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FOR THE TECHNOLOGY INSIDER | 11.14

Sweat: the details

Perspiration monitoring will supercharge health trackers P. 38

IEEE


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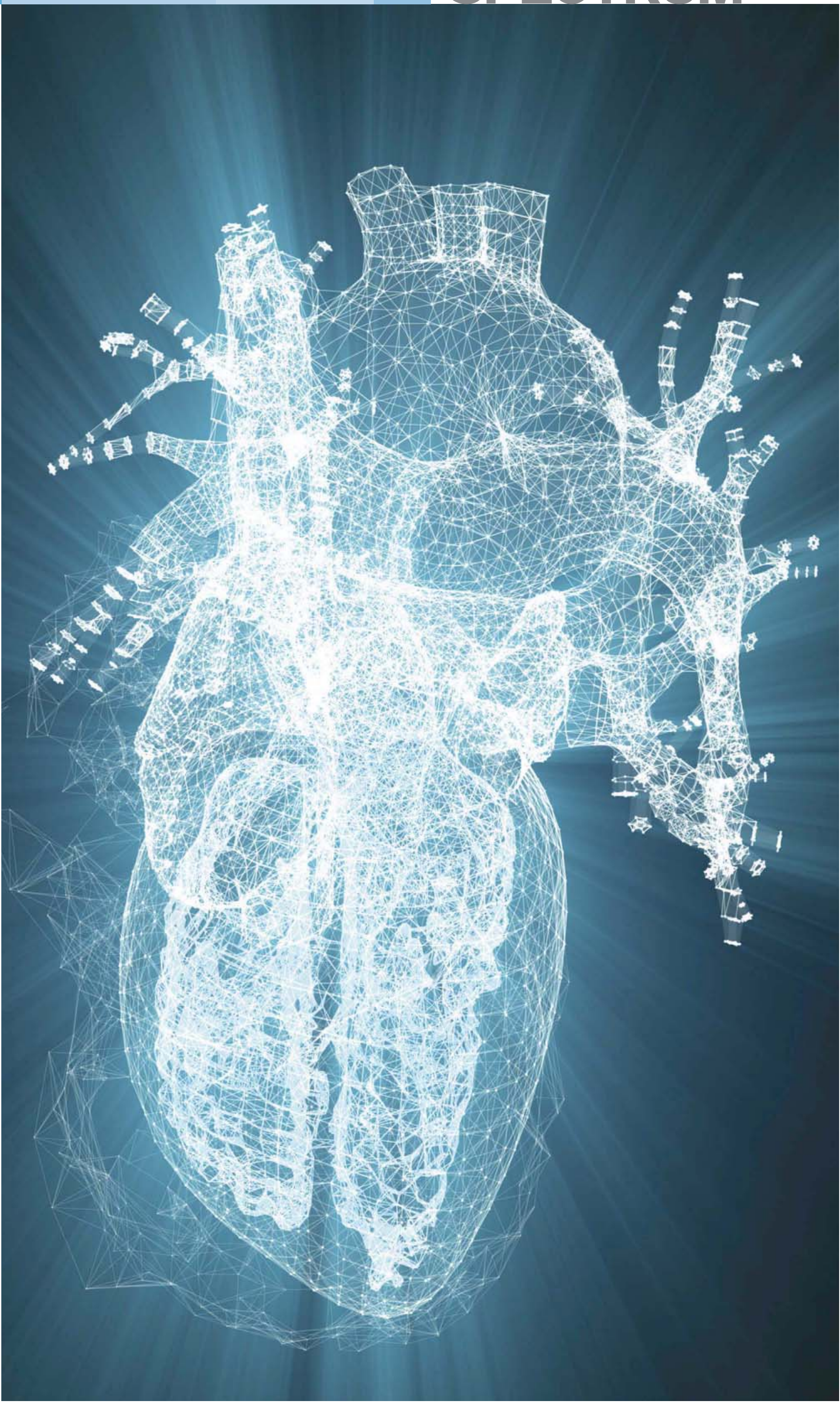

On the Cover **Photograph by Tim Tadder/Corbis**

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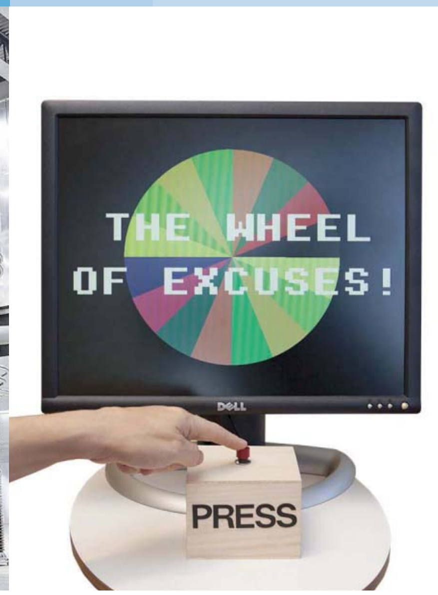

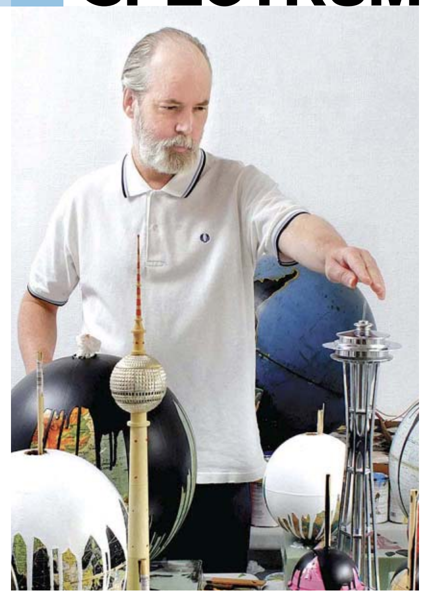

Online

Spectrum.ieee.org

The Tao of Alcatel-Lucent
Writer Douglas Coupland (coiner of the term "Generation X") spent months visiting Alcatel-Lucent sites, from Bell Labs in New Jersey to new research facilities in Shanghai. In a "Techwise Conversations" podcast, he talks about his quest to find out what being a telecommunications company really *means*.

ADDITIONAL RESOURCES

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COUNTERFEITING IN 3-D Anyone with a 3-D printer can replicate brand-name items and sell them with the help of open-source libraries that let users download blueprints. Companies are now implementing anticounterfeiting technologies such as quantum-dot detection and permanent ink to mark their products with unique signatures. But will these be enough?

WHAT TO ASK DURING AN INTERVIEW To help you get to know a potential employer and determine whether a job is right for you, we've compiled a list of important questions that all candidates should ask.

KEEPING THE LIGHTS ON Member Tanuja Ganu grew up in a small town near Mumbai, where power outages happen all the time. Now an engineer with the Smarter Energy Group at IBM Research–India, she has invented a device that can warn users when the local power grid is likely to shut down.

FROM LEFT: ABB; RANDI KLETT; BYRON DAUNCEY

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BACK STORY_

Strangers on a Bus

JOURNALISTS MUST SOMETIMES go to great lengths in order to track down an interesting subject for a story. But Bill Glovin [above, left] didn't have to go far to meet Joe Kinney [above, right], the man who keeps the memory of inventor Nikola Tesla alive at the New Yorker Hotel. He just took a bus home.

As described in Glovin's article "Nikola Tesla Slept Here," Kinney is the chief engineer of the New York City hotel where Tesla, the great electrical inventor and pioneer, died, nearly destitute, in 1943. Kinney takes a bus home every day from Manhattan to the town of Nutley, N.J., and Glovin, after a job change last year, started taking the same bus to the same stop. The two didn't interact, however, until Glovin and Kinney found themselves deposited at their stop during a downpour: Glovin called his wife to pick him up and offered Kinney a ride.

With the ice broken, the two began chatting during their commutes, but it was months before Kinney mentioned his fascination with Nikola Tesla. As it turned out, Glovin was acquainted with Michael Geselowitz of the IEEE History Center, and he thought someone at the IEEE would be interested in Kinney's work to commemorate Tesla's residence at the New Yorker Hotel. Geselowitz connected Glovin with *IEEE Spectrum*, and Kinney took Glovin on a tour of the hotel where Tesla spent the last 10 years of his life. Since then, the men have become firm commuter buddies: "He's just a fascinating guy," Glovin says. "Also, he fixes everybody's stuff in the neighborhood, so that's a good reason to be friends with him." ■

JOE KINNEY

CITING ARTICLES IN IEEE SPECTRUM *IEEE Spectrum* publishes an international and a North American edition, as indicated at the bottom of each page. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, Dataflow is in *IEEE Spectrum*, Vol. 51, no. 11 (INT), November 2014, p. 60, or in *IEEE Spectrum*, Vol. 51, no. 11 (NA), November 2014, p. 88.

11.14

CONTRIBUTORS_

Jason Heikenfeld

Heikenfeld is a professor of electrical engineering and director of the Novel Devices Laboratory at the University of Cincinnati. A founder of Gamma Dynamics, a maker of electrofluidic displays, he wrote *IEEE Spectrum*'s 2010 article "The Electronic Display of the Future." An avid runner, Heikenfeld has recently focused his research on sweat—something he deals with both in and out of the lab—which he writes about in "Let Them See You Sweat" [p. 38].

Ann Johnson

Johnson is an associate professor of history at the University of South Carolina. She first learned about the Ford Motor Co.'s unlikely involvement in basic superconductivity research [p. 32] while writing a paper on the origins of nanotechnology. She's no stranger to the automotive industry, however. Her Ph.D. dissertation was on the invention of car antilock braking systems; it later became the book *Hitting the Brakes: Engineering Design and the Production of Knowledge* (Duke University Press, 2009).

Sarah Lewin

Lewin was an editorial intern at *IEEE Spectrum* from June to September 2014. Now a master's student of journalism at New York University, she studied math at Brown University and enjoyed *Spectrum*'s tech-centric focus. Still, writing about the new microwave stethoscope [p. 12] was a challenge. "I had to carefully balance talking about the stethoscope's technological potential with its applicability as a medical tool, which are two very different things," she says. "It was troublesome, but rewarding."

