can we get better at sharing the wealth that technology creates?

By David Rotman

The way Hod Lipson describes his Creative Machines Lab captures his ambitions: "We are interested in robots that create and are creative." Lipson, an engineering professor at Cornell University (this year he moved his lab to Columbia University), is one of the world's leading experts on artificial intelligence and robotics. His research projects provide a peek into the intriguing possibilities of machines and automation, from robots that "evolve" to ones that assemble themselves out of basic building blocks. (His Cornell colleagues are building robots that can serve as baristas and kitchen help.) A few years ago, Lipson demonstrated an algorithm that explained experimental data by formulating new scientific laws, which were consistent with ones known to be true. He had automated scientific discovery.

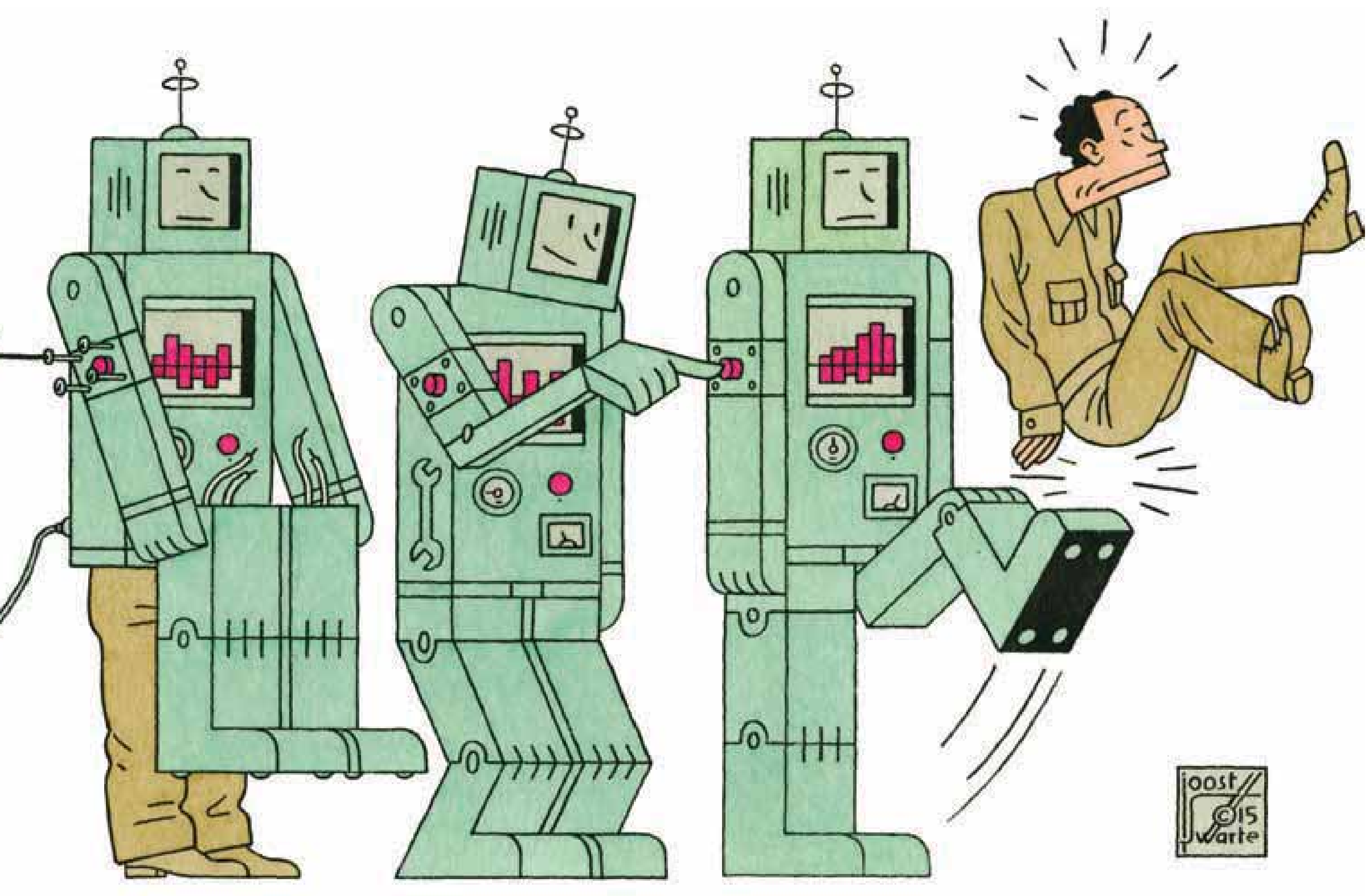


Illustrations by Joost Swarte

Lipson's vision of the future is one in which machines and software possess abilities that were unthinkable until recently. But he has begun worrying about something else that would have been unimaginable to him a few years ago. Could the rapid advances in automation and digital technology provoke social upheaval by eliminating the livelihoods of many people, even as they produce great wealth for others?

"More and more computer-guided automation is creeping into everything from manufacturing to decision making," says Lipson. In the last two years alone, he says, the development of so-called deep learning has triggered a revolution in artificial intelligence, and 3-D printing has begun to change industrial production processes. "For a long time the common understanding was that technology was destroying jobs but also creating new and better ones," says Lipson. "Now the evidence is that technology is destroying jobs and indeed creating new and better ones but also fewer ones. It is something we as technologists need to start thinking about."

Worries that rapidly advancing technologies will destroy jobs date back at least to the early 19th century, during the Industrial Revolution in England. In 1821, a few years after the Luddite protests, the British economist David Ricardo fretted about the "substitution of machinery for human labour." And in 1930, during the height of the worldwide depression, John Maynard Keynes famously warned about "technological unemployment" caused by "our discovery of means of economising the use of labour." (Keynes, however, quickly added that "this is only a temporary phase of maladjustment.")



Now, technology is once again under suspicion as rising income inequality confronts the United States, Europe, and much of the rest of the developed world. A recent report from the Organization for Economic Cooperation and Development concluded that the gap between the rich and poor is at a historically high level in many of its 34 member countries, driven largely by a drop in earning power for the bottom 40 percent of the population. Many of the lowest earners have seen wages decrease over the last few decades, and the OECD warns that income inequality is now undermining economic growth.

Meanwhile, the erosion of the American middle class and the pressure on the lowest-paid U.S. workers has been painfully evident for years. Only 68 percent of men between 30 and 45 who have a high school diploma were working full time in 2013, according to a recent report by the Hamilton Project at the Brookings Institution, a Washington-based public-policy group. Earnings for the typical worker haven't kept up with the growth of the economy for decades. Median earnings for a man without a high school diploma fell 20 percent from 1990 to 2013, while wages for those with only a high school diploma dropped 13 percent. Women have fared somewhat better, though they still generally earn less than men. Over the same period, earnings for women without a high school diploma dropped 12 percent, while earnings for those with a high school diploma actually rose by 3 percent.

Do today's rapid advances in artificial intelligence and automation portend a future in which robots and software greatly reduce the need for human workers?

It is notoriously hard to determine the factors that go into job creation and earnings, and it is particularly difficult to isolate the specific impact of technology from that of, say, globalization, economic growth, access to education, and tax policies. But advances in technology offer one plausible, albeit partial, explanation for the decline of the middle class. A prevailing view among economists is that many people simply don't have the training and education required for the increasing number of well-paying jobs requiring sophisticated technology skills. At the same time, software and digital technologies have displaced many types of jobs involving routine tasks such as those in accounting, payroll, and clerical work, forcing many of those workers to take more poorly paid positions or simply abandon the workforce. Add to that the increasing automation of manufacturing, which has eliminated many middle-class jobs over the past decades, and you begin to see why much of the workforce is feeling squeezed.

These are long-term trends that began decades ago, says David Autor, an MIT economist who has studied "job polarization"—the disappearance of middle-skill jobs even as demand increases for low-paying manual work on the one hand and highly skilled work on the other. This "hollowing out" of the middle of the workforce, he says, "has been going on for a while."

Nevertheless, the recession of 2007–2009 may have sped up the destruction of many relatively well-paid jobs requiring repetitive tasks that can be automated. These so-called routine jobs "fell off a cliff in the recession," says Henry Siu, an economist at the University of British Columbia, "and there's been no large rebound." This type of work, which includes white-collar jobs in sales and administration as well as blue-collar jobs in assembly work and machine operation, makes up about 50 percent of employment in the United States. Siu's research also shows that the disappearance of these jobs has most harshly affected people in their 20s, many of whom seem to have simply stopped looking for work.

That's bad enough. But there's an even more fundamental fear. Is this a harbinger of what's to come for other sectors of the workforce, as technology takes over more and more of the jobs that have long been considered secure paths to a middle-class life? Are we at the beginning of an economic transformation that is unique in history, wonderful for what it could do in bringing us better medicine, services, and products, but devastating for those not in a position to reap the financial benefits? Will robots and software replace most human workers?

Scaring children

No one knows the answer. Many economists see little convincing evidence that advances in technology will be responsible for a net decrease in the number of jobs, or that what we're undergoing is any different from earlier transitions when technology destroyed some jobs but improved employment opportunities over time. Still, over the last several years, a number of books and articles have argued that the recent advances in artificial intelligence and automation are inherently different from past technological breakthroughs in what they portend for the future of employment. Martin Ford is one of those who think this time *is* different. In his new book, *Rise*

Automation Angst

Rise of the Robots: Technology and the Threat of a Jobless Future
by Martin Ford
Basic Books, 2015

The Great Divide: Unequal Societies and What We Can Do About Them
by Joseph E. Stiglitz
W.W. Norton, 2015

Inequality: What Can Be Done?
by Anthony B. Atkinson
Harvard University Press, 2015

The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies
by Erik Brynjolfsson and Andrew McAfee
W.W. Norton, 2014

of the Robots: Technology and the Threat of a Jobless Future, Ford points to numerous examples of new technologies, such as driverless cars and 3-D printing, that he thinks will indeed eventually replace most workers. How then will we adapt to this "jobless future"?

Ford recommends a guaranteed basic income as part of the answer. Simply put, his prescription is to give people a modest amount of money. It's not a new idea. One version of it, called a negative income tax, was popularized by the conservative economist Milton Friedman during the early 1960s as a way to replace some of the growing government bureaucracy. And Ford quotes the economist Friedrich Hayek, who in 1979 described assuring a minimum income as a way to provide "a sort of floor below which nobody need fall even when he is unable to provide for himself." Both Richard Nixon and his 1972 presidential rival George McGovern, a liberal Democrat, championed some form of the policy.

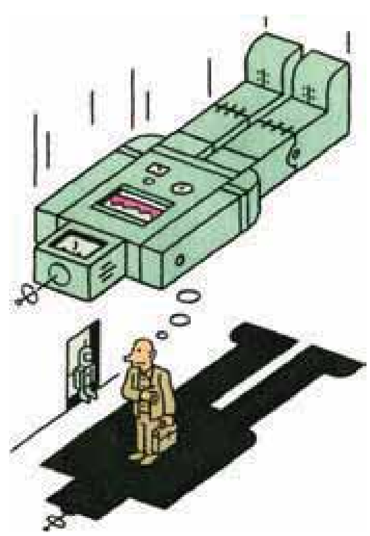
The idea went out of fashion in the 1980s, but it has returned in recent years as a way to help those people shut out of the labor markets. In the libertarian version, it's a way to provide a safety net with minimum government involvement; in the progressive version, it supplements other programs to help the poor.

Whether it is good politics or good social policy has been endlessly debated. Recently, others have suggested a related policy: expanding the Earned Income Tax Credit, which would give some extra money to low-paid workers. These ideas probably do make sense as a way to strengthen the social safety net. But if you believe that the rapid advance of technology could eliminate the need for most workers, such policies do little to directly address that scenario. Allowing a large number of workers to become irrelevant in the technology-centric economy would be a huge waste of human talent and ambition—and would probably put an enormous financial burden on society. What's more, a guaranteed basic income does not offer much to those in the middle class whose jobs are at risk, or to those who have recently fallen from financial security in the absence of well-paying jobs.