Susumu Tachi

Tachi and coauthor Masahiko Inami are professors at the Graduate School of Media Design at Keio University, in Yokohama, Japan; coauthor Yuji Uema is a Ph.D. candidate there. Tachi is also director of the university's International Virtual Reality Center. When he first drove a car using his team's internal display system, which makes the car's body seem transparent [p. 44], Tachi says he was surprised at how realistic the simulation was: "I almost felt like I was on a bike."

Natalia A. Trayanova

Earlier in her career, Trayanova created computer models of the human heart for basic scientific research. Now, as a professor of biomedical engineering at Johns Hopkins' Institute for Computational Medicine, she's tailoring models for individual cardiac patients. In this issue, she explains how doctors can run simulations on a patient's virtual heart to test treatments [p. 26]. Integrating such computer models into clinical practice could "change the paradigm," she says.

11.14

PHOTO-ILLUSTRATIONS BY **Gluekit**

SNOW MEN: *IEEE Spectrum*'s executive editor, Glenn Zorpette, interviews Brian Johnson, an Antarctic survival specialist, for a radio program produced in 2010. The location was the McMurdo Ice Shelf.

JOSH LANDIS

Exploring the Radio Spectrum

How and why a print magazine got into the radio business

IN ANCIENT TIMES, before the Internet, the terms "print media" and "broadcast media" were pretty literal descriptions of the two main kinds of news organization. But journalism's steady migration to the World Wide Web has blurred the lines considerably. Nowadays, traditional broadcasters are putting up text stories and blogs on their websites. And *IEEE Spectrum* and other historically print-centric media are producing videos, podcasts, slideshows, and radio shows. Each of *Spectrum*'s radio segments, in fact, is being broadcast to some 4 million listeners across the United States via stations syndicated through the country's NPR network.

Our foray into public radio began exactly a decade ago. *Spectrum*'s editor in chief, Susan Hassler, hired Sharon Basco, an NPR veteran, to test the idea that some of our print stories could be turned into radio segments of interest to NPR shows. But that limited goal soon prompted a question: Could our journalists do radio reporting alongside their print reporting, so that timely stories in different media but on the same general topic could be released around the same time? Basco was confident that it could be done.

IEEE SPECTRUM 1964 / 2014

Basco was a seasoned journalist who had made a splash in her first job, interning for columnist Jack Anderson, by uncovering a big drug scandal at Walter Reed Army Medical Center in Washington, D.C. After marrying and settling in the Boston area, she switched from print journalism to radio.

She first met the *Spectrum* staff in the spring of 2004. Addressing us at our annual retreat, she described how augmenting our coverage with radio would expand our reach and spread our journalism, and the IEEE's name, to a large and high-demographic audience. She had no doubt that she could turn a bunch of ink-stained wretches into skilled radio reporters. "Radio is easy," she assured the staff, who looked at her blankly.

Well, there have been times when it didn't seem all that easy. I myself recorded an entire interview in Guadeloupe in an office that was all glass, stone, and metal; the resulting sound was so bad that no broadcast-quality segment could be salvaged from it. During an assignment in the Netherlands to record a segment about a state-of-the-art recumbent bicycle, Harry Goldstein instrumented himself with sound-recording gear before settling onto the US $10,000 bike–and then falling three times and bloodying his knees, as the bike's designer looked on in dismay. Visiting Gordon Moore at his home for an interview recently, Rachel Courtland decided to record the sound of herself approaching and knocking on the door of Moore's fabulous seaside estate in Hawaii, followed by Moore himself opening the door and greeting her. It all went off like a charm. Except Courtland forgot to push the "record" button before the approach.

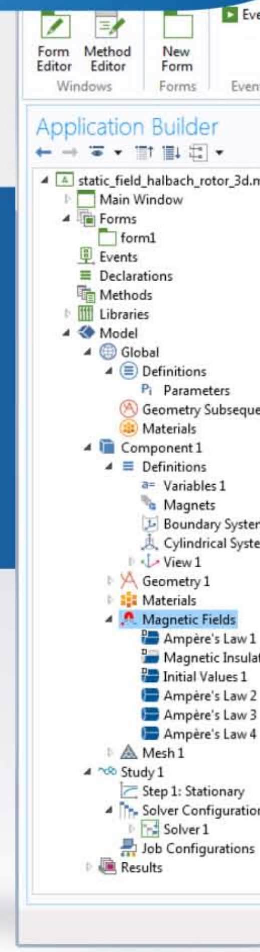
Goldstein and Courtland still managed to get excellent segments out of their reporting adventures, with help from Basco and Dennis Foley of HomeWork Productions, in Austin, Texas. From the very beginning we were fortunate to have had as collaborators some of the most extraordinarily talented people in radio. Foley, for example, is an audio-mixing wizard whose artistry has brightened many of our segments over the past decade. We also found some gifted radio stringers, who still contribute to our operation. These include reporters Ari Daniel in Massachusetts, Giselle Weiss in Switzerland, Prachi Patel in Pittsburgh, and producer Mia Lobel in New York state. In New York City, the legendary recording engineer Paul Ruest has captured the sound for many of our most important segments.

Before long, as our print and online editors became increasingly comfortable with radio reporting, our pieces crossed the threshold into broadcast quality. We

CORRECTION: In "Identifying Explosives at a Distance" [October], we incorrectly stated that James Kelly and his team at the Pacific Northwest National Laboratory are attempting to measure a substance at a dosage of 1 milligram per square centimeter on a surface. The actual dosage is 1 microgram.

Editor's note: In this 50th anniversary year of IEEE Spectrum*, we are using each month's Spectral Lines column to describe some pivotal moments of the magazine's history. Here we recount the establishment and evolution of* Spectrum*'s radio news operation.*

FROM MODEL



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SPECTRAL LINES_

were soon placing pieces on "Living On Earth," an ecology-themed program, and "Here & Now," the midday news and public-affairs show, and even a few on "Weekend Edition." Memorable segments from those early years include ones on the Keck telescope in Hawaii, the use of handheld devices to track wild animals in Africa, how electronics were giving new life to old musical performances, earthquake preparedness in Japan, and how sonar systems were affecting whales.

Meanwhile, another opportunity presented itself. Public Radio Exchange (PRX), a marketplace for content for public radio stations, was expanding and looking to add segments, programs, and shows. Basco began producing 1-hour shows on a single topic, based on ideas, reporting, and writing from our staffers and radio stringers. We did several of these shows each year, distributed by NPR's ContentDepot and by PRX. A popular show would be picked up by several hundred stations, introducing millions of people to *Spectrum*'s reporting.

We did shows on robots, on the fastest-moving things on Earth, on efforts to adapt to climate change, on breakthroughs in human-genome sequencing, and on how technology is changing the culture of work. I myself visited Antarctica, where I did reporting for a show on the work and living conditions of scientists and engineers on the continent. Many of these radio specials were produced with funding from the Directorate for Engineering of the United States' National Science Foundation. For these we had the great advantage of being able to use the outstanding talents of the NSF's Laurie Howell.

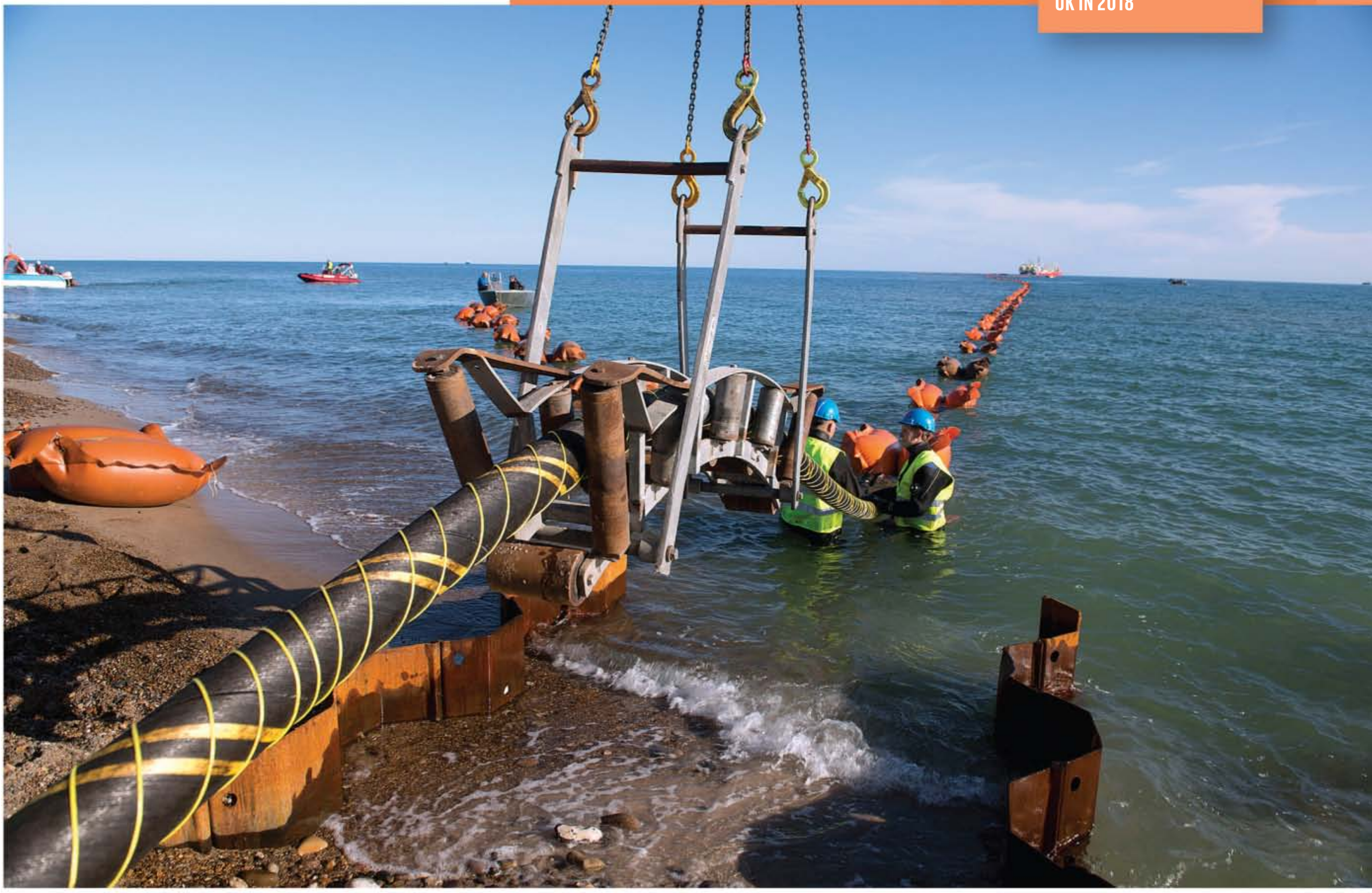
Lately, we have returned to our roots. A year and a half ago, NPR announced that it was discontinuing "Talk of the Nation," the midday public-affairs and current-events show, and replacing it with "Here & Now." As "Here & Now" was set to increase its listening audience from hundreds of thousands into the millions, we were pleased to forge a closer relationship with the show's producers. Earlier this year, we were named "Technology Partner" of the show, which is now broadcast to some 4 million listeners daily. We agreed to provide a segment on a technology-related topic every three weeks. Among our first segments were ones on Volkswagen's ultrahigh-mileage car and on an experimental system that monitors hatchings of sea-turtle eggs.

We are delighted with this new opportunity to reach the influential and intellectually engaged people who listen to "Here & Now." As technology continues to alter and reshape society in surprising ways, the IEEE should be at the forefront of interpreting and explaining those developments to a large and growing general-interest audience. Increasingly, the most effective channels for reaching such people and in such large numbers are going to be electronic ones. Technology gave us radio, video, and the Internet. Now they, and our powerful media partners, are giving us the means to expand our reach as we chronicle technology's expanding dominion.

—GLENN ZORPETTE *Twitter: @Electric_Genie*

NEWS

720 KM: LONGEST UNDERSEA HVDC CABLE, SET TO JOIN NORWAY AND THE UK IN 2018



NORWAY WANTS TO BE EUROPE'S BATTERY

A new HVDC line will let Europe store more wind energy in Norway's hydropower system

THE VIKING CONNECTION: A new high-voltage DC cable will connect Denmark to Norway.

STATNETT

Norway's hydropower reservoirs make up nearly half of Europe's energy storage capacity. European grid operators need energy storage to cope with an ever-mounting, always-shifting torrent of wind power. See the connection? So does Norway. In December, engineers will energize a new subsea power cable that will begin to bridge the gap between need and opportunity, greatly expanding European power systems' access to Norway's hydropower-rich power grid.

The 240-kilometer cable across the Skagerrak Strait separating southern Norway and northern Denmark is Norway's first new power link to Denmark since 1993. Called Skagerrak 4, its high-voltage direct current (HVDC) converters—the electronic units at either end of the line that transform AC into high-voltage DC and vice versa—are also the building blocks for more ambitious cables from Norway to wind-power heavy- »

weights Germany and the United Kingdom. Construction on those is expected to commence during the coming year.

The existing Skagerrak interconnection, three HVDC cables with a combined 1,000 megawatts of capacity, is already showing the world just how well wind and hydropower complement each other. According to the Danish Energy Agency, such interconnectors are why Denmark can accommodate the world's highest levels of wind power, which met 41.2 percent of Danish demand in the first half of this year. At times wind power production even exceeds the country's domestic power demand.

SMOOTH OPERATORS: Reactors on the Denmark side of a new HVDC link even out the flow of power stored in Norway. The country plans similar links to the United Kingdom and Germany.

ABB

"We store their surplus in the hydro reservoirs and then feed it back on a seasonal basis or a daily basis. This is a very strong business case," says Håkon Borgen, executive vice president at Statnett, Norway's state grid operator.

Norwegian hydropower turbines throttle down as Norway consumes Danish wind energy instead, leaving an equivalent amount of energy parked behind dams. And when the weather shifts and becalms the North Sea winds, the reservoirs and Skagerrak's cables feed that stored energy back to Denmark.

Borgen says the addition of the 700-MW Skagerrak 4 advances plans to plug the U.K. and Germany into Norway's batteries by pushing the most flexible form of HVDC technology—voltage source converters (VSCs)—to its highest voltage yet. VSCs' ability to stabilize the voltage of the AC grids on both sides of a cable makes the technology better suited than any existing alternative for handling intermittent flows of renewable energy, he says. Skagerrak 4's VSCs operate at 500 kilovolts each—30 percent higher than the previous record holder. Borgen says that voltage boost will be needed to reduce losses on longer runs such as the 720-km cables to the U.K., which will be the world's longest subsea power cables.

ABB, of Zurich, which built Skagerrak 4's VSCs, says the tougher technology challenge was ensuring that the VSCs function well alongside the older HVDC lines. That's because current that Skagerrak 4 carries south across the strait must cycle back to Norway via the Skagerrak 3 cable, which uses the older, classic HVDC converters. This will be the world's first paired operation of cables using VSCs and classic HVDC converters.

Such a pairing gets interesting when operators want to reverse the flow of power—something that can happen up to 1,000 times per year at Skagerrak as winds and markets shift. VSCs normally reverse power flow by reversing a line's current, whereas classic HVDC converters must flip the line's voltage polarity.

So how to reverse power flow on both lines? ABB's solution is a 5- to 10-second process that uses coordinated actions by both converter types and eight high-speed switches that reconfigure the wiring of the VSCs, flipping their polarity so that the flow of power in Skagerrak 4 can change direction while its current keeps flowing south.

The process interrupts the circuit by which current flows from one cable to the other. But Lars-Erik Juhlin, an HVDC expert at ABB, says there is no meaningful loss or surge in power to the AC grids.

The key, explains Juhlin, is the excellent electrical conductivity of seawater. When the power-reversal scheme interrupts the circuit, the converters use subsea electrodes at either shore to feed the return currents across the strait through the water. Sending current through seawater can corrode subsea infrastructure such as natural gas pipelines, but here, the dose makes the poison. "They can accept even 2,000 amps for up to 2 hours. So for a short pulse, it's no problem," says Juhlin.

Statnett's follow-on interconnection projects could move quickly because they will just be longer versions of Skagerrak 4. The first, a pair of 500-kV VSC cables between Norway and Germany, was nearing final regulatory approvals when *IEEE Spectrum* went to press in October. Statnett and its European grid partner, Dutch-German firm Tennet, foresee charging up the 1,400-MW NordLink in 2018. The pair of Norway-U.K. cables, a joint effort of Statnett and London-based National Grid, is slated to start by 2020.

There should be many more cables to come if European countries make good on official goals to eliminate carbon emissions from power generation by 2050. The German government's Advisory Council on the Environment, for example, concluded in its influential 2011 report that an optimal zero-carbon power system for Germany would need more than 40 gigawatts of interconnection to Norway. That system, the council projected, would deliver power at a very affordable 6 to 7 euro cents per kilowatt-hour. Without Norwegian storage, power costs would rise to 9 to 12 euro cents per kilowatt-hour.

Ånund Killingtveit, a professor of hydraulic and environmental engineering at the Norwegian University of Science and Technology, says Norwegian hydropower is up to at least part of the task. Killingtveit led a five-year, US $5.7 million research program on hydropower balancing, which showed that existing hydropower reservoirs could "fairly easily" move about 25 GW of energy in and out of storage without damaging the environment–five times as much as they currently manage. The key, he says, is installing pumps to shift water from one reservoir to a higher one nearby, thus actively storing power rather than just deferring production.

If there is a limit to Norway's energy storage potential, it may ultimately be the country's own grid. Statnett has begun a 10-year, $8 billion to $10 billion grid upgrade, but it factors in only 3.5 GW of additional power from the three cable projects. The question may be how many power lines the Norwegians will accept to smooth Europe's departure from fossil fuel power. –PETER FAIRLEY

TWIST AND SHOUT

Spiraling radio beams send data at 32 gigabits per second

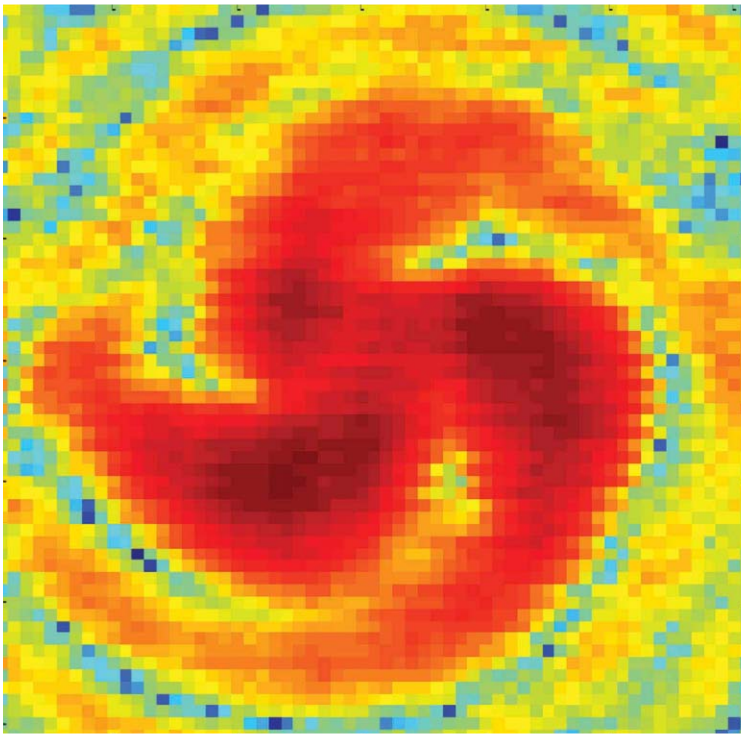
A team led by engineers at the University of Southern California has sent multiple channels of data over a single frequency by twisting them together into a beam resembling a piece of fusilli pasta. By combining several polarized beams carrying information into a single spiraled beam, the team was able to send up to 32 gigabits per second across 2.5 meters of open air, a rate around 30 times as fast as an LTE wireless connection.