It might also be premature to plan for a dystopian future of hardly any jobs. Ford's *Rise of the Robots* offers many examples of impressive achievements in automation, software, and AI that could make some jobs obsolete—even those requiring highly trained professionals in fields like radiology and law. But how do you assess just how specific technologies like these will affect the total number of jobs in the economy?

In fact, there is not much evidence on how even today's automation is affecting employment. Guy Michaels and his colleague Georg Graetz at the London School of Economics recently looked at the impact of industrial robots on manufacturing in 17 developed countries. The findings tell a mixed story: the robots did seem to replace some low-skill jobs, but their most important impact was to significantly increase the productivity of the factories, creating new jobs for other workers. Overall, there was no evidence that the robots reduced total employment, says Michaels.

If it's difficult to quantify the effect of today's technology on job creation, it's impossible to accurately predict the effects of future advances. That opens the door to wild speculation. Take an extreme example raised by Ford: molecular manufacturing. As proposed by some nanotechnology boosters, most notably the author K. Eric Drexler, the idea is that one day it will be possible to build almost anything with nanoscale robots that move atoms around like tiny building blocks. Though Ford acknowledges that it might not happen, he warns that jobs will be devastated if it does.



The credence Ford gives to Drexler's vision of nanobots slaving away in molecular factories seems less than warranted, though, given that the idea was debunked by the Nobel-winning chemist Richard Smalley more than a decade ago (see "Will the Real Nanotech Please Stand Up?" March/April 1999). Smalley saw great potential for nanotech in areas such as clean energy, but his objection to molecular manufacturing as Drexler described it was simple: it ignores the rules of chemistry and physics governing the way atoms bind and react with each other. Smalley admonished Drexler: "You and people around you have scared our children. I don't expect you to stop, but … while our future in the real world will be challenging and there are real risks, there will be no such monster as the self-replicating mechanical nanobot of your dreams."

Though Ford does note Smalley's criticism, one begins to wonder whether his conjuring the "rise of the robots" might not indeed be needlessly scaring our children. Speculating about such far-fetched possibilities is a distraction in thinking about how to address future concerns, much less existing job woes.

A more realistic, but in its way more interesting, version of the future is being written in the downtown Chicago offices of Narrative Science. Its software, called Quill, is able to take data—say, the box score of a baseball game or a company's annual report—and not only summarize the content but extract a "narrative" from it. Already, *Forbes* is using it to create some stories about corporate earnings, and the Associated Press is using a rival's product to write some sports stories. The quality is readable and is likely to improve greatly in coming years.

Yet despite the potential of such technology, it is not clear how it would affect employment. "As AI stands today, we've not seen a massive impact on white-collar jobs," says Kristian Hammond, a Northwestern University computer scientist who helped create the software behind Quill and is a cofounder of the company. "Short-term and medium-term, [AI] will displace work but not necessarily jobs," he says. If AI tools do some of the scut work involved in analyzing data, he says, people can be "free to work at the top of their game."

And as impressive as Quill and other recent advances are, Hammond is not yet convinced that the capabilities of general-purpose AI are poised for great expansion. The current resurgence in the field, he says, is being driven by access to massive amounts of data that can be quickly analyzed and by the immense increase in computing power over what was available a few years ago. The results are striking, but the techniques, including some aspects of the natural-language generation methods that Quill employs, make use of existing technologies empowered by big data, not breakthroughs in AI. Hammond says some recent descriptions of certain AI programs as black boxes that teach themselves capabilities sound

"Short-term and medium-term, [AI] will displace work but not necessarily jobs."

more like "magical rhetoric" than realistic explanations of the technology. And it remains uncertain, he adds, whether deep learning and other recent advances will truly "work as well as touted."

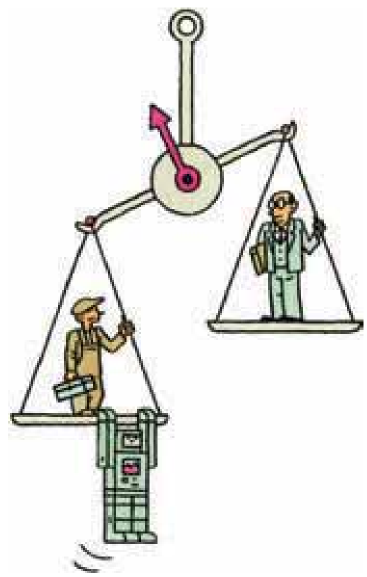
In other words, it would be smart to temper our expectations about the future possibilities of machine intelligence.

The gods of technology

"Too often technology is discussed as if it has come from another planet and has just arrived on Earth," says Anthony Atkinson, a fellow of Nuffield College at the University of Oxford and a professor at the London School of Economics. But the trajectory of technological progress is not inevitable,

he says: rather, it depends on choices by governments, consumers, and businesses as they decide which technologies get researched and commercialized and how they are used.

Atkinson has been studying income inequality since the late 1960s, a period when it was generally a subject on the back burner of mainstream economics. Over those years, income inequality has grown dramatically in a number of countries. Its levels rose in the U.K. in the 1980s and have not fallen since, and in the United States they are still rising, reaching historically unprecedented heights. The publication in 2013 of his frequent collaborator Thomas Piketty's remarkably successful *Capital in the 21st Century* made inequality the hottest topic in economics. Now Atkinson's new book, called *Inequality: What Can Be Done?*, proposes some solutions. First on his list: "encouraging innovation in a form that increases the employability of workers."



When governments choose what research to fund and when businesses decide what technologies to use, they are inevitably influencing jobs and income distribution, says Atkinson. It's not easy to see a practical mechanism for picking technologies that favor a future in which more people have better jobs. But "at least we need to ask" how these decisions will affect employment, he says. "It's a first step. It might not change the decision, but we will be aware of what is happening and don't have to wait until we say, 'Oh dear, people have lost their jobs.'"

Part of the strategy could emerge from how we think about productivity and what we actually want from machines. Economists traditionally define productivity in terms of output given a certain amount of labor and capital. As machines and software—capital—become ever cheaper and more capable, it makes sense to use less and less human labor. That's why the prominent Columbia University economist Jeffrey Sachs recently predicted that robots and automation would soon take over at Starbucks. But there are good reasons to believe that Sachs could be wrong. The success of Starbucks has never been about getting coffee more cheaply or efficiently. Consumers often prefer people and the services humans provide.

Take the hugely popular Apple stores, says Tim O'Reilly, the founder of O'Reilly Media. Staffed by countless swarming employees armed with iPads and iPhones, the stores provide a compelling alternative to a future of robo-retail; they suggest that automating services is not necessarily the endgame of today's technology. "It's really true that technology will take away a class of jobs," says O'Reilly. "But there is a choice in how we use technology."

In that sense, Apple stores have found a winning strategy by not following the conventional logic of using automation to lower labor costs. Instead, the company has cleverly deployed an army of tech-savvy sales employees toting digital gadgets to offer a novel shopping experience and to profitably expand its business.

O'Reilly also points to the enormous success of the car service Uber. By using technology to create a convenient and efficient reservation and payment service, it has created a robust market. And in doing so, it has expanded the demand for drivers—who, with the aid of a smartphone and app, now have greater opportunities than they might working for a conventional taxi service.

The lesson is that if advances in technology are playing a role in increasing inequality, the effects are not inevitable, and they can be altered by government, business, and consumer decisions. As the economist Paul Krugman recently told an audience at a forum called "Globalization, Technological Change, and Inequality" in New York City, "A lot of what's happening [in income inequality] is not just the gods of technology telling us what must happen but is in fact [due to] social constructs that could be different."

Who owns the robots?

The effects of automation and digital technology on today's employment picture are sometimes downplayed by those who point to earlier technology transitions. But that ignores the suffering and upheaval during those periods. Wages in England were stagnant or fell for around 40 years after the beginning of the Industrial Revolution, and the misery of factory workers is well documented in the literature and political writings of the day.

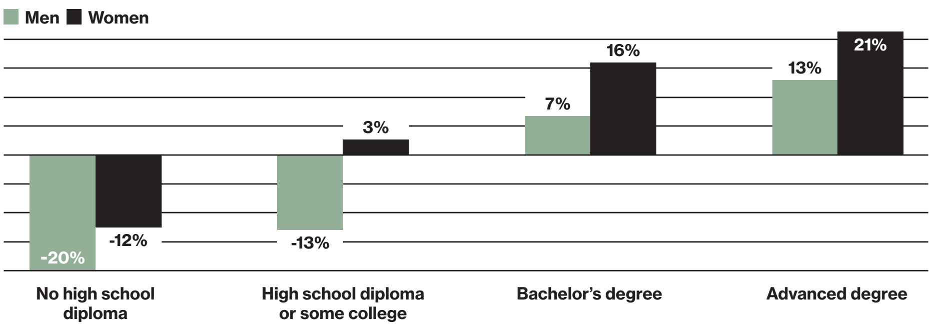
In his new book, *The Great Divide*, the Columbia University economist Joseph Stiglitz suggests that the Great Depression, too, can be traced to technological change: he says its underlying cause was not, as is typically argued, disastrous government financial policies and a broken banking system but the shift from an agricultural economy to a manufacturing one. Stiglitz describes how the advent of mechanization and

Disappearing Jobs

Automation and digital technology have replaced many jobs involving repetitive tasks in manufacturing and office work. The remaining jobs often require increasingly advanced skills.

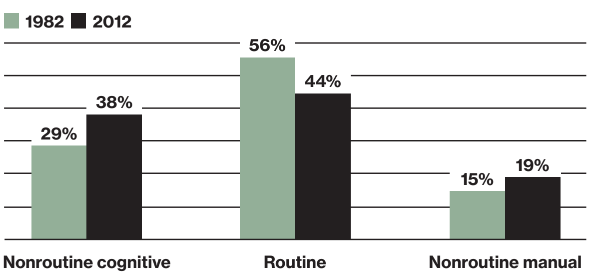
U.S. Median Real Earnings by Education Level, 1993–2013

Wages for men with a high school diploma have dropped as the number of production jobs has decreased and more men have taken low-paying jobs in food services, cleaning, and groundskeeping.



Share of U.S. Employment by Type of Occupation

Jobs are considered routine when they involve specific, repetitive tasks. These are the easiest jobs to automate.



Who's Working?

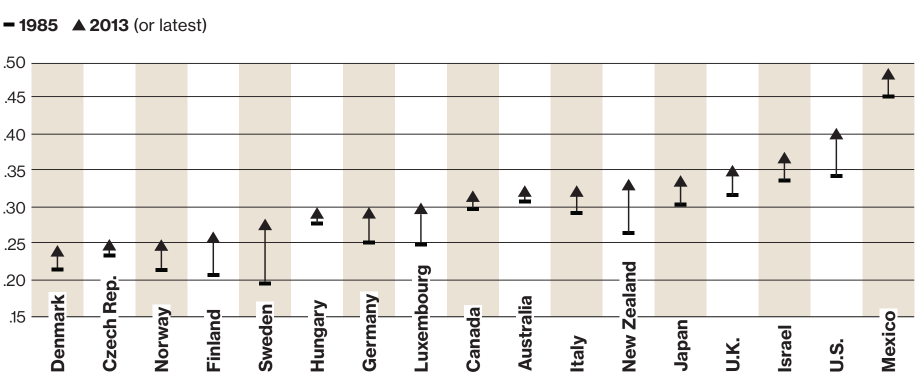
Fewer American men with high school diplomas or some college are employed full time.

1990
76%

2013
68%

Levels of Income Inequality in OECD Countries

Inequality as measured by the Gini coefficient, reflecting income distribution; 1.0 would be maximal inequality.



improved farming practices quickly transformed the United States from a country that needed many farmers to one that needed relatively few. It took the manufacturing boom fueled by World War II to finally help workers through the transition. Today, writes Stiglitz, we're caught in another painful transition, from a manufacturing economy to a service-based one.