The high data rate was made possible through a technique known as orbital angular momentum (OAM) multiplexing, says USC electrical engineering professor Alan Willner, who partnered with researchers from the University of Glasgow and Tel Aviv University on the experiment.

A property of electromagnetic waves first identified in the 1990s, OAM can be harnessed to let multiple channels of information ride along a single frequency. "I could have a wave that twists slowly and one that twists a little faster, and those waves are now orthogonal to one another," Willner says. "If you put them together and send them spatially co-located through the same medium, you have doubled your capacity."

Willner and others have previously demonstrated the twisting technique with beams of light, reaching data transmission speeds of 2.56 terabits per second through the air in 2012 and 1.6 Tb/s over optical fiber in 2013.

ROTATING RADIO: Waves of the same frequency won't interfere with one another if they are given different degrees of orbital angular momentum.



YAN YAN, GUODONG XIE, AND ALAN WILLNER

Proving the technology works at high data rates with radio waves is important, because those frequencies are less affected by obstacles and atmospheric conditions than optics and could have broader commercial applications.

Willner and his team used four antennas to send eight channels of data. Those beams of data were sent through specially shaped "spiral phase plates," plastic plates that don't absorb the beams but do cause them to change their shape, twisting them slightly. The twisted waves are then gathered by a multiplexer and sent through a single transmitter aperture. Since each wave has a slightly different OAM, they can travel along a shared axis without interfering with one another.

The combined beam, which takes on a helical shape, travels through another aperture at the receiver, after which it is split back into four beams by a demultiplexer. The four beams then pass through another set of spiral phase plates. These plates are inverted versions of the first set, which undo the initial twisting and prepare the waves to deliver their data payload.

This isn't the first time radio waves have been used to demonstrate the potential of OAM. Italian and Swedish researchers in 2012 used the same principles to send a pair of radio waves sharing a single frequency between two islands in Venice. At the time, some communications engineers criticized that work, suggesting it was not significantly different than existing multiple-input, multiple-output (MIMO) techniques.

Willner says this latest study demonstrates that there are clear implementation differences between conventional MIMO and OAM multiplexing. MIMO sends different streams of data from different antennas broadcasting on the same frequency and decodes the inevitable cross talk on the receiving end using digital signal processing. OAM multiplexing sends multiple channels of information along a single beam without any interference between them. That means once the phase plate at the receiver unwinds the helical beam into its component channels, they don't have to undergo further cleanup.

One of OAM radio's early critics, Lund University radio-systems professor Ove Edfors, remains unconvinced, however. While he doesn't question Willner's results, Edfors remains incredulous that radio-based OAM could be made practical for long-range communications. Without the assistance of impractically large antennas to transmit and receive them over long distances, Edfors says now, "signals carried on…OAM components rapidly become useless from a communication point of view."

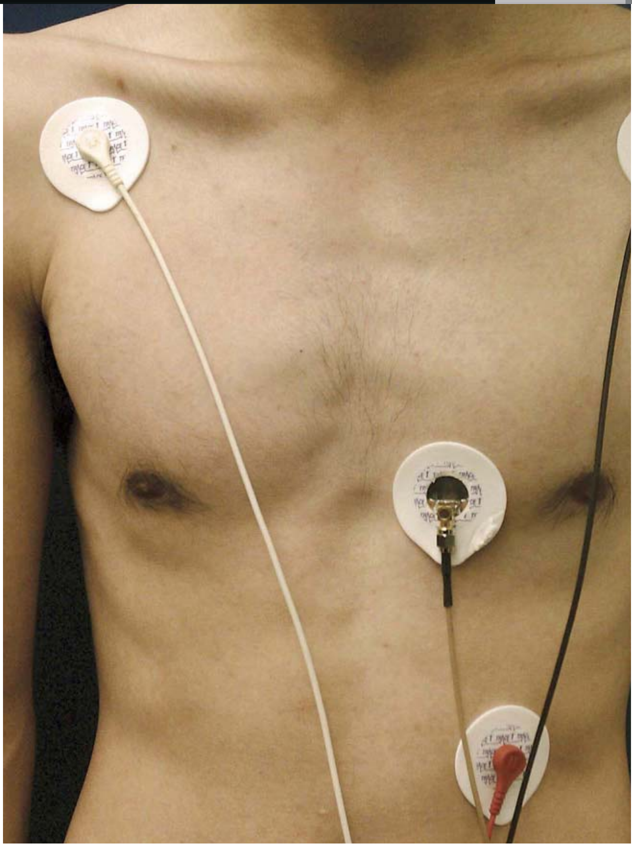
Fabrizio Tamburini, one of the scientists behind the 2012 Venice OAM experiment, sees a lot of promise in the latest work, saying that "very good ideas can come from it." Tamburini is now working on ways to refine OAM for use in telecommunications and other industries.

If OAM pans out, the technology could be adopted in places where high-speed, line-of-sight wireless connections are in demand, such as for wireless backhaul in cellular networks, suggests Willner. OAM could be a good fit for transmitting data among "a dense network of small base stations without…the stringing of fiber to connect them to the core network," he says. He and USC colleague Andy Molisch also see the potential for OAM in data centers. "With better equipment, [transmission rates] could go much higher," Willner says. "A radio backhaul like that could be a huge pipe for data centers or building-to-building connections."

OAM techniques might also be used in other fields, such as microscopy, Willner says. "There are potential applications outside of communications. We're going to continue learning how to tailor and manipulate the structure of waves in ways we've never thought of before."
—IAN CHANT

A version of this article appeared online in September.

Twisted radio waves sent 32 gigabits per second across 2.5 meters of air, about 30 times as fast as an LTE wireless connection



HAWAII CENTER FOR ADVANCED COMMUNICATIONS/THE UNIVERSITY OF HAWAII (2)

MICROWAVE STETHOSCOPE LETS PHYSICIANS PEER INTO THE LUNGS

A stick-on sensor can measure vital signs and lung fluid

When a person's heart is failing, water begins to build up in the lungs, making it increasingly difficult to breathe. The sensation, patients say, is like drowning.

Deciding whether it's safe for that patient to go home can depend on whether the water level goes back down. But today the options for measuring lung water are cumbersome, such as taking chest X-rays, inserting a tube into the lung, doing blood tests, or

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

HEART-FAILURE HELPER: A microwave transceiver [center] can do what other sensors can't: measure the accumulation of water in a patient's lungs.

even weighing the patient over time to quantify the decrease. The most hands-off method requires measuring the impedance of electricity passing through the patient's body with a bulky vest, but this method can fail if the patient shifts position.

Now a team of researchers at the University of Hawaii, at Manoa, have a new way to measure lung water, along with many other vital signs. As their coin-size sensor rests on a patient's chest, it emits microwaves and measures how they reflect. The list of what the researchers can decode from these patterns of reflected microwaves is only growing.

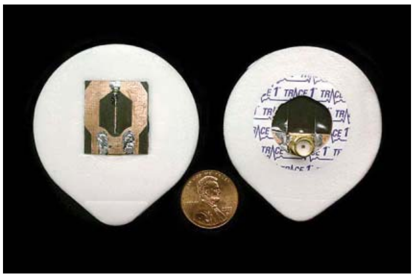
"Because of the ability for microwaves to penetrate the body, we can extract a wide variety of things, depending on what you are trying to monitor," says Magdy Iskander, director of the Hawaii Center for Advanced Communications at the University of Hawaii's College of Engineering. But the ability to measure fluid in a patient's lungs might be what really sets the microwave stethoscope apart. The level of water in the lungs can be an indicator of a patient's reaction to medication, the effectiveness of treatment for critically burned patients, and, most important, the extent of heart failure, he says.

To get a clear signal, Iskander's team had to develop a compact microwave transmitter that beams tightly focused waves, something that ordinary antennas won't do. "You can't use microwave antennas—the signal is all over the place," says Iskander. "What you receive next to it is coming from the transmitter and not from inside the body." Instead, the device focuses the beams using waveguides. Upon capturing the reflected waves, the engineers apply advanced signal processing algorithms to pull out as much information as possible. The signals can then be sent to a smartphone or another display.

The group first tested the sensor solely for measuring lung water, but they soon realized that the data also revealed other vital signs—heart rate, breathing, and volume of blood pumped per beat. They've rigorously measured the lung water content of model systems and of animals and are just beginning human tests. In the meantime, the team has ensured that the stethoscope can accurately measure vital signs by using it side by side with a commercial set of medical sensors.

Ruthsenne Perron, a Ph.D. student who's worked on developing the stethoscope's different incarnations with Iskander, says that there are several devices for reading vital signs noninvasively. But their microwave stethoscope has a key difference—mobility. "We used some of the devices that they use in the hospital to benchmark our results," she says. "But when the person is moving around, they just start beeping because they can't handle the movement. That's one of the advantages to what we have—it doesn't hinder mobility for the patient."

"It's a huge challenge managing patients whose cardiac status varies a lot," says John Spertus, a cardiologist at Saint Luke's Mid America Heart Institute, in Kansas City, Mo. Spertus learned about the device in April and has helped Iskander's group improve protocols for tests on humans. "The holy grail is to be able to detect early that somebody's accumulating fluid," Spertus says. Although there are other ways to approximate changes in lung water levels, he says, "none of them are either accurate enough or accessible enough in routine clinical care to reach the vast majority of heart failure patients. This is a really creative and novel solution for addressing that." Still, Spertus acknowledges that the device needs more testing before it's ready for hospital or home use.



STICK-ON SENSOR: The microwave stethoscope consists of a transmitter, a focusing antenna, and a receiver.

According to Kenneth Foster, a professor of bioengineering at the University of Pennsylvania, in Philadelphia, it's also challenging to ensure that new sensors will work with any kind of patient: "The device would need to give reliable and medically useful information for every patient who walks through the door—300-pound Sumo wrestlers to 95-pound cancer patients. It is premature at this point to speculate how the device will work in the real world of medicine."