Those who are inventing the technologies can play an important role in easing the effects. "Our way of thinking as engineers has always been about automation," says Hod Lipson, the AI researcher. "We wanted to get machines to do as much work as possible. We always wanted to increase productivity; to solve engineering problems in the factory and other job-related challenges is to make things more productive. It never occurred to us that isn't a good thing." Now, suggests Lipson, engineers need to rethink their objectives. "The solution is not to hold back on innovation, but we have a new problem to innovate around: how do you keep people engaged when AI can do most things better than most people? I don't know what the solution is, but it's a new kind of grand challenge for engineers."

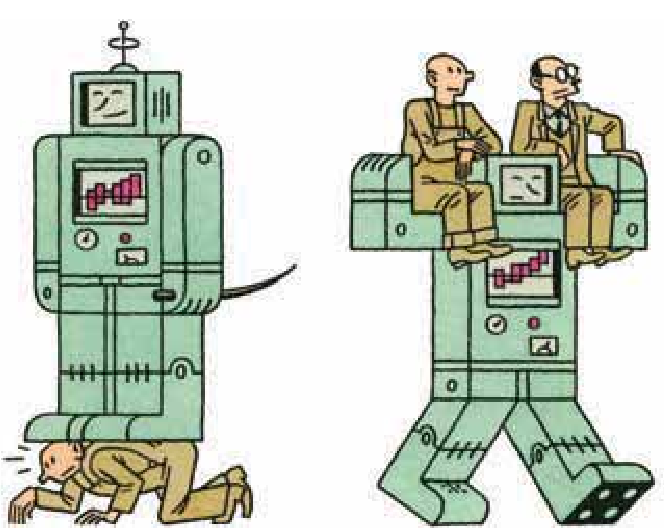
Ample opportunities to create jobs could come from much-needed investments in education, aging infrastructure, and research in areas such as biotechnology and energy. As Martin Ford rightly warns, we could be in for a "perfect storm" if climate change grows more severe at a time when technological unemployment imposes increased economic pressure. Whether this happens will depend in large part on which technologies we invent and choose to embrace. Some version of an automated vehicle seems inevitable, for example; do we use this to make our public transportation systems more safe, conve-

DATA FROM THE HAMILTON PROJECT; HENRY SIU, NIR JAIMOVICH; OECD nient, and energy efficient, or do we simply fill the highways with driverless cars and trucks?

There is little doubt that at least in the short term, the best bulwark against sluggish job creation is economic growth, whether that's accomplished through innovative service-intensive businesses like the Apple stores and Uber or through investments in rebuilding our infrastructure and education systems. It is just possible that such growth will overcome the worries over robots taking our jobs.

Andrew McAfee, the coauthor with his MIT colleague Erik Brynjolfsson of *The Second Machine Age*, has been one of the most prominent figures describing the possibility of a "sci-fi economy" in which the proliferation of smart machines eliminates the need for many jobs. (See "Open Letter on the Digital Economy," July/August 2015, in which McAfee, Brynjolfsson, and others propose a new approach to adapting to technological changes.) Such a transformation would bring immense social and economic benefits, he says, but it could also mean a "labor-light" economy. "It would be a really big deal, and it's not too soon to start the conversation about it," says McAfee. But it's also, he acknowledges, a prospect that is many decades away. Meanwhile, he advocates pro-growth policies "to prove me wrong." He says, "The genius of capitalism is that people find things to do. Let's give it the best chance to work."

Here's the rub. As McAfee and Brynjolfsson explain in *The Second Machine Age*, one of the troubling aspects of today's technological advances is that in financial terms, a few people have benefited from them disproportionately (see "Technology and Inequality," November/December 2014). As Silicon Valley has taught us, technology can be both a dynamic engine of economic growth and a perverse intensifier of income inequality.



In 1968, J.C.R. Licklider, one of the creators of today's technology age, co-wrote a remarkably prescient article called "The Computer as a Communication Device." He predicted "on line interactive communities" and explained their exciting possibilities. Licklider also issued a warning at the end of the paper:

"For the society, the impact will be good or bad, depending mainly on the question: Will 'to be on line' be a privilege or right? If only a favored segment of the population gets a chance to enjoy the advantage of 'intelligence amplification,' the network may exaggerate the discontinuity in the spectrum of intellectual opportunity."

Whoever owns the capital will benefit as robots and artificial intelligence inevitably replace many jobs.

Various policies can help redistribute wealth or, like the guaranteed basic income, provide a safety net for those at or near the bottom. But surely the best response to the economic threats posed by digital technologies is to give more people access to what Licklider called "intelligence amplification" so that they can benefit from the wealth new technology creates. That will mean providing fairer access to quality education and training programs for people throughout their careers.

It also means, says Richard Freeman, a leading labor economist at Harvard University, that far more people need to "own the robots." He's talking not only about machines in factories but about automation and digital technologies in general. Some mechanisms already exist in profit-sharing programs and employee stock-ownership plans. Other practical investment programs can be envisioned, he says.

Whoever owns the capital will benefit as robots and AI inevitably replace many jobs. If the rewards of new technologies go largely to the very richest, as has been the trend in recent decades, then dystopian visions could become reality. But the machines are tools, and if their ownership is more widely shared, the majority of people could use them to boost their productivity and increase both their earnings and their leisure. If that happens, an increasingly wealthy society could restore the middle-class dream that has long driven technological ambition and economic growth.

David Rotman is the editor of MIT Technology Review.

35 Innovators Under 35 2015

There's more than one way to read these stories. Sure, the subjects are inspiring and creative people. But these are not merely personality profiles. They also illustrate the most important emerging technologies of the moment. In biomedicine, for example, we feature several people who are figuring out in detail how the brain works and how we might stave off mental disorders. Others are unearthing knowledge about cancer that might open new avenues for treatment. Meanwhile, as robotics and artificial intelligence make astonishing progress, innovators in those fields are showcased here. So are people who are cleverly taking advantage of the falling cost of sensors and bandwidth.

The selection process for this package begins with hundreds of nominations from the public, *MIT Technology Review* editors, and our international partners who publish Innovators Under 35 lists in their regions. Our editors pare the list to about 80 people, who submit descriptions of their work and letters of reference. Then outside judges rate the finalists on the originality and impact of their work; that feedback helps the editors choose this group.

NEXT YEAR
Suggest candidates for the 2016 list at technologyreview.com/nominate

JUDGES

Zhenan Bao
Professor of Chemical Engineering, Stanford University

David Berry
General Partner, Flagship Ventures

Edward Boyden
Co-director, MIT Center for Neurobiological Engineering

Yet-Ming Chiang
Professor of Materials Science and Engineering, MIT

James Collins
Professor of Biomedical Engineering, Boston University

John Dabiri
Professor of Civil and Environmental Engineering, Stanford

Tanuja Ganu
Cofounder, DataGlen

Javier García-Martínez
Director of Molecular Nanotechnology Laboratory, University of Alicante, Spain

Julia Greer
Professor of Materials Science and Mechanics, Caltech

Christine Hendon
Assistant Professor of Electrical Engineering, Columbia University

Eric Horvitz
Managing Director, Microsoft Research

Rana el Kaliouby
Chief Strategy & Science Officer, Affectiva

Hao Li
Assistant Professor of Computer Science, University of Southern California

Cherry Murray
Professor of Physics and Technology and Public Policy, Harvard University

Carmichael Roberts
Entrepreneur and General Partner, North Bridge Venture Partners

John Rogers
Professor of Chemistry and Materials Science Engineering, University of Illinois

Umar Saif
Vice Chancellor, Information Technology University Lahore, Pakistan

Julie Shah
Associate Professor of Aeronautics and Astronautics, MIT

Rachel Sheinbein
Managing Director, Makeda Capital

Leila Takayama
Senior Researcher, Google X

Kay Tye
Assistant Professor of Neuroscience, MIT

Sophie Vandebroek
CTO, Xerox

Jennifer West
Professor of Engineering, Duke University

Jackie Ying
Executive Director, Institute of Bioengineering and Nanotechnology, Singapore

Ben Zhao
Professor of Computer Science, UC Santa Barbara

Xiaolin Zheng
Associate Professor of Mechanical Engineering, Stanford

Color portraits by Matthew Hollister; black-and-white portraits by Ping Zhu

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CANAN DAGDEVIREN

A master of flexible sensors and batteries sees opportunities for a new class of medical devices.

What do you do when your mother complains that she can't tell if her skin cream is working? If you're the Turkish materials scientist Canan Dagdeviren, you build a device that can measure changes in skin quality too slight to be detected by human touch. While working with dermatologists to develop the instrument, however, Dagdeviren found that it could be put to a more significant use: screening for skin cancer, either to catch it earlier or to help patients avoid unnecessary biopsies.

One early indicator of cancer is a patch of skin slightly thicker than the skin around it. It turns out that Dagdeviren's device, a tiny sensor and battery embedded in a translucent patch of stretchy rubber, can detect variations in skin density more accurately than a doctor's fingers. It can be pulled over skin anywhere on the body to take such measurements.

As a PhD student at the University of Illinois, Urbana-Champaign, Dagdeviren also developed a device that can be permanently implanted inside the body and harvest energy from the movements of organs. It can send that power directly to devices like pacemakers or be used to charge a battery. Today, pacemaker batteries are bulky and need to be surgically replaced every five to eight years. Dagdeviren's self-powering device, which has been tested in animals, could make life with a pacemaker that much easier.

While the flexible energy harvester works by a different mechanism than her skin sensor, both projects fit with the overall goal Dagdeviren is pursuing as a postdoctoral researcher at **Harvard** and **MIT**: creating a new class of biomedical electronics that are far less rigid and clunky than what we use today. *—Julia Sklar*

At right and in the top two images, Dagdeviren displays flexible, implantable devices that harvest energy from the movement of organs. Third image above: a close-up of the wiring. Fourth image: Dagdeviren's stretchable skin sensor for detecting early signs of cancer.

CHRISTOPHER CHURCHILL

Inventors

Yunji Chen

Improvements in artificial intelligence call out for new hardware.

"The current smartphone is not smart. But if the phone can continuously learn, then it could be."

Yunji Chen, iconoclastic and cosmopolitan, is sporting an untucked flannel shirt and sipping a mango smoothie at an Italian coffee shop in Beijing. He is talking about how he can make deep learning, a hot field of artificial intelligence, far more useful to people.

Once an obscure research branch, deep learning has quickly improved image search, speech recognition, and other aspects of computing (see "Teaching Machines to Understand Us," September/October 2015). Companies such as Google and Baidu are heavily invested in using it to get computers to learn about the world from vast quantities of data. However, the technology is resource-intensive: when the Google Brain project trained a computer to recognize a cat face in 2012, it required 16,000 microprocessor cores. That dismays Chen. "The expense and energy consumption is quite high," he says, noting that only large companies can afford it.

The reason is that most processors can quickly repeat basic math functions but need "hundreds of instructions" to perform the more elaborate functions needed in advanced AI techniques, Chen says. So he is designing dedicated deep-learning processors, optimized "to compute the basic blocks of machine learning." In his lab at the **Institute of Computing Technology**, research assistants run a computer program that simulates how precise tweaks in chip blueprints will affect processing speeds. "We are changing the wires, the connections, the circuits," he says. His latest design appears to be hundreds of times faster than today's central processing units, yet it requires only a thousandth as much energy.

As impressive as that may be, Chen, who entered college at age 14 and raced through his PhD in computer science by 24, envisions reducing energy consumption by a factor of 10,000, which could let deep-learning functions work on mobile or wearable devices. "After five or more years," he says, "I think each cell phone can be as powerful as Google Brain." —*Christina Larson*

JAMIE SHOTTON

He gives computers new ways to see the world.

While working at **Microsoft Research** shortly after he earned his PhD in computer vision at the University of Cambridge, Jamie Shotton developed a way for a computer to identify different objects in a moving video. By dividing pixels into segments according to color, the software could separate, for example, a sheep from a field, or a bookshelf from a desk.

This brought Shotton widespread attention, and one evening he received a call asking him to join a secret team working on a new video-game control system for Microsoft. The group hoped to have the system classify individual human body parts in a video stream and then allow people to interact with a game using nothing but their bodies. In the shower one day, Shotton realized that he could segment objects according to their distance from the camera rather than their color.