Brian Rosenfeld, the chief medical officer for telehealth at Philips, says that a microwave stethoscope may be more practical for one-off uses than for full-time monitoring, which could add unnecessary expense to an intensive care unit. For continuous monitoring, as in a remote ICU, Rosenfeld thinks that physicians should instead use improved algorithms to collect and analyze the measurements already available, which would allow them to predict patient outcomes without extra equipment.

Besides beginning a human lung water-measurement trial at the Queen's Medical Center, in Honolulu, Iskander's group is considering other uses for the stethoscope—like sewing it into a shirt or a bra to monitor the medical condition of a soldier over time. The sensor could even watch for signs of dehydration, which earlier research has connected to lung water content.

"We're just beginning to find out more about what our device can do," says Perron. —SARAH LEWIN

NEWS

SUPERCOMPUTER COOLING FOR PHOTOVOLTAICS

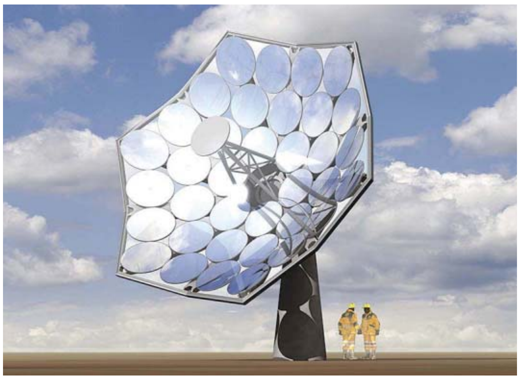
A start-up is using a system designed to cool a supercomputer to increase the efficiency of solar

Flat photovoltaic panels have come to dominate the global solar market thanks to a dramatic drop in panel prices over the past five years. A Swiss start-up, using technology that IBM Research-Zurich developed for one of its supercomputers, is challenging the status quo with a dish-shaped solar concentrator that produces both electricity and hot water.

The start-up, Airlight Energy, developed the dish and has created a spin-off company—called Dsolar for "dish solar"—and plans to release the concentrator in 2017. It will be targeted at off-grid communities in areas like deserts that get a lot of direct sunlight but want for both electricity and hot water. In developed countries, the 10-meter-high concentrator can be used for on-site power generation at corporate campuses or hotels, says Ilaria Besozzi, business development manager at Airlight Energy.

The parabolic dish, which automatically reorients to track the sun throughout the day, is made up of 36 elliptical reflectors that concentrate light onto very efficient, multijunction solar cells to produce electricity. These types of cells use materials tuned for different wavelengths and in this device will be able to convert about 30 percent of sunlight into current, says IBM.

Typically, the solar cells exposed to concentrated sunlight are air cooled. Airlight Energy hopes to increase the electrical output—and produce hot water—by using liquid cooling. Behind each set of solar cells is a structure that houses IBM's water-cooling technology, which is now used in its SuperMUC supercomputer in Germany. Water flows through a network of small tubes, or "microchannels," etched into a layer of silicon to wick away the heat from the solar cells, says Bruno Michel, the manager of advanced thermal packaging at IBM Research-Zurich. In supercomputers, the liquid coolers are attached directly to the processors, where most of the heat is generated, says Michel.



SUPERSOLAR: A cooling system originally designed for an IBM supercomputer would let a photovoltaic system produce both 12 kilowatts of electricity and 20 kW of heat.

IBM RESEARCH–ZURICH

Because the dish uses active cooling, the solar cells should be able to withstand a very high concentration of light—the equivalent of 2,000 suns—and still operate for 25 years. The higher concentration has the side effect of heating the cooling water to about 90 °C. At that temperature, the water can be used to power desalination systems or, oddly enough, a particular type of heat-driven cooling system, Michel says. In full sunlight, the dish is designed to generate 12 kilowatts of electricity and 20 kW of heat.

Concentrated photovoltaic (CPV) systems have been around for decades, and the technology offers, at least in theory, a number of advantages. They can generate more power in a given amount of space and offer higher conversion efficiency than flat panels can. In fact, by generating both heat and electric power, Airlight Energy says it converts 80 percent of sunlight into usable energy. But the cost of CPV technology and its complexity have kept it from becoming commonplace with utilities.

To keep costs low, Airlight Energy is using two materials not normally used in solar concentrators. Rather than have glass mirrors to concentrate light, the mirrors will be made of the same thin plastic foil used to wrap Swiss chocolates, says Besozzi. The main structure of the dish will be made of a specialized concrete, which can be precisely molded, doesn't shrink, and costs far less than metals or plastic building materials, Airlight Energy says.

Engineering a system to simultaneously generate electricity and process the thermal energy will be difficult, says Sarah Kurtz, principal scientist at the U.S. National Renewable Energy Laboratory. For example, if the heat-driven cooling fails, the dish needs to quickly steer away from the sun or transfer the heat in another way. Using thin-film mirrors lowers the cost, but first-of-a-kind systems are typically expensive. "The challenge is to reduce the cost of the other components, but at 2,000 times concentration, this is feasible," she says. Having IBM's technology behind the product gives it commercial credibility, notes Matthew Feinstein, an analyst at Lux Research, in Boston. Traditionally, CPV systems were targeted at utilities, but many industrial companies, such as data center operators and manufacturers, can easily make use of the solar dish's thermal energy, he adds. Still, "commercialization and early adoption have always been a challenge for unique solar technologies," he says. —MARTIN LAMONICA

A version of this article appeared online in September.

IEEE SPECTRUM | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

PHOTOGRAPH BY Michael Porro/Getty Images

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

TOUR DE STROLL

DUTCH INVENTOR Bruin Bergmeester enjoyed everything about his 12-kilometer bike ride to work—except for the fact that it was literally a pain in the, er, saddle. After opting to get rid of the seat altogether, Bergmeester decided to start from scratch, with a design that more closely resembled a scooter than a bicycle. And instead of pedals, he outfitted the vehicle—which he dubbed the Lopifit—with a treadmill deck that lets him propel himself just by walking. Then he added an electric motor that multiplies his effort four times. So when he walks on the treadmill at 5 kilometers per hour, he travels down the road at 20 km/h. Nonstop inquiries about the Lopifit—which he first built in his living room—have prompted him to start selling them. They're available at his website, http://www.lopifit.nl, for €1,250 (about US $1,600).

RESOURCES

50 BILLION: NUMBER OF ARM-BASED CHIPS SHIPPED SINCE 1990

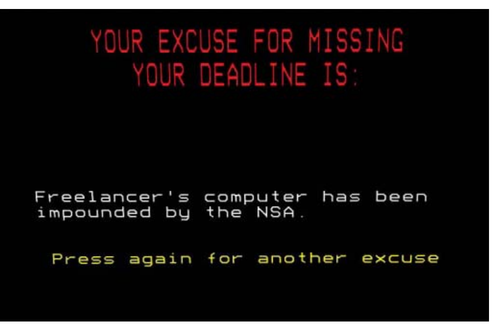
BACK TO BASIC

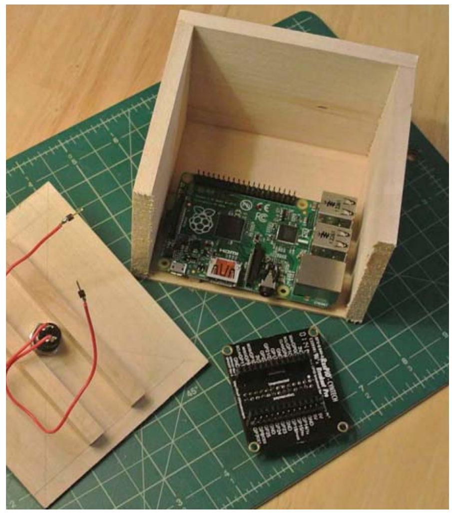
A DIGITAL LOTTERY WHEEL BUILT WITH AN OLD OS AND THE NEW RASPBERRY PI

Many years ago in the offices here at *IEEE Spectrum*, we had a "Wheel of Excuses" pinned to the outside wall of a cubicle. Made from paper and cardboard in the style of a small lottery wheel, it could be spun to suggest plausible excuses to luckless editors seeking to explain a blown deadline. The wheel had its limitations, however, chief among them being the small number of excuses that could be squeezed onto a disk just 25 centimeters across, and a tendency to fall off the wall if spun with too much vigor or desperation. ● *Spectrum*'s offices were renovated this year, the dingy cubicle walls swept away for a modern office layout. So I thought it might be time for an updated Wheel of Excuses—a digital one, naturally. I wanted a one-touch system that would show an animation of a spinning wheel, followed by the display of a randomly selected excuse from an extended list. ● Initially, I thought I would make the new wheel using an Arduino and a touch-screen add-on shield. But the speed at which graphics could be drawn on the touch screen proved too slow for the kind of animation I wanted, and the 2.8-inch screen was on the small side in any case. ● So I turned to the US $35 Raspberry Pi microcomputer, which had the final release of its first generation in July—the Model B+. Among other changes, the Model B+ has two more USB ports than the Model B

RESOURCES_HANDS ON

PHOTOGRAPH BY Randi Klett





The Model B+ Raspberry Pi [bottom of photo, top left] has an upgraded version of the I/O hardware in the Model B. Using a RasPiO breakout board [above], I connected a button to the 40-pin GPIO header. Button presses generate excuses [bottom left], which appear on a monitor attached via an HDMI cable.

along with an expanded general-purpose input/output (GPIO) connector, and it relies more heavily on HDMI for video output.

The Pi was first released in 2012 as a "spiritual successor" to the BBC Microcomputer System, which was created by Acorn Computers in 1981 for Britain's national Computer Literacy Project. The naming scheme for Pi models echoes that of the BBC Micro series, and like the original BBC Micro, the Pi has rapidly spread beyond the classroom.

The links to the BBC Micro are more than just circumstantial. The Pi is built around an ARM chip (a Broadcom BCM2835), and while ARM currently dominates the world of smartphones and tablets, the architecture was originally developed to provide a high-performance coprocessor for BBC Micros, and it later powered the Archimedes line of PCs. The Archimedes came with RISC OS, a graphical user interface–based operating system that has since been ported to the Pi.