That led to Kinect, a motion sensor for the Xbox 360 game console that was a monumental development in computer vision and machine learning. It has not represented a sea change in computer interaction, though, perhaps because it requires too much physical effort to use one's body in such a way for a sustained length of time. Shotton remains undeterred. His latest software will debut in HoloLens, Microsoft's forthcoming augmented-reality device. It allows even basic depth-sensing webcams to interpret subtle hand movements. A user can zoom in with a simple pinch of the fingers in space, or enter a password using nothing but hand signals. "There are new and better ways of interacting with computers in the future," he says. —*Simon Parkin*

BENJAMIN TEE

A synthetic sense of touch could help both people and machines.

"As a kid I was always curious about things, and I tended to break things," says Benjamin Tee. "One of the things I broke was my great-grandmother's alarm clock—you know, back then it was a winding alarm clock, it was one of those really old antiques, and she got really upset when I broke it and I couldn't fix it."

The experience only made Tee more curious about how things worked, and now, through innovations in electronic skin and pressure-sensing devices, he is addressing much more complex problems than fixing an alarm clock.

As a PhD student at Stanford, Tee and colleagues built what he calls "a smart bandage." Tape it on your wrist, "and it can detect your pulse on the radial artery near the wrist," he says. "We did it in such a high-resolution manner that we can tell if your arteries are actually healthy."

He also developed a highly pressure-sensitive electronic skin, which could someday coat prosthetic limbs to give them some of the sense of touch that human skin has. "Your brain needs a lot of feedback to do your daily activities, and the skin allows you to do that," Tee explains. "The fact that I'm sitting down and not falling over—a large part is really because I'm getting sensory information from the chair."

Inspired by slicing his finger while making lasagna, Tee has also invented electronic skin that can heal itself multiple times.

Such sensors have other applications: for example, a tiny wireless monitor can be implanted in the skull to measure pressure inside the brain, a technology he has tested in mice. Measuring cranial pressure is extremely important for people who have had brain injuries or are recovering from brain surgery, and doctors usually do it by implanting a catheter that runs through a small hole in the skull.

Today Tee has a Singapore-based startup, **Privi Medical**, that is developing diagnostic and treatment technologies. It should offer him more chances to fix problems, given that health care, he says, is "ripe for disruption." —*Anna Nowogrodzki*

LISA DELUCA

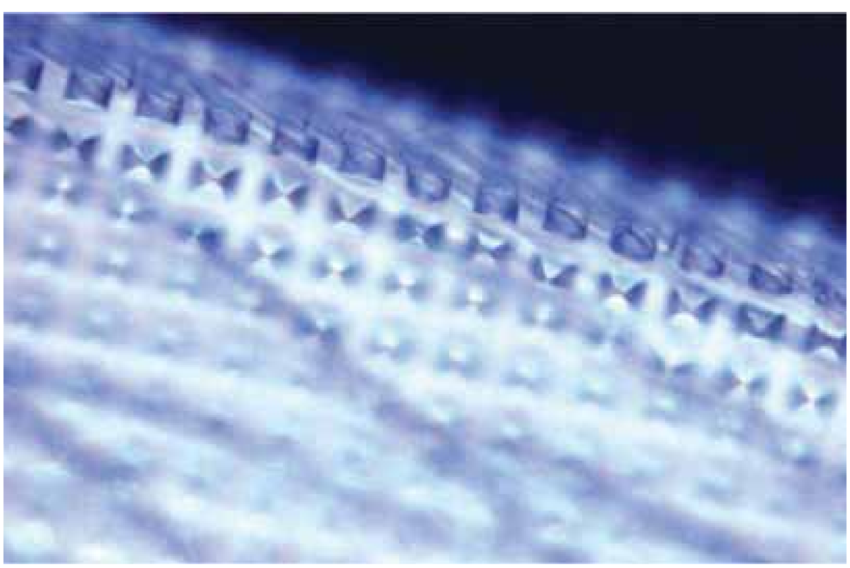
A software engineer makes a habit of going after everyday problems.

With more than 150 patents, Lisa Seacat DeLuca is **IBM**'s most prolific female inventor ever. Her inventions include a way for people on conference calls to get alerts when a certain topic comes up or a certain person starts talking; a system that can guide cell-phone users as they walk and talk so they don't lose service; a necklace that lights up every time a given Twitter hashtag is used; and a locator service in cars that can track items like, say, a wallet that falls under the seat.

"The idea generation isn't the slow part," DeLuca says. "Anyone can come up with ideas very quickly. It's taking the time to write them down and do research to figure out if it's a great idea or how to make it an even better idea—that's really the bottleneck in innovation."

As a child, DeLuca went through Ms. Pac-Man not by playing it but by figuring out the codes that unlocked each level.

Most of that research happens outside the office on nights and weekends. By day, she works on mobile computing and commerce for IBM. Her latest project is an app for retailers that can send



Small pyramids in Tee's electronic skin distort with pressure, altering the electrical charge they hold.

COURTESY OF BENJAMIN TEE

Inventors

shoppers targeted offers based on their location in a store. DeLuca has filed nine patents related to the app and is testing out the necessary Bluetooth beacons in her own home. She also recently bought a 3-D printer that she plans to use for prototyping ideas. First up: a Fitbit key chain for her husband, who always forgets his fitness tracker on his way to work.

—Suzanne Jacobs

CONOR WALSH

This robotics researcher might have something in just your size.

Most robotics labs don't contain sewing machines. But there's a room full of them in Conor Walsh's lab, along with three full-time textile experts and a wall of fabrics in neat plastic bins. There's a rack that looks as if it belongs in a sporting goods store, with a row of what could be some new kind of running shorts in an array of sizes.

For Walsh, a robot is not necessarily a rigid metal machine. He's working on robots that are soft, lightweight, and flexible so people can wear them to enhance their abilities.

The running shorts are part of an exosuit for the legs. Sensors in the suit mea-

MIGUEL PORLAN; PHOTO BY CHRISTOPHER CHURCHILL

Walsh with a mannequin wearing his robotic exosuit on its legs and a backpack that soldiers use.

Travis Deyle

He has built robots that can be powered wirelessly and ones that can bring people medication. Now **Google** has him trying to use technology to improve health care.

Q: At the Google X research lab, you've been part of the team that is building glucose-measuring contact lenses. Now you're working on a different, undisclosed health-care-related project. How do you apply your robotics experience at Google X?

A: Almost every field can benefit from robotics. "Robotics" is really just a nice way of saying "massive multidisciplinary everything," because you have sensing, perception, controls, machine learning, mechanics—everything. Automation. And having that broad exposure lets you plug in to any group, regardless of the domain, and make massive contributions.

Q: What impact do you hope to make?

A: Improving people's lives is the key thing. Health care is one of those things that's been stagnant for a while, and there's a lot of regulatory reasons for that, but there's also just a lot of risk aversion. I think by taking a more agile approach we can actually make giant leaps and bounds.

Q: Why is Google in any kind of position to solve big problems, such as those in health care?

A: It has buy-in from the highest level. Google's founders take risks that no one else will. It reminds me a lot of the amazing things that came out of Bell Labs, like the transistor, which obviously drove entire revolutions in technology. So I think they have the right mind-set to embrace innovation and failure in ways that other organizations just won't. *—Rachel Metz*

sure a person's movement and then tell a motor to pull on cables attached to the fabric in order to assist the muscles at the right moment. The exosuit could support soldiers as they walk, to increase their endurance. Or it could help patients who have trouble walking. "For people whose limbs don't work very well, there's really no good technologies that exist today," says Walsh, a faculty member at **Harvard** and its **Wyss Institute for Biologically Inspired Engineering**. In a video of one trial, a stroke patient walks visibly faster, and with a more symmetrical gait, when the robot is turned on.

Using fabric and cables keeps the exosuit lightweight. But the suit also needs to fit just right, so it can apply forces to the body without restricting movement. "The textile component is probably the most critical," says Walsh. Hence the sewing machines. *—Anna Nowogrodzki*

Inventors

RICHARD LUNT

Making invisible solar cells for electronic devices requires some exceptional creativity.

Richard Lunt invented solar cells you can see through. They're made of molecules that absorb ultraviolet and infrared light—wavelengths that we can't see—and convert it into electricity while letting visible light through. Applied as a coating on the screen of a phone or smart watch, they generate power so the gadget lasts longer between charges. Some low-power devices with the coating, such as e-readers, might not need to be plugged in at all.

Prototypes of devices with these materials are on display at a company that Lunt cofounded, Ubiquitous Energy (the CEO, Miles Barr, was an Innovator Under 35 in 2014). However, one challenge in developing the technology is that it is complex to manufacture, especially for larger screens. So Lunt is also trying a second approach.

Lunt, a materials scientist based at **Michigan State University**, has concocted a combination of see-through materials that convert ultraviolet and infrared light to wavelengths that are then directed to photovoltaic cells at the edges of the screens. Because this design is simpler than the original approach of putting transparent solar cells directly on the surface of a screen, it could be cheaper to manufacture, especially for bigger devices.

The technology could boost conventional photovoltaic designs, too. If included as a coating on a standard solar panel, Lunt says, the new materials could increase the panel's power output by converting more of the sun's energy to electricity. —*David Talbot*

Rohan Paul

To create an affordable obstacle detection system for blind people, this **MIT** postdoc began by simply asking them what they needed.

These ultrasonic sensors detect obstacles.

The device vibrates in patterns that indicate the distance to obstacles.

The full system includes a foldable cane for easy storage. It can also be mounted on a traditional cane.

CHRISTOPHER CHURCHILL

"In 2005, I was at the Indian Institute of Technology in Delhi as an undergraduate. As part of a course intended to design solutions for real-life challenges, we visited the National Association for the Blind in Delhi. We heard stories of how people with blindness get hurt when out walking—abruptly hitting open windows, tree branches, or vehicles. It creates so much fear that they are reluctant to step out without assistance.

"We envisioned a sensing system on canes. By the end of the first year we had a basic prototype using ultrasonic ranging for detection and vibrations for feedback. You could see the users smile once they detected an obstruction; many refused to give back the prototypes!

"We involved the users from the very beginning. They insisted that the device has to be small; if it falls it should not break; and it should allow any gripping or holding style. It has to detect everything, from signboards, people, parked cycles, or even cattle blocking the path—and also respond to obstacles approaching fast.

"Women told us they wanted a device to be small enough so the cane can fold and fit into their purse. And they debated about color. Why? Because they would show it to someone else and say: 'Am I looking smart with this?' Men wanted to know if it will prevent touching or colliding with people; they told of women turning around and slapping them after such unintentional accidents. They don't want to say, 'Oh ... excuse me, I didn't see.' It is about dignity as well as everyday safety. We engineers at times overlook the human side of a technology like this.

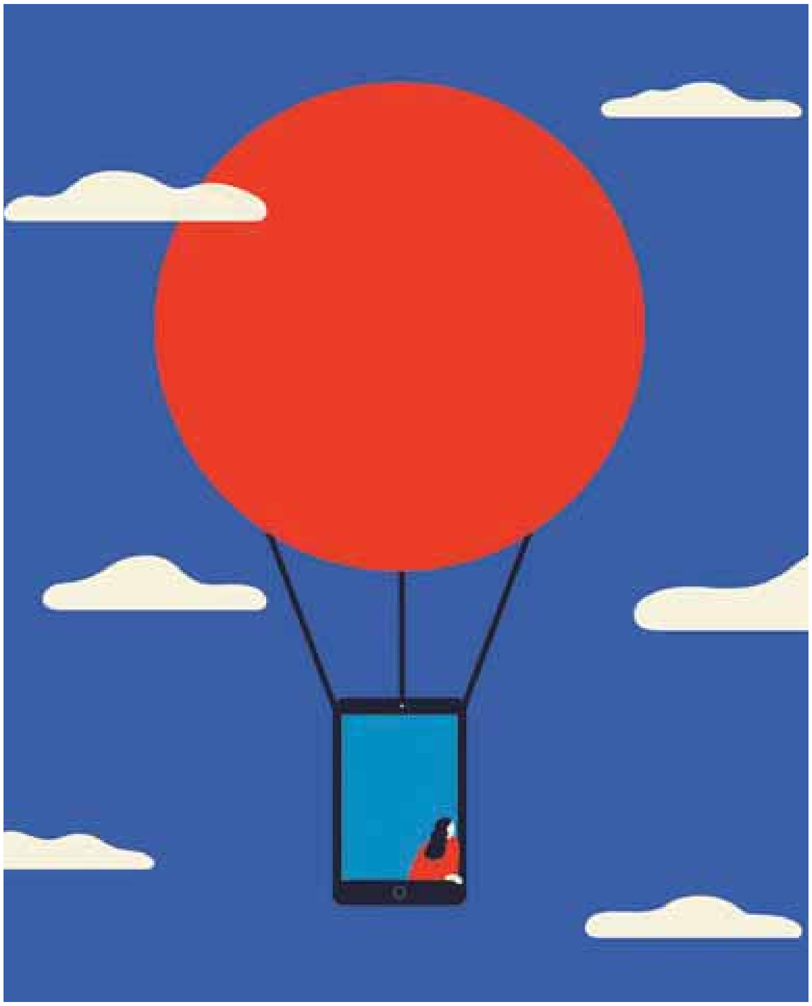
"We ended up with a sleek handle-shaped attachment that fits on the traditional white cane. When we tested it in 2012 we saw users had 95 percent fewer collisions. We released it as a product in early 2014. The SmartCane costs only about $50 and is already in the hands of about 10,000 people. Our aim is to help one million or more worldwide.

"It is a 'people's product'—a humble tribute to the Mahatma, who inspired innovators to harness science and technology for the masses."

—as told to David Talbot

Entrepreneurs

They see technologies as sparks of opportunity.



MAGOZ

JINI KIM

A stint helping the government altered her view of her health-care business.

The phone call that changed Jini Kim's life came at 2 A.M. in November 2013. The White House needed the former Google product manager's help with Healthcare.gov, which had been meant to help people buy health insurance but was riddled with embarrassing glitches. She hopped on a plane that day and worked marathon hours to fix the site, giving up Thanksgiving, Christmas, and her birthday. By the time she left, six months later, the site had enrolled eight million people in insurance plans—and Kim had gained insight that would be crucial for her own health-care analytics company, **NunaHealth**.

Before her five-plus years at Google, Kim investigated mental institutions as an intern in the U.S. Department of Justice.

Founded in 2010, Nuna helps companies shape their health-insurance benefits and wellness programs. It analyzes anonymized data about employees' behavior to determine the answers to questions such as "Are there differences in how people in certain demographic groups seek health care?" or "Can more generous health insurance help improve the productivity of someone with a seriously ill family member?"

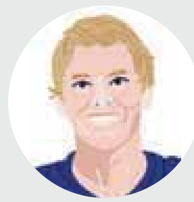
Before she bailed out Healthcare.gov, Kim viewed the government the way many people in Silicon Valley do: as a hindrance to innovation. Accordingly, Nuna originally sold its services only to corporations. But during her stint working for the Obama administration, she saw the enormous potential the government had to effect change. "You can touch millions of people so easily," says Kim, recalling a day at a Healthcare.gov call center when she overheard desperate people crying because they were unable to sign up for insurance.

Upon her return to San Francisco, Kim expanded Nuna so that it now also works with local, state, and national governments. For example, the company helps the Centers for Medicare and Medicaid Services find patterns in their vast amounts of data.

For Kim, reforming health care is not a theoretical issue. Her 33-year-old brother, Kimong, has severe autism. She has been involved in his care since she was nine years old and had to sign him up for Medicaid on behalf of her immigrant parents. She still lives at home to help out. Nuna's meeting rooms are named after Kimong's favorite *Sesame Street* characters, and she brings him to work regularly to give her parents a break. The name "Nuna" comes from the Korean word for "big sister," one of three words he knows.
—*Yukari Iwatani Kane*

Patrick Collison

He and his brother started **Stripe** to make money flow easily online.



"I grew up in very rural Ireland. The Internet was a connection to the greater world. It was very clear just how potent a force the Internet was and could be. While my brother John and I were tinkering with some new apps in Ireland and then in Boston and Silicon Valley, we experienced firsthand the difficulty of accepting online payments. We were just baffled at how convoluted and awkward the process appeared to be. The ecosystem seemed designed to reduce the number of Internet businesses.

"The same way Google exists as a foundational component of the Internet around information retrieval, it felt like there should be a developer-focused, instant-setup payment platform. Many people in financial services told us it couldn't work.

"Stripe now processes billions of dollars a year for thousands of businesses, from startups to publicly traded companies. There's a ton of database and distributed-system work that has to be done to make that experience possible. We have a 10-person machine-learning team that works on compliance, risk, fraud, identity verification, all of those things behind the scenes.

"Making it so easy to participate in the online economy has a far larger effect than one might imagine. We're enabling new business models, like crowdfunding. And mobile marketplaces, like Lyft, Postmates, and Instacart. That enables more people in society to take advantage of these services. My youngest brother is disabled, and for him it's not just a convenience. He can now do grocery shopping in a way that he could not before." *—as told to Robert D. Hof*

RIKKY MULLER

Hardware that buzzes the brain at the right moments could help treat debilitating mental disorders.

One of the most audacious projects funded last year under the Obama administration's BRAIN initiative aims to intervene in mental disorders using an electrical brain interface. The plan is to develop a system that both senses and modulates abnormal electrical activity, in hope of helping patients with conditions ranging from severe anxiety to post-traumatic stress disorder. Rikky Muller, an Israeli-born entrepreneur and the cofounder of **Cortera Neurotechnologies**, is designing the implantable hardware intended to interact directly with the brain.

Muller has long been interested in brain interfaces with clinical potential. After training as an electrical engineer and then designing chips for digital cameras, she gravitated toward neuroscience. In graduate school at Berkeley, she worked on neural implants that might decode human thought to control robotic prostheses. She also built a wireless device that could interpret brain signals in detail while resting on the surface of the cortex, rather than deeper in the brain. That work led to the founding of Cortera, in 2013, during the final year of her PhD studies. "We thought it could change patients' lives," she says.

Devices that record electrical activity directly from the surface of the brain—like Cortera's founding work—are already used clinically to map the cortex during surgery and to pinpoint the location of seizures. In theory, these devices could also monitor severe neurological or psychiatric conditions on an ongoing basis. Muller is cagey, however, when it comes to Cortera's plans in the growing neuromodulation market. "We do have a specific application in mind," she says, "but we are not disclosing what it is." *—Amanda Schaffer*

Entrepreneurs

MELONEE WISE

Affordable robots for the warehouse and beyond.

Melonee Wise imagines that all homes will have autonomous robots—something like *The Jetsons*' Rosie the robot maid, minus the apron and Brooklyn accent. Just one problem: Wise, chief executive of the year-old startup **Fetch Robotics**, thinks it won't happen in her lifetime, because the challenges in hardware and software are too big. "I'm probably one of the most pessimistic roboticists you'll ever meet," she admits.

Nonetheless, Wise still thinks smaller and more powerful computers, affordable sensors, more adept machine vision, and better artificial intelligence are coming together to make robots capable of a wide range of tasks—if not yet all in a single machine. That's why Fetch Robotics is going after one promising area: warehouses and e-commerce fulfillment centers, which are plagued with high turnover, injuries, employee theft, and a chronic shortage of workers, who, of course, also have a biological need to sleep.

Although dedicated robots are common in giant distribution centers, Wise thinks there's a bigger market for more flexible "mobile manipulation" robots that can help smaller companies ease into automation. In a simulated warehouse set up in a corner of Fetch's San Jose headquarters, a knee-high, cylindrical rolling robot called Freight smoothly follows Wise like a very attentive dog as she picks up boxes of crackers and cereal from shelves. She drops them in a plastic crate atop the robot, and when she's done with the fake order, it zips off to a mock shipping area.

Another robot, Fetch, is intended not to aid but to replace warehouse workers. It has one jointed arm with a gripper on the end, along with a "head" that uses a depth camera similar to a Microsoft Kinect game controller, so it can identify and pluck items from a shelf and place them in Freight's crate. Both robots are taught to navigate by leading them around the warehouse to create a map. They're even trained to recognize people's legs, so they can follow particular individuals. Unlike some robots that navigate using radio beacons or bar codes on the floor, Fetch's robots use 3-D laser scanners to get around and avoid obstacles, expected or otherwise.

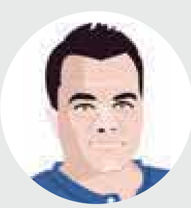
Wise won't disclose the exact price of Fetch robots, but she says they will be in the tens of thousands—much less than the cost of an employee. The company has sold some of its initial run of 40 robots to unnamed pilot customers, with plans for a much larger run if the automated workers can do the job. *—Robert D. Hof*

Wise spent more than five years at Willow Garage, a seminal robotics incubator that has spawned a half-dozen startups.

Ben Rubin

The cofounder of a live-streaming video app explains what makes it tick.

"Three things: simple, rewarding, and not creepy."



Ben Rubin is talking about the key qualities of **Meerkat**, an app that helped fuel a live-streaming craze this year. Type in a subject, press a button to start filming with your smartphone camera, and Meerkat sends out a tweet with a link that your friends can click to watch—and comment on if they want. That's all it had to be, he says: "The medium is new, and if you make a complicated product in a medium that already makes people uncomfortable, you end up with zero adopters."

One thing Rubin couldn't control, however: after Meerkat got popular, Twitter began offering a similar app, Periscope, and cut off Meerkat's access to its network. That made it harder for new users to find friends who also use Meerkat. The company has since let users connect Meerkat to their Facebook profiles.

Rubin envisions live-streaming eventually giving rise to a new form of entertainment: "an ongoing live show that is taking place in real time and involves the audience and everyone. Something where you're no longer the couch potato; you're part of the script." *—Rachel Metz*

To keep costs low, Wise's robots use only 500 unique parts. Top right: The Freight robot moves a crate. Bottom right: Fetch waits at a row of shelves.

Dena Marrinucci Her startup bets it can track cancer from an early stage, without any biopsies.

Problem:
Tumor cells that metastasize through the blood are generally very difficult to detect until they have spread to the point of being deadly.

Solution:
Dena Marrinucci cofounded **Epic Sciences** in 2008 to commercialize a cell detection and analysis technology that she developed to find cancer earlier. It can find and profile nearly all the tumor cells in two tablespoons of blood taken from a patient. On average, a sample that size has 50 billion red blood cells, 50 million white blood cells, and only a few circulating tumor cells. "You're basically looking for needles in a haystack," says Marrinucci.

Other technologies miss some circulating tumor cells because they are scanning for only one biological marker or are filtering cells by size. Epic says it finds more because it detects not only genomic abnormalities but also other biological markers, such as protein expression in cells. That should be useful in tracking the progress of a patient's cancer over time, so that treatments can be adjusted as the disease evolves. Twenty-six pharmaceutical companies are using Epic's technology in clinical trials of cancer drugs.

Marrinucci had just begun graduate school at the Scripps Research Institute in San Diego in 2004 when her grandmother was diagnosed with advanced melanoma. Less than a year earlier, however, doctors had given her grandmother an all-clear after a PET scan. "By the time you see cancer cells on a PET or CT scan, there are thousands of them," she says. "And that's what we're trying to change." *—Eilene Zimmermann*

WINNI WINTERMEYER

Entrepreneurs

"Images are universal," Systrom says. "They transcend language and cultural barriers."

WINNI WINTERMEYER

KEVIN SYSTROM

Instagram's cofounder maintains his sharp focus.

Kevin Systrom started **Instagram** in 2010, when he was 26, with a guy he'd befriended in a San Francisco coffee bar. Eighteen months later, when the company was just 13 people and still without a business plan, Mark Zuckerberg came calling with an offer of $300 million in cash and $700 million in Facebook's pre-IPO stock. Systrom said yes only after he persuaded Zuckerberg to keep the Instagram brand alive and to let him and cofounder Mike Krieger run it.