I first used Acorn's dialect of BASIC way back in the day on a BBC Micro. One of the nice things about it was that it let you mix BASIC commands with assembly code for the BBC Micro's 6502 processor. I was pleased to discover that RISC OS has retained a great deal of compatibility with the systems it grew out of, right back to that original dialect.

RISC OS's version of BBC BASIC—version VI—is, of course, greatly expanded compared with its 8-bit ancestor: As I said when I first tried it out, "it's like meeting someone you palled around with in high school, and now they own a business and have two kids." But it still includes an in-line assembler for combining machine code subroutines—now ARM code, of course—with BASIC. The integration allows for streamlined passing of variables back and forth between a BASIC program and machine code—for example, a set of BASIC integer variables, A% through H%, are automatically copied into the first eight registers of the ARM chip when a subroutine is called.

This integration let me quickly write the spinning wheel animation and display code in BASIC, reaching back across the years to cobble together commands to draw colored segments of a circle and store the text of excuses using "data" and "read" commands. (When I started programming, BASIC code would have been too slow for the wheel's animation, but 30 years of Moore's Law has solved that problem.) I needed to dip into assembly only in order to read the state of a button connected to the GPIO hardware. The button triggers the animation and has the program select and display an excuse.

I wired the button to the Pi's GPIO port using a $10 RasPiO Breakout Pro, which provides basic protection against miswiring. (Unlike the more robust Arduino, which can handle enough current to drive a servo, the Pi's GPIO can be damaged if connected to circuits that expose it to more than a few milliamperes or exceed 3.3 volts.) The Breakout Pro is designed for the GPIO on earlier Pi models, but the B+'s expanded port keeps the same pin configuration for the first 26 pins, so I was able to use the Breakout Pro and simply ignore the B+'s extra pins.

Reading the GPIO hardware was a good chance to get acquainted with the guts of a system using a reduced-instruction-set-computing architecture (so many registers!)—the last time I programmed on the metal was for the 6502. The Pi's GPIO pins are mapped into the system's memory as a series of 3-bit segments stored within 32-bit status words, so my machine code subroutine has to do some bit bashing to set a GPIO pin as an input. Then my subroutine reads the relevant GPIO status word and passes it back to BASIC. (For my code, I combined some snippets from Bruce Smith's book *Raspberry Pi Assembly Language RISC OS Beginners* and a Raspberry Pi online forum.) My BASIC program then simply uses a loop that calls the subroutine and looks for any changes in the status word, indicating a button press.

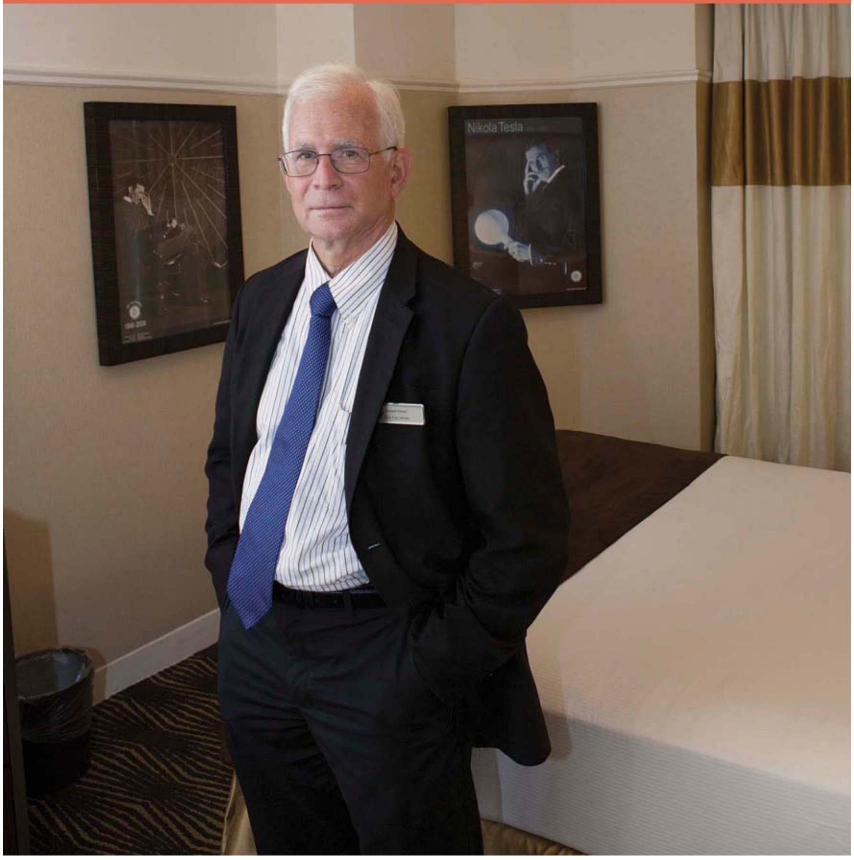
With the software written, all that was left to do was build a case (from a few dollars' worth of basswood) and hook the video output up to an old monitor. And voilà! A new era of digitally driven excuses. —**STEPHEN CASS**

TOP: STEPHEN CASS (2); BOTTOM: RANDI KLETT

RESOURCES_GEEK LIFE

NIKOLA TESLA SLEPT HERE

THE NEW YORKER HOTEL'S JOE KINNEY KEEPS THE INVENTOR'S MEMORY ALIVE



OUTSIDE THE 34TH STREET SIDE OF THE NEW YORKER HOTEL in Manhattan, it seems fitting that lightning cracks the sky as Joseph Kinney [above] points to a plaque recognizing that the father of AC power, Nikola Tesla, once lived at the hotel. That very few among the thousands of people walking by each day realize that the inventor and engineer once rivaled Thomas Edison, Alexander Graham Bell, and Henry Ford for the mantle of greatest American inventor is why Kinney has spent nearly 20 years championing Tesla. ● Kinney, the chief building engineer for the hotel as well as its unofficial historian, is a 63-year-old bespectacled man with white hair and a perpetual twinkle in his eye. His sarcasm and intensity often ignite a rather goofy, high-pitched chortle. Dressed in tie and jacket despite the oppressive humidity of a hot summer day, he is clearly proud of the Tesla plaque, which reads, in part: "Here died, on January 7, 1943, at the age of 87, the great Yugoslav-American scientist-inventor."

Moving through the hotel's art deco lobby, we descend the stairs to Kinney's subterranean office, and he talks as we go. "This hotel is the only place in the country where Tesla spent a lot of time and that still exists much as it was when he was alive," says Kinney. "Everyplace else is either demolished or radically changed."

From 1933 until his death in 1943, Tesla lived in relative obscurity at the New Yorker Hotel with little means. Considered quirky, he loved pigeons and was known to spend time every day in nearby Bryant Park visiting them or feeding them from the windows of his room. Tesla's *New York Times* obituary refers to his claims about death beams and communications from Mars.

But in his earlier days, Tesla made critical contributions to establishing electricity as the ubiquitous workhorse it is today. Electrical power was still a novelty when the Croatian-born, ethnic Serbian visionary arrived in New York City with pennies in his pocket at the age of 28 in 1884. He also had a head full of ideas, many of them formed while working for the Continental Edison Company in France. He worked on improving Edison's DC system, but he fell out with Edison over pay. Eventually, Tesla found a backer in Pittsburgh industrialist George Westinghouse for his designs for motors and transformers that used AC.

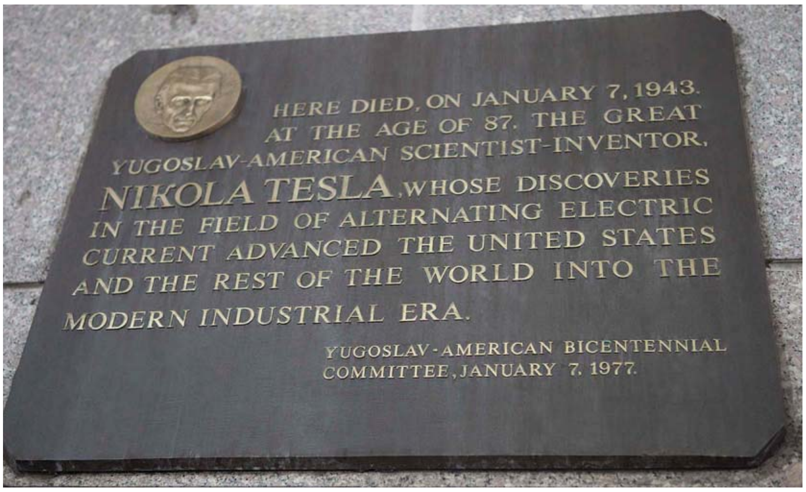
The rivalry between the backers of AC and DC power became known as the War of Currents. In the end, AC power triumphed over DC power, and Tesla conducted many spectacular, well-attended high-voltage power demonstrations, including a high-profile appearance at the Chicago World's Fair (formally known as the World's Columbian Exposition) in 1893. Edison, shortly before his death in 1931, said that one of the biggest mistakes of his life was his failure to back AC power.

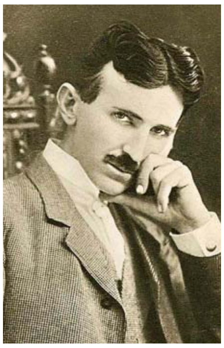
But inventing AC power failed to sustain Tesla, who foolishly released Westinghouse

PHOTOGRAPH BY Randi Klett

from the royalty agreements that should have made him a rich man. He received backing from J.P. Morgan to build a laboratory and a huge radio tower to pursue ideas for transatlantic telecommunication and wireless power transmission technologies. The promised results never materialized, and the tower was scrapped. No longer able to afford a laboratory, Tesla continued to privately pursue his experiments in places like the New Yorker Hotel. His death in 1943 was barely acknowledged; World War II was consuming the country, and his major accomplishments had come more than four decades before.

But recognition for Tesla has been on the rise in recent years, with, for example, the unveiling of a statue in the heart of Silicon Valley. The biggest grassroots effort is the construction of the Tesla Science Center on the 16-acre Wardenclyffe site, in Shoreham, N.Y., where Tesla built the J.P. Morgan–funded laboratory. One of the effort's leaders is Matthew Inman, a cartoonist and Tesla fan who runs the popular blog *The Oatmeal* and who recently solicited a US $1 million donation from Elon Musk, the billionaire founder of Tesla Motors.