By now it's clear that the creation of Instagram was remarkably well timed and well executed. The service is like Twitter, but with pictures and videos primary rather than text. It works because people like to tell stories with pictures: it's easy, and it has impact across languages and cultures. Instagram has more than 300 million users, who post more than 70 million photos and videos every day.

One big question still faces Systrom, though: can he turn all this attention into a real business? He started rolling out an advertising program last fall and remains coy about how it's doing. Systrom says he just has to find a way to present the ads without upsetting his users, the vast majority of whom are younger than 30.

Systrom himself is something of a model for an emerging kind of high-tech entrepreneur, at the intersection of technology and the liberal arts. He's a jock, having been captain of his high school lacrosse team. He's also artistic, having effectively minored in photography while getting an engineering and management degree at Stanford. He knows the corporate world: he's on the board of Walmart. And he's an extrovert, as comfortable with runway models in New York and movie stars in Hollywood as he is with coders in Silicon Valley. As mobile applications and social networking permeate more of our economy, people who understand how these technologies make the physical world more interesting or productive will become as important as the hard-core engineers.

—Fred Vogelstein

Visionaries

These people are showing how technologies will give us new ways of doing things.

MAGOZ

ILYA SUTSKEVER

Why one form of machine learning will be particularly powerful.

Artificial-intelligence researchers are focusing on a method called deep learning, which gets computers to recognize patterns in data on their own. One person who demonstrated deep learning's potential is Ilya Sutskever, who trained under a deep-learning pioneer at the University of Toronto and used the technique to win an image-recognition challenge in 2012. Sutskever is now a key member of the **Google Brain research team**. I asked him why deep learning could mimic human vision and solve many other challenges.

"When you look at something, you know what it is in a fraction of a second," he says. "And yet our neurons operate extremely slowly. That means your brain must only need a modest number of parallel computations. An artificial neural network is nothing but a sequence of very parallel, simple computations.

"We started a company to keep applying this approach to different problems and expand its range of capabilities. Soon, we joined Google. I've shown that the same philosophy that worked for image recognition can also achieve really good results for translation between languages. It should beat existing translation technology by a good margin. I think you will see deep learning make a lot of progress in many areas. It doesn't make any assumptions about the nature of problems, so it is applicable to many things." —*Tom Simonite*

Sutskever says he was interested in AI when he began college but "it seemed impossible, so I studied math instead."

Visionaries

The most recent SpaceX launch was an ill-fated mission in June.

LARS BLACKMORE

Would space travel flourish if we could reuse the rockets?

Sixty years after *Sputnik* blasted into space, escaping our atmosphere remains absurdly expensive. Lars Blackmore, an engineer at **SpaceX**, is working on changing that with rockets that could be flown back to Earth in reverse.

As things stand, every time a space rocket takes off and releases its payload, it breaks up and falls into the ocean. "It's basically like flying a 747 across the country and then, instead of refueling it, throwing it away," says Blackmore, a soft-spoken Brit who leads a team at SpaceX that's developing the onboard software necessary for a rocket to come down gently in an upright position onto a platform in the ocean.

SpaceX has come agonizingly close to sticking a rocket landing several times, but it didn't get a chance to try again in its most recent flight, when the Falcon 9 rocket exploded during takeoff.

Landing a rocket backwards is an insane trick. The descent is extraordinarily unpredictable, and rockets aren't meant to travel in reverse, so it requires extremely fine control over the boosters and guidance fins. Blackmore has devised algorithms to enable a rocket's onboard computer to deal with this chaotic situation while safely controlling the craft's fall.

If the feat can be perfected, it would change the economics of space travel entirely. Fuel accounts for less than half of 1 percent of the cost of a rocket launch, so refurbishing a rocket would make the next launch considerably cheaper. How much cheaper would depend on how well the booster could be reconditioned following the extreme stress of takeoff.

Blackmore grew up dreaming of working at NASA Mission Control. After a PhD at MIT, he joined NASA's Jet Propulsion Lab, where he worked on precision landing systems and a climate probe called SMAP. He went to SpaceX in 2011. "I'd heard that Elon [Musk] had these dreams of making reusable rockets," Blackmore says. "And since I was working on precision landing for Mars, I thought I would be the right guy to do that."

Would he want to go back to NASA someday? "When you hear about the Apollo program in its heyday, it was a bunch of young kids, and no one told them what they could do," he says. "That is exactly what I've found at SpaceX." —*Will Knight*

Cigall Kadoch A major vulnerability of certain kinds of cancer is becoming clear.

Problem:
The exact biochemical mechanisms involved in many kinds of cancer remain unknown.

Solution:
While completing her PhD at Stanford, Cigall Kadoch discovered a link between a genome regulator in cells called the BAF protein complex and a rare cancer called synovial sarcoma. She and colleagues later showed that mutations of BAF are involved in at least 20 percent of human cancers, opening the door for research on drugs that target mutated BAFs.

BAF's job in the cell is to open and close DNA to allow the right genes to be expressed at the right time. When mutated, it can "activate sites that it shouldn't"—including genes that drive cancer, says Kadoch, who has appointments at **Harvard Medical School** and the **Broad Institute of Harvard and MIT**.

She learned this by focusing on one particular subunit of BAF. This piece of the protein has a deformed tail in 100 percent of patients with synovial sarcoma. When Kadoch put the deformed subunit into normal cells, she detected "blazing cancer," she says. "That little tail is entirely responsible for this cancer."

The good news is that this is reversible. If she added enough normal pieces of the subunit to cells in a petri dish, it replaced the mutated form, killing the cancerous cells on the spot. —*Anna Nowogrodzki*

BOB O'CONNOR

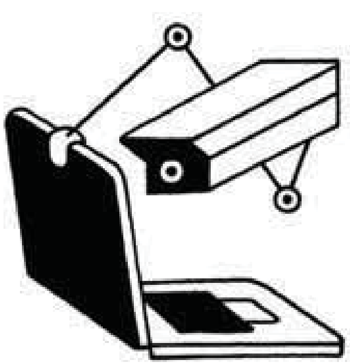
Visionaries

ZAKIR DURUMERIC

A computer scientist sees a way to improve online security.

"It's absolutely astounding what people attach to the Internet," Zakir Durumeric says. He would know, because he invented a way to probe every computer online in just minutes. "We have found everything from ATM machines and bank safes to industrial control systems for power plants," he says. "It's kind of scary."

A bank safe! Why would someone put that online? So someone in the bank can operate it from home?



"Yes. You sit there and you wonder: who on earth thought this was a good idea?"

Bad computer security practices like that can be mitigated far more readily with the ZMap scanning system Durumeric developed. It determines not only which machines are online at any given moment, but also whether they have security flaws that should be fixed before miscreants exploit them. It finds everything from obvious software bugs to subtle problems like the ones that can be caused if an IT administrator fails to properly implement an arcane aspect of a cryptography standard.

Pinging all four billion devices on the Internet took weeks until Durumeric, who is pursuing a PhD at the **University of Michigan**, came up with a process that now takes about five minutes. He has used it to quickly inform website administrators about their vulnerability to catastrophic flaws such as the Heartbleed bug in 2014, and he hopes other security researchers will routinely do the same when they find weaknesses. "There's always been this period where a vulnerability is [found] and then it takes weeks, months, or years for administrators to patch their servers," he says. "We have an opportunity to change that." —*Brian Bergstein*

Adam Coates

Artificial intelligence could make the Internet more useful to the millions of people coming online for the first time.

Q: You invented ways to put more computing power behind deep learning. Now you lead a lab in Silicon Valley for the Chinese search company **Baidu**. Why did it need a lab there?

A: They spin up new projects very fast. It's partly driven by the dynamism in China—tech companies have to go quickly from having nothing to having state-of-the-art something. My lab's mission is to create technology that will have an impact on at least 100 million people; it is intended to move rapidly, like a startup. We're recruiting AI researchers and many people in Silicon Valley who have amazing skills from working on products and haven't thought they could use that to make progress on artificial intelligence.

Q: What is the lab working on?

A: The first technology that we are focusing on is speech recognition. Touch screens on phones are fine for some things but really awful for others, and there are all kinds of other devices that are crying out for better interfaces. People don't use speech today because it doesn't work well enough. Our goal is to get it to a level where it's as easy to talk to your devices as it is to talk to the person next to you. In December we hit our first milestone with DeepSpeech, a speech engine we built quickly from scratch using deep learning. When there's a lot of background noise it's dramatically better.

Q: Why would that have an impact on 100 million people?

A: In rapidly developing economies like in China, there are many people who will be connecting to the Internet for the first time through a mobile phone. Having a way to interact with a device or get the answer to a question as easily as talking to a person is even more powerful to them. I think of Baidu's customers as having a greater need for artificial intelligence than myself. —*Tom Simonite*

MIGUEL PORLAN

Pioneers

Extending our scientific knowledge and paving the way for future technologies.

MAGOZ

ELIZABETH MORMINO

A telltale protein seen in people's brains before they have Alzheimer's could offer a clue about possible treatments.

Elizabeth Mormino knows it's too late to save her grandfather, whose Alzheimer's disease was diagnosed a few years ago. "It's really hard to see a familiar face go through this, knowing that there's really no drugs that work right now," she says. But her work may help future patients by showing an intriguing new path to treating the disease.

Mormino has figured out a way to combine two imaging technologies to detect the protein beta-amyloid, which is found in patients with Alzheimer's, and has used them to look at the brains of people with no signs of cognitive decline. Although researchers have already been using one of the imaging technologies, called PIB-PET, to see beta-amyloid in the brains of living patients for a few years, Mormino is able to identify brain regions more accurately by combining PIB-PET and MRI data.

"I feel like we're taking snapshots of people's brains," she says. "It feels very personal and intimate."

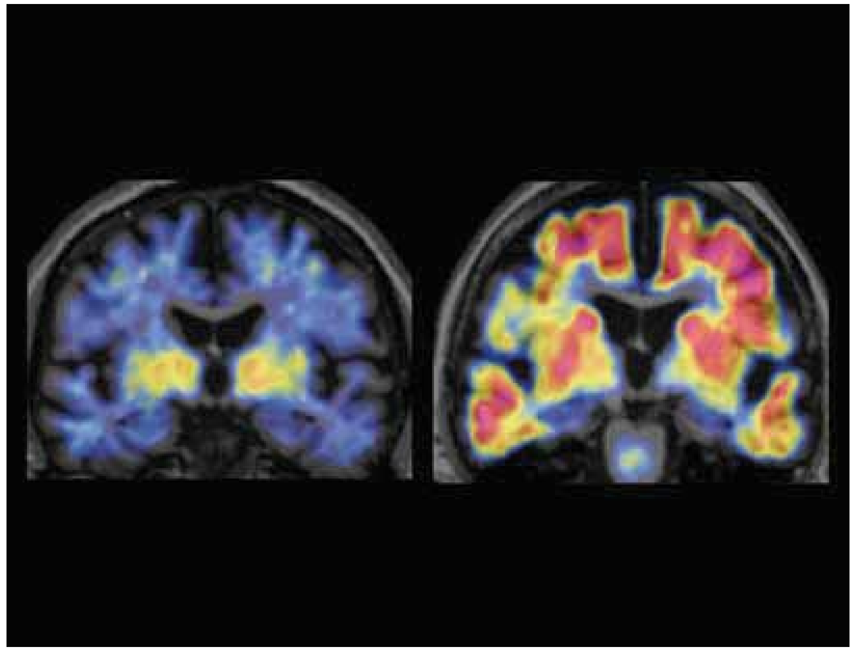
The most surprising insight from her work is that some outwardly normal people are "walking around with a head full of amyloid, and oftentimes as much amyloid as somebody who actually has clinical Alzheimer's disease," she says.

How could this be? One hypothesis is that amyloid causes neurons to die, which then causes the clinical symptoms of Alzheimer's. So by the time patients have Alzheimer's, anti-amyloid treatment is too late—the protein has already damaged too many brain cells. (Indeed, anti-amyloid drugs have not proved effective at treating Alzheimer's.) But some of her healthy patients could have protective factors, whether in their genes or in their lifestyle, that allow them to tolerate high amyloid levels without developing Alzheimer's.

Understanding such protective factors might "offer some insights into successful aging or the ability to remain resilient," says Mormino. And there is a chance it could help specifically with Alzheimer's prevention. To that end, researchers at the University of California, San Diego, and **Massachusetts General Hospital**, where Mormino is an assistant in neuroscience, have started clinical trials in which people who have high amyloid levels but no Alzheimer's symptoms are getting anti-amyloid infusions to see if that staves off the disease.

The hope is that eventually Alzheimer's could be prevented by regularly checking and treating amyloid levels, much the way heart attacks are averted by monitoring cholesterol.

—*Anna Nowogrodzki*



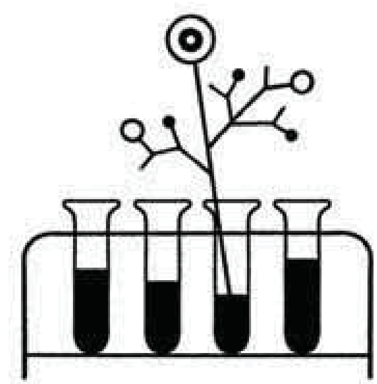
These brain scans intrigue Mormino because both come from healthy patients, and yet the one on the right is riddled with amyloid, seen in red.

JUN GE

Why we might use tiny flowers, trees, and spindles to create the pharmaceuticals of the future.

Manufacturing pharmaceuticals is typically a messy business. Catalyzing the necessary chemical reactions often requires toxic solvents and large amounts of energy. Jun Ge hopes to clean up the process substantially by instead harnessing enzymes, nature's catalysts, to do the work.

Lots of people have had that idea. The challenge is that enzymes tend not to hold up well in industrial processes, and protecting them by attaching them to other materials greatly lessens their activity level. But Ge, a slender and soft-spoken chemical engineer at China's elite **Tsinghua University**, had an insight a few years ago. While working as a postdoc at Stanford, he had a hunch that adding copper ions to a solution containing a certain enzyme could help activate and stabilize it. What he didn't expect to find were the wondrously strange structures that soon precipitated at the bottom of his test tube: "very beautiful structures, like flowers made of protein and crystal." Significantly, the enzymes held in this extraordinary "nano-flower" shape are stable and seven times more active than when they float freely in a solution. The findings made the cover of *Nature Nanotechnology* in 2012.



Ge, who grew up in a "small, beautiful city" in Jiangsu Province, wants to help address China's environmental problems.

Today Ge is studying a range of enzyme nanostructures—which he dubs "nano-trees" and "nano-spindles"—and exploring whether they could be used in everything from the production of a cancer drug to a next-generation glucose strip for diagnosing diabetes. —*Christina Larson*

MIGUEL PORLAN; BRAIN SCANS COURTESY OF ELIZABETH MORMINO

Pioneers

AASWATH RAMAN

Your next air-conditioning system might save energy by beaming heat into outer space.

Aaswath Raman holds a thin, silvery disc. It looks like a very clean mirror, but it's hardly ordinary: it gets colder under direct sunlight and stays about 5 °C cooler than the surrounding air.

Raman is a practical person with a gentle personality; his button-down shirt and flip-flops blend in on the campus of **Stanford**, where he is a postdoctoral researcher. This mirror, he calmly explains, has a coating that sends heat into the vastness of outer space—which could make it ideal for air-conditioning and refrigeration systems that would require very little or no electricity.

Raman has $3 million in funding from the Advanced Research Projects Agency for Energy to develop the technology.

The cooling material takes advantage of a fascinating phenomenon. Objects are always cooling down by radiating heat—this is why dew forms on blades of grass at night. Some of the radiation occurs at frequencies that send the energy right through Earth's atmosphere and into space, allowing the object's temperature to drop below that of the surrounding air.

During the day, the sun's heat usually overwhelms the cooling effect. But while reading through old papers on the subject from the 1960s, Raman thought of a way around that. He applied his knowledge of nanoscale manufacturing techniques that didn't exist decades ago to make something with optimum levels of thermal radiation and solar reflection. It is a multilayered film of hafnium dioxide, silica, and other materials deposited at carefully controlled thicknesses. It can be made over large areas using the same manufacturing techniques that are used to coat windows.

Coating the roof of a small structure with some of his material would wick heat away and keep the inside cool without electricity, as long as the roof wasn't insulated. Since most buildings in developed areas have insulated roofs, Raman is working on integrating the material into existing air-conditioning infrastructure. He has a prototype on the roof of Stanford's Packard Electrical Engineering Building. It is made up of a sheet of the passive cooling material about a square meter in area, mounted in a custom-machined plexiglass box patterned with water channels. In a finished system, the water would circulate through the building air-conditioning system, then go into the cooler box to chill and back into the building system. However, he still needs to demonstrate that his prototype can chill a substantial volume of water.

He has already partnered with a manufacturer that can produce large sheets of the cooling material for further development. He jokes that many researchers in his branch of physics tend to stay in their labs all day and "don't like to go outside." But he adds: "If you just go outside, there's opportunity." —*Katherine Bourzac*

Zhen Gu Diabetics are tired of sticking themselves with needles. Someday they may not have to.

Problem:

People with diabetes must monitor their blood sugar and inject themselves with insulin several times a day. Even those with insulin pumps risk complications from injecting too much or too little insulin.

Solution:

Zhen Gu, a researcher at the **University of North Carolina**, whose grandmother died from diabetes complications, is developing insulin delivery mechanisms that could be better. The most recent one is a fingernail-size patch covered in more than 100 microneedles. When you put the patch on your skin, you feel momentary pinpricks as the needles poke into your blood vessels. The needles are full of tiny sacs containing insulin and an enzyme. The sac is just permeable enough to allow glucose inside, where the enzyme converts it to an acid that—when blood sugar is too high—makes the sac open and release the insulin. The sacs fall apart at different rates, so the insulin is released over hours rather than in one burst.

When Gu tested the patch on five mice, it controlled their blood sugar for nine hours, although it takes half an hour to work, and people without diabetes naturally regulate their blood sugar much faster than that. Now he has begun testing the patch on pigs, whose thin skin is more similar to humans'. Eventually, Gu hopes, people with diabetes could slap on a patch every two or three days to reliably and precisely control blood sugar without much pain or effort. —*Anna Nowogrodzki*

Polina Anikeeva

A creative scientist sees new ways to record and stimulate brain activity.

Anikeeva says medical devices should be far more sophisticated.

KEN RICHARDSON

"For my PhD at **MIT**, I worked on quantum-dot LEDs, and having zero biological experience, I chose to spend two years in Karl Deisseroth's neuroscience lab at Stanford. When I saw that they were developing methods to control the brain optically and investigate brain function, I was really blown away. [But] the tools we were using were too large and too bulky, and didn't have enough capability. Since my background was nano-optoelectronics and nanofabrication, I felt that we should be able to do better. That became the foundation of my lab [at MIT].

"The lab is divided into two main directions. One is using fiber fabrication to create neural probes that have multiple functions. The other is to figure out if we can interact with the nervous system in an essentially wireless and noninvasive way.

"Ultimately, you want to figure out how specific patterns of neural activity correspond to specific behaviors. What we're trying to do is push the resolution of our recording and stimulation capability, which will allow us to decipher those neural circuits. If you're trying to, say, restore function after spinal-cord injury, if we were able to record signals from both sides [of the injury] and convert them into patterns of stimulation, we would be able to start building a synthetic bridge across that connection. Right now, we would love to work with people and get this technology into as many labs as we can."

—as told to Courtney Humphries

Pioneers

Garcia at IBM's Almaden research center in San Jose, California. Left: a material she created that solidifies under ultraviolet light but can become flexible again. Center: A detail of her lab setup. Right: A sample of her super-strong yet recyclable plastic.

WINNI WINTERMEYER

JEANNETTE GARCIA

A chance discovery sparked a quest for plastics that are both strong and recyclable.

If Jeannette "Jamie" Garcia hadn't been so obsessed with understanding what things are made of, she probably would have "red-canned" her big discovery—that is, tossed it in the trash.

It was the young chemist's first week at **IBM**, and she had a simple task: mix three ingredients together in a flask and heat them up, the goal being to use one of those ingredients—a solution made from broken-down plastic bottles—as the basis for an even stronger material. After she combined the first two ingredients, she went off to weigh out the third. By the time she got back, the solution had solidified into something so hard that she needed a hammer to break it free. "A lot of people would've considered it a failed experiment," Garcia says. But she adds: "I didn't really want to just drop it. I wanted to try to figure out what I had made."

It turned out that the plastic was not only much stronger than what she had originally been trying to make but entirely recyclable. Those properties made it a promising gateway to desirable new materials.

Plastics that harden when heated are nothing new; we use them in everything from electronics to airplanes. But these so-called thermosets are not remoldable once hardened and mostly end up as garbage because they are very difficult to recycle. The thermoset plastic that Garcia made, on the other hand, completely reverted to its base compound, or monomer, when soaked in acid. "As chemists," she says, "if we understand what we're doing well enough, then we can actually go in and undo it too, in just as efficient a way as we built it."

Now, with the right monomers and the right temperatures, Garcia can make both super-strong recyclable plastics and moldable gels that solidify in their desired shape under ultraviolet light. She has nicknamed the first class of materials Titan and the second one Hydro.

There's still work to do before they are ready for commercial applications. But now that we know recyclable thermosets are possible, Garcia says, we can think of how they might replace materials we've been using for decades.

—Suzanne Jacobs

GOZDE DURMUS

It's amazing what you can learn about a cell when you levitate it.

Cells that are dying, turning cancerous, or responding to drugs undergo physical changes. They might become stiffer or squishier. Or they might get heavier or lighter. The instruments for detecting these changes in individual cells are usually complex and expensive, which is why microbiologists still assess the state of a disease by waiting for cells to grow in a lab, and why doctors examine whether a drug is working by waiting to see whether the patient worsens or improves.

Gozde Durmus has invented a simple, fast method for detecting cells' telling physical characteristic: making them levitate in a magnetic field and measuring how high they rise. White blood cells, red blood cells, cancer cells, and different bacteria each rise to a different height, because they have a characteristic density that determines the balance between the pull of gravity on the cell and the push of the magnetism. And Durmus has found that when a bacterial cell has responded to an antibiotic, it tends not to rise as high in the magnetic field as it did before. This change can be detected in about an hour, instead of the day traditionally required to determine how a microbe responds to a drug.

At her bench at the **Stanford** Genome Technology Center, Durmus makes cell-levitating devices by sliding a few laser-cut pieces of plastic over two small bar magnets. This keeps them from flipping and sticking together, so a magnetic field can be created in the space between them. She puts a thin capillary tube into that space. Then she adds two mirrors that will beam an image of the tube up to a conventional microscope. Samples of the cells to be levitated go into the tube along with a solution of gadolinium, an element that's used as an MRI contrast agent. "It helps the cells fly in the magnetic field," says Durmus. Their height can then be measured under the microscope.

Durmus knows from experience how important rapid, personalized drug monitoring could be. When she was a child in İzmir, Turkey, she had a bacterial infection that lasted three years, and she vividly remembers going to the hospital for painful and ineffective penicillin shots until she got the right treatment.

> Durmus says it costs her less than $1 to make the magnetic "microgravity on a chip" cell detector.

Her work also has a more whimsical inspiration. In 1997, physicists in the Netherlands used an ultrastrong magnet to levitate a living frog. Subsequent efforts to levitate things in weak magnetic fields—even objects much smaller than frogs—required toxic magnetic solvents. Durmus figured out how to do levitation without toxic materials, using only cheap magnets and some pieces of plastic.

—Katherine Bourzac

Pioneers

MICHELLE O'MALLEY

Understanding a tricky kind of single-cell creature could help reduce the cost of biofuels.