A TESLA TRIBUTE: Following the loss of his purpose-built lab [left], Nikola Tesla [far left] lived the last 10 years of his life at the New Yorker Hotel, a stay now marked by a plaque outside the hotel [top]. His rooms [below] are available to guests.

CLOCKWISE FROM TOP: RANDI KLETT (2); NYPL/SCIENCE SOURCE/GETTY IMAGES; PHOTO RETOUCHERS/GETTY IMAGES

Prior to this Tesla revival, however, Kinney was one of the few people keeping the inventor's memory alive. William Terbo, Tesla's 84-year-old grandnephew—who was one of the last people to see Tesla alive, when he visited him at the hotel as a 9-year-old—says that before Kinney was hired, Tesla proponents had been unable to convince management to publicly recognize that the inventor had spent the last 10 years of his life there. Kinney convinced the hotel to move a memorial plaque to the outside of the building in 2001; to officially recognize rooms 3327 and 3328, in which Tesla lived and worked; and to put a Tesla poster in the hall outside the rooms.

Kinney first heard about Tesla while growing up in Memphis, Tenn. As a teenage amateur radio enthusiast, he learned about the Tesla coil, a transformer circuit used to produce high-frequency, high-voltage AC. Now Tesla enthusiasts contact Kinney weekly, and he finds himself giving tours and dispensing information like a de facto publicist. Kinney once described to *The New Yorker* magazine the three types of visitors he received: "Electrical engineers and technology enthusiasts; people interested in UFOs, anti-gravity airships, death-ray weapons, time travel, and telepathic pigeons; [and] Serbs and Croats."

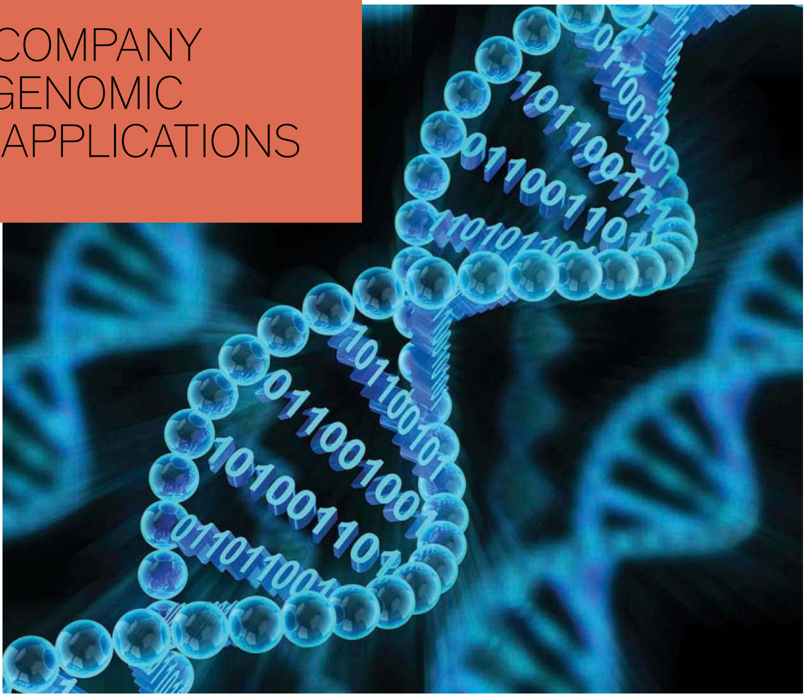
In Kinney's basement office, shelves are crammed with Tesla memorabilia, including a book signed by Božidar Đelić, who was vice president of Serbia from 2007 to 2011. Kinney's favorite hobby is photography, and his hard drive contains hundreds of Tesla-related shots, including archival portraits and a photo that Kinney took in 2006 of the presidents of Croatia and Serbia shaking hands in front of the Tesla plaque. "Yes, I've collected a lot of material, but I don't consider myself as a resource," he says modestly. "Others have studied the man in a much more substantial way. I'm just someone with the keys to Tesla's house and who has kept the front door open." (While Kinney may not consider himself a resource on Tesla, the producers of a Travel Channel program thought differently when they chose him to narrate Tesla's story in a "Hotel Secrets & Legends" segment.)

Tesla's two rooms—which still accommodate paying guests—are often requested by devotees from around the world. During a tour, Kinney knocked before using a passkey to open one door, and a quick peek in revealed an ordinary hotel room with two Tesla posters hanging on the walls. Kinney says Tesla used the rooms together and points to a spot in the hallway where a door once set off the rooms as a suite.

One request for a Tesla room came from actor Nicolas Cage, who stayed for a night in 2010 while preparing for his role as a wizard who throws balls of electricity in *The Sorcerer's Apprentice*. "Cage was trying to 'call up the spirits' and believed something hit the window, and he suggested it may have been a pigeon," says a bemused Kinney. —**BILL GLOVIN**

RESOURCES_START-UPS

SOLVEBIO
A BIOINFORMATICS COMPANY WANTS TO BRIDGE GENOMIC RESEARCH AND ITS APPLICATIONS



Cheap DNA-sequencing technologies have sparked rapid growth among biomedical companies looking to create new diagnostic tools and personalized therapeutic drugs, and even to give consumers insight into their own genomes. However, the raw data from an individual DNA sequence actually isn't very informative on its own; as is the case with a raw trace of GPS data, making sense of an individual DNA sequence usually means situating it in the context of a map. And that's what New York City–based SolveBio is doing: building a kind of Google Maps for genomics, by combining both public and private data sets into a standardized, quality-controlled collection. Computational biologists and bioinformaticists can then enhance their own software by programming it to tap into SolveBio's knowledge base using an online connection.

The motivation to build SolveBio was born out of cofounder and CEO Mark Kaganovich's frustrations with the typical lab's low-tech approach to bioinformatics. While at Stanford pursuing a Ph.D. in genomics, Kaganovich noticed that he spent most of his time cleaning and organizing external data sets, and he realized that other researchers and developers had the same problem.

Kaganovich hacked together some ideas for standardized and shared access to common data sets with his friend David Caplan. The duo brought on as cofounders Paul George and David Gross to build the infrastructure and develop the online application programming interfaces, or APIs, that programmers use to integrate SolveBio into their applications.

SolveBio's curated data library includes hundreds of data sets for genomics, proteomics, and the clinical and scientific literature used to annotate these collections. Imported data is normalized to allow results from different sources to be combined.

"In order for medicine to advance substantially, we will need more precise, molecular descriptions of disease. This means [information about] DNA, RNA, proteins, small molecules, and other things that is digital, precise, and specific," says Kaganovich.

Recently, SolveBio announced a seed round of US $2 million from venture-capital firms Andreessen Horowitz and SV Angel and individual investors including Charlie Cheever, Max Levchin, and Flatiron Health's Nat Turner and Zach Weinberg.

There are several companies working in the same broad area of genomics software as SolveBio, including Bina, DNANexus, Illumina, and Seven Bridges Genomics. SolveBio differentiates itself by focusing on building a public API-accessible reference rather than providing software tools to analyze private genome sequence data.

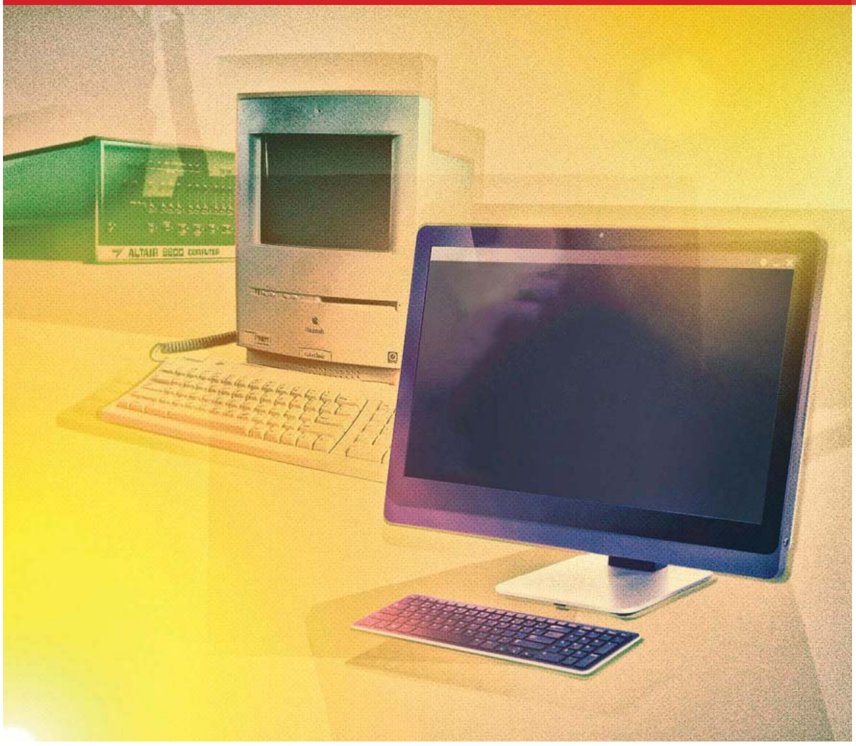
"There is a tremendous wealth of public data that can be integrated and mined towards new discoveries in biology and medicine. However, these data sources are disparate, and it often takes a tremendous amount of work to wrangle and maintain all of the large-scale data sources you need to do the kind of biomedical informatics investigations we need to advance medicine," says Joel Dudley, director of biomedical informatics and assistant professor of genetics and genomic sciences at the Icahn School of Medicine at Mount Sinai, in New York City.

"One challenge SolveBio will face is in integrating clinical data from electronic medical records and other sources. This type of data presents several challenges ranging from maintaining patient privacy to dealing with inherent biases in how clinical data is collected," says Dudley.