Chemical engineer Michelle O'Malley is trying to figure out how an understudied type of microbe could be harnessed to make better biofuels or pharmaceuticals. O'Malley works with anaerobic microbes—organisms that can't live in the presence of oxygen, making them extremely difficult to cultivate. In fact, her lab at the **University of California, Santa Barbara**, is the only one in the United States that is able to study the behavior of anaerobic microbial communities.

Why go to all the trouble? Because these organisms are more efficient than aerobic ones at chewing up plant material and secreting something else, like a biofuel. They also create fewer unintended by-products, which are costly to deal with.

To study microbial communities, O'Malley combines a 1970s cultivation method with today's genome sequencing technology.

O'Malley is particularly interested in how different kinds of anaerobic microbes function in concert. Sometimes in such communities, whether in landfills or our guts, microbes work together to attack substances in their midst, while other times they interact peacefully with their environment. Their behavior, it seems, is determined by a complex communication system: microbes can physically attach to each other and exchange nutrients, or they can secrete chemicals into the environment that another microbe can metabolize.

Understanding this process is the first step in getting anaerobic microbes to churn out more cost-effective fuels or pharmaceutical products—and things we can't yet imagine. After all, O'Malley explains, many of the enzymes produced in anaerobic microbe communities "perform chemistries never seen before."

—Julia Sklar

GILAD EVRONY

Single-neuron genome sequencing is revealing clues about what goes wrong in the brain.

From studying 300 neurons one at a time, **Harvard Medical School** researcher Gilad Evrony helped make a surprising discovery: brain cells sitting right next to each other don't always have the same genetic codes. This could provide insight into age-related cognitive decline and brain disorders such as epilepsy and schizophrenia.

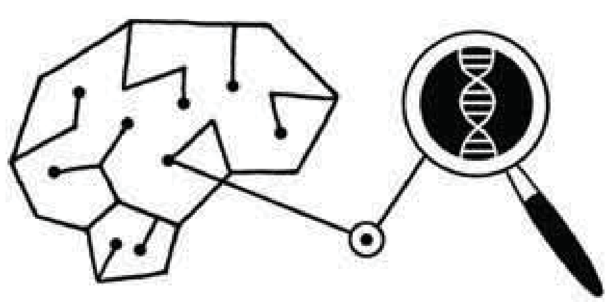
When scientists sequence DNA, they typically examine genetic material from thousands or millions of cells at a time. Decoding the genome of an individual cell is more challenging. Although researchers had done it with cells from other parts of the body, Evrony developed a way to do it with neurons from cadavers. Then he painstakingly mapped the origins of the mutations he found.

The implications are remarkable. For one thing, finding out the precise location of mutations indicates that some psychiatric diseases and mental disorders can be traced back to just a few bad neurons. Crucially, such mutations apparently are not inherited and don't arise during the brain's initial development. Instead, they crop up in brain cells during our lifetimes—and accumulate as we age. The rate at which those errors occur is not clear, though, and figuring that out could help explain how cognitive decline sets in and how it might be staved off.

Evrony took three and a half years off in the middle of college at MIT to serve in an intelligence unit of the Israeli military.

Such insights appear to be just the beginning of what we might discover by analyzing individual neurons. The National Institutes of Health has organized a consortium of labs that will study several mental disorders using this method, among others. Evrony calls the technology "the brain's new microscope."

—Julia Sklar



MIGUEL PORLAN

Humanitarians

Using technology to tackle problems caused by poverty, war, or disability.

MAGOZ

YEVGEN BORODIN

A software tool conceived for blind people could offer an intuitive way for anyone to listen to online material.

Yevgen Borodin, an assistant professor at **Stony Brook University** and CEO of Charmtech Labs, is making it easier for people who are blind—and everyone else, too—to listen to content published only as text online.

Borodin's software, Capti Narrator, serves as a hub for spoken material drawn from many written sources: Dropbox, Google Drive, Web pages, e-book repositories such as Bookshare and Gutenberg, and more. To create the software, Borodin and his team at Charmtech devised ways of extracting content from documents and websites and running it through text-to-speech engines. The software also lets users start listening on one device and continue on another, picking up where they left off.

Borodin has published more than 50 research papers on nonvisual interaction with computers.

"Blind people easily [take] far longer to do simple computer tasks than others do, and I decided that I had to do something about it," says Borodin, who grew up in Ukraine and came to the United States for college. His ultimate goal is for his invention to follow the path of assistive technologies such as optical character recognition and speech-to-text, which started out as niche tools for people with disabilities but became mainstream. Capti Narrator was unveiled at the 2014 Consumer Electronics Show and has been downloaded hundreds of thousands of times worldwide.

—David Talbot

Humanitarians

Rebecca Steorts Big data could cut through the fog of war.

Problem:

Determining the number of people killed in wars is immensely difficult: chaos, poor communication, and propaganda can wildly distort the figures.

Solution:

Rebecca Steorts, an assistant professor of statistics at **Duke University**, is using advanced data-analysis techniques to help human rights groups get definitive casualty counts.

Since the Syrian civil war began in 2011, six private organizations have been building databases of death totals. There is also an "official" governmental tally. But compiling them into one master document is a data nightmare because of duplicates, misspelled names, inaccurate dates, and even wrong genders. One estimate showed that running a basic comparison algorithm on the combined lists would take 57 days. In 2013, Steorts realized that by combining a Bayesian statistical approach with a machine-learning technique called blocking, she could reliably merge the databases—and do it in less than a day.

Blocking works by placing items that are similar to one another—say, similar names or approximate dates of death—in the same group for comparison. (A simple analogy: if you were trying to compile one whole set of cards out of two incomplete decks, you'd separate them into suits first and then discard the duplicates.) Only after it has assembled the various blocks does Steorts's software do the intensive work of linking individual records.

The Human Rights Data Analysis Group, a nonprofit that publishes a death toll for Syria once every year, is testing Steorts's method to see if it can be incorporated into the estimate it will release in 2016. —*Patrick Doyle*

SAURABH SRIVASTAVA

Voice and gestural interfaces could make digital technologies available to the world's poorest people.

More than 750 million people lack basic reading and writing skills. Saurabh Srivastava, a researcher at **Xerox India**, has been prolific in crafting technologies that could eventually make it easy for people with limited literacy to obtain information and use online services by simply speaking into phones or making gestures picked up by inexpensive cameras.

Building such interfaces is very hard because of the wide variation in cultural norms, not to mention languages and dialects. In some of his most recent work, in the rural Assam province, Srivastava investigated a system pregnant women might use to disclose medical problems to a Web interface that could refer them to free tests and services. The system used a $150 Microsoft Kinect camera to detect arm gestures, which in turn controlled displays of information. The display included animated representations of female health aides to guide the patients. Among the findings: the system should not require any gestural input that involves shoulder movements, since shoulders were often obscured by the women's saris. And when indicating medical complaints (say, a headache), women didn't understand why they should point to an on-screen picture of a head, but instead would point to their own head.

Improving health services this way could make a dent in big problems—such as the fact that nearly 63,000 women in India die in childbirth every year. —*David Talbot*

DUYGU KAYAMAN

What her parents did for her, she hopes to do for many other blind people.

Turkey is a tough place to live without sight. A dearth of social services and education for blind children means families often seclude them at home. Daily activities are riddled with peril: in cities, shoddily built sidewalks are littered with broken paving stones and sudden drop-offs. Gainful employment is a distant aspiration for many.

Duygu Kayaman lost her vision to an optic nerve tumor at two and a half. Growing up in Istanbul, she was determined to attend school with seeing students, but the lack of textbooks for the blind made it hard for her to compete. Her parents spent evenings and weekends dictating lessons into a tape recorder to help her keep up.

Those homemade audio books later inspired Kayaman to develop a mobile-phone application, Hayal Ortağım (My Dream Partner), to make daily activities easier for the visually impaired. It offers news and editorial columns through text-to-speech technology. Books, courses from the Khan Academy, and chess and guitar lessons are at hand. Location services help users find pharmacies and hospitals, and navigation systems for indoor spaces guide them through shopping centers; airports and subways are to be added soon. Also in the works is a function for restaurants: it will alert staff through a Bluetooth beacon that a blind customer has arrived, and then transcribe the menu for the patron.

Some 150,000 Turks use My Dream Partner, out of an estimated visually impaired population of 700,000. Kayaman developed it with other vision-impaired members of an Istanbul-based organization, Young Guru Academy, and the support of Turkey's biggest mobile-phone operator, Turkcell.

Today she works as a sales specialist for **Microsoft** while studying for her MBA at Istanbul's Bilgi University. "It is only recently that people with disabilities are being hired by corporate firms," she says. "Managers simply did not know that a person with blindness or another physical disability could work in these environments. My friends and I are breaking down those stereotypes." *—Ayla Jean Yackley*

"My philosophy," Kayaman says, "is that life is beautiful, despite its obstacles."

Rahul Panicker

This engineer from India returned home after graduate school with a new approach to helping premature babies.

"Humanity has known for over 100 years that keeping premature babies warm dramatically increases their survival rates. Yet most vulnerable babies around the world don't benefit from this knowledge.

"In 2007 I and three classmates at Stanford were encouraged to do fieldwork in Nepal. The first thing we realized was that low cost is not always the solution. Donated incubators were being used as filing cabinets, because there wasn't the electricity or the expertise to use them. Secondly, we found that parents desperate to keep their children alive were the users we should focus on, rather than doctors.

"We needed to reframe the problem. So we came up with a prototype incubator that costs 1 percent as much as traditional solutions and can be operated by a non-expert. It uses phase-change materials to keep babies at the ideal temperature of 37 °C for up to six hours without electricity. When heated with hot water or another source, a phase-change material melts, and it can release heat the baby needs at a constant temperature.

"NGOs we'd partnered with passed on the design. We realized if we didn't take this forward, no one else would. After a year of working on the project in my free time, we finally had our seed capital, and in 2009 I quit my job, moved to Bangalore with my three cofounders, and started **Embrace**. Since then our warmers have been used in 15 countries to help nearly 200,000 babies. We've implemented a hybrid for-profit/not-for-profit business model that lets us scale much faster than a charity.

"I hope future generations look to us as role models and take inspiration to go down the route of social entrepreneurship. Too many young people, especially in India, don't take risks because they worry about their futures. But I realized many years ago that someone with my education was never going to starve."

—as told to Edd Gent

MIKHAIL GALUSTOV

82 Years Ago

A steam turbine in a power plant.

The End of Drudgery

From the Great Depression, a call to embrace the benefits of machinery.

"Those who allege that the general introduction of machinery has been the cause of an unfair, disparate distribution of wealth and an overall instability of employment in this age must have failed to examine the facts, upon which the truth of such allegations must rest.

The old-time work period, beginning before sunrise and ending after sunset, has been lifted from the poor. The early factory period, an 84 or even 90-hour week, has come down to the 48, 44, or even 40-hour week. The dignity of the human mind makes it appropriate to relieve man-labor by substitution of machine-labor in drudge work, and invention is accomplishing the result.

In the United States, a highly mechanized nation, the proportion of the population ten years of age and older in gainful occupations has varied only six or seven per cent from its average figure during the 50 years from 1880 to 1930. Nevertheless, during the same time a large change occurred in the percentages employed in different occupations. The numbers of individuals gainfully occupied in trade, transportation, and clerical work expanded tremendously. Similar shifts have occurred in western Europe.

Employees of the more advanced ages and least mental skill are likely to be permanently displaced by such shifts. The uneducated and meager-minded man who is destitute is a continuing cost-burden to society; and it is a poor order of intellect which can look upon the poorhouse as a desirable haven for old age.

The only civilized cure is to prevent these changes from causing destitution. This may be done by placing responsibility on those commercial, industrial, or other profit-making activities favorably affected by the changes. Replacement of man-hours by machine-hours should be restrained unless the replacement enlarges net earnings sufficiently to provide a reasonable contribution for reestablishing the displaced employees' status of living. Applying these principles would introduce a restraint upon the improper or socially unprofitable introduction of machinery."

Excerpted from "Machinery and Unemployment," by Dugald C. Jackson, head of MIT's Department of Electrical Engineering from 1907 to 1935, in the March 1933 issue of Technology Review.

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