—**BOONSRI DICKINSON**

Company: Solvebio **Founded:** 2013
Headquarters: New York City
Founders: David Caplan, Paul George, David Gross, Mark Kaganovich,
Funding: US $2 million **Funders:** Andreessen Horowitz, SV Angel; Charlie Cheever, Max Levchin, and Nat Turner and Zach Weinberg (from Flatiron Health) **Employees:** 8
Website: http://www.solvebio.com

ISTOCKPHOTO



THE PC PLATEAU

Has Moore's Law become moot for PCs?

DESKTOP COMPUTERS ARE NO LONGER THE POLESTAR OF the computing firmament, as people have embraced smartphones and tablets by the million. These portable devices have the obvious advantage of being with you wherever you go, but they are also empowered with a multitude of sensors–such as barometers, GPS, and accelerometers–that make no sense in a stationary PC. • Still, when at home or the office, I feel more comfortable interfacing with a physical keyboard, a large display, a powerful processor, and lots of memory. So, bucking the trend, I recently invested in a new PC. My existing PC was four and a half years old and was a packaged system from a large electronics retailer. I assembled the new PC myself from premium components–CPU, motherboard, memory, power supply, case, and so forth. After I got the new PC going, I studied the old and new systems and thought about what the comparison told me about the future of the PC. • My first thought is one of admiration for the design engineers who make heroic efforts to keep up with Moore's Law. Between the construction times of the two systems, Moore's Law predicted there would be three doublings of performance, for a potential gain of a factor of eight. But as we know, raw machine speeds have not been increasing at that rate. In this instance, the older processor clocks at 2.93 gigahertz and the new one at 3.5 GHz. That leaves a lot of ground to be made up through architectural improvements. The new processor has four cores versus two cores in the older one. The new processor uses 22-nanometer lithography, compared with 32 nm in the older. Combined with a considerably larger die size, this means it has about 1.4 billion transistors versus a mere 393 million in the older processor. In addition to processor improvements, significant improvement in peripheral and storage access speeds has been afforded by new standards in USB 3 and SATA 3.

Depending on which benchmark programs I run, the actual observed factor of improvement in performance between the old and new systems varies from about two to six. However, this brings me to my second thought: Unless I'm running benchmark programs, I don't notice any difference in performance. Most everything I do is either so fast anyway that I don't notice a difference or is constrained by some other bottleneck, like Internet connectivity. Of course, if I were a heavy user of games, the difference might be evident, but it would depend mostly on the graphics card used.

When I examine the two systems visually, I'm struck by another thought. Inside the case, the older, packaged system looks cheap. The power supply is minimal, the connecting cables hang loose, and the motherboard looks flimsy and is populated with no-name components. Nonetheless, this system has worked perfectly for almost five years, and I bought it at a bargain. Perhaps there are certain virtues in cheap electronics in a throwaway era. Maybe I didn't really need all those premium components in the new system after all.

My final thought is one of nostalgia and regret. I think of my PC as a machine and those other computational devices as gadgets. Moreover, the PC is the last vestige of visible, accessible electronics in the home. Those other gadgets don't even have any insides–at least not any I can get at, as not so much as the head of a screw mars their contoured casings. But, alas, with diminishing incentives to replace older PCs and the increasing power and ubiquity of smartphones and tablets, it's hard to imagine a bright future for the machine that, starting with the Altair 8800 in 1975, so changed the world. ■

PHOTO-ILLUSTRATION BY Gluekit

YOUR PERSONAL VIRTUAL HEART

INDIVIDUALIZED COMPUTER MODELS WILL LET CARDIOLOGISTS TEST LIFE-SAVING INTERVENTIONS

By NATALIA A. TRAYANOVA

Illustration by JAMES ARCHER/ ANATOMYBLUE

A POET MIGHT SAY THAT EACH HUMAN BEING'S HEART IS A UNIQUE mystery. Those of us working in the brand new field of computational medicine, however, can now model each of those unique hearts with marvelous accuracy and reveal their secrets. In my laboratory at Johns Hopkins University, my team creates computer models to simulate individual patients' hearts, which can help cardiologists carry out life-saving treatments. Such models may soon transform medicine, ushering in a new kind of personalized health care with radically improved outcomes. ● Biomedical engineers have learned how to use numerical models to generate increasingly sophisticated "virtual organs" over the past decade, and rapid developments in cardiac simulation have made the virtual heart the most complete model of all. It's a complex replica, as it must mimic the heart's workings at the molecular scale, through the cellular scale, and up to the level of the whole organ, where muscle tissue expands and contracts with every heartbeat. What's more, the modeling at these different scales must be tightly integrated to accurately render the constant feedback interactions that govern the functions of the heart.

HANDS: GETTY IMAGES

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

Such models have already proved their value for basic cardiac research, allowing scientists to plug in experimental data and study what goes on in both normal and diseased hearts. Now, virtual hearts are poised to deliver breakthroughs at the bedside.

Starting with a patient's MRI scans, specialists in computational cardiology can create a personalized model of the patient's heart to study his or her unique ailment. Doctors can then poke and prod the computerized organ in ways that simply aren't possible with a flesh-and-blood heart. With these models at their disposal, cardiologists should be able to improve therapies, minimize the invasiveness of diagnostic procedures, and reduce health-care costs. While this simulation-based medicine is still in the experimental stages, I believe upcoming clinical trials will show the real value of virtual hearts.

TO GRASP THE VITAL IMPORtance of this technology, you have to understand today's standard of cardiac care. So imagine a patient–let's call him Jim–who has survived a serious heart attack. It was a terrifying experience. He fell down, clutching his chest, fearing he was about to expire. But he was rushed to the emergency room, where doctors took swift action to restore the flow of oxygen-rich blood to his heart muscle. Jim is alive–but not quite as alive as he used to be. Some of the heart muscle, which was deprived of oxygen during the crisis, has died. The resulting patches of scar tissue can interfere with the electrical signals that propagate through the heart muscle, thus disrupting the contractions that should pump blood through the body in a steady rhythm.

If Jim develops an irregular heartbeat, called an arrhythmia, he may be in serious danger of cardiac arrest. His doctors must assess whether he's at high risk of developing this life-threatening condition and decide whether to implant a defibrillator in his chest. Just like external defibrillators used in ambulances and emergency rooms, an implanted device shocks the heart back into normal rhythm if arrhythmia develops, thus saving the patient's life. To keep an at-risk patient like Jim from ending up in the ER, doctors may insert the internal device as a precautionary measure.

How can doctors judge whether or not to implant such a device in Jim? It's a big decision, because they don't want to needlessly put him through this invasive procedure and expose him to the possible complications that come with the defibrillator. Currently, cardiologists make their decision based on the patient's ejection fraction–the proportion of blood that is pumped out of the heart with every beat. If this number is below 35 percent, then doctors advise the patient to undergo the implantation procedure. Lots of patients are getting implants based on this strategy, but in the first year after the procedure only 5 percent will go on to develop ventricular arrhythmias and receive a necessary shock. In other words, 20 devices are implanted for every one life saved.

Doctors can poke and prod a virtual heart in ways that simply aren't possible with a patient's flesh-and-blood heart

It's clear that many patients are needlessly risking surgical complications, infections, and device breakdowns. The defibrillators aren't perfect, and the electrodes that monitor the heart can malfunction, triggering an unnecessary shock. And a shock is a serious event–it can feel like getting kicked in the chest by a horse. Patients sometimes lose consciousness, which could prove deadly if they're driving, for example, or soaking in the tub. Most important, the ejection fraction isn't a good predictor of arrhythmia; it misses many at-risk patients. Many patients who don't fit the current criteria for an implanted defibrillator go on to die of sudden cardiac arrest, often in the prime of their lives.

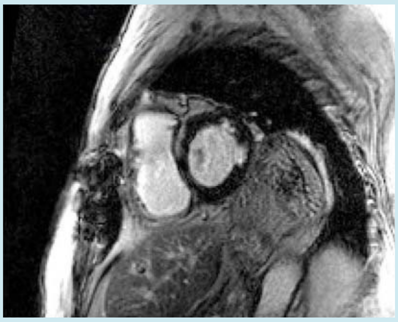
My colleagues and I are now testing whether we can use patient-specific heart models to make better predictions of a person's risk of developing a life-threatening arrhythmia, and hence his or her need for an implanted defibrillator. To do that, we run simulations on the patient's virtual heart to assess how prone it is to arrhythmia. We can do risky things to the virtual heart that physicians are reluctant to do to a live patient–such as generate small electric pulses in different locations and then watch to see whether arrhythmia develops.

Our first retrospective study at Johns Hopkins, in Baltimore, was promising. We created heart models for about 40 patients who had suffered heart attacks and received implanted defibrillators, and we predicted which of them would develop arrhythmias in the five years after surgery. Then we compared our forecast with the real data from that group of patients, revealing which of them had indeed received shocks from their devices to terminate arrhythmia episodes. With our virtual heart simulations, we correctly identified those at-risk patients 85 percent of the time over that five-year time span. In comparison, the accuracy of standard predictions for this group based on ejection fraction was only 51 percent over the same period of time.

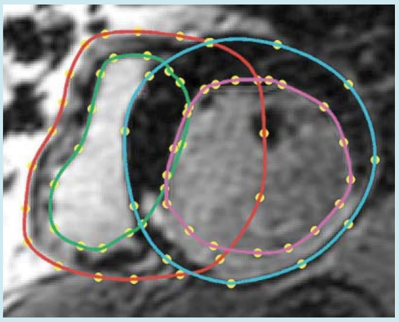
JOHNS HOPKINS UNIVERSITY (6)

Making the Mock-up

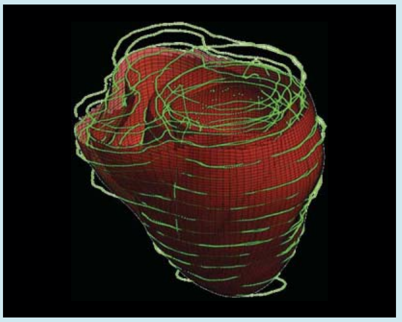
Here's how to create a personalized model of the heart of a patient who has suffered a heart attack. It's necessary to map the pattern of scar tissue and the orientation of muscle fibers, because these factors determine how electrical signals move through the cardiac tissue to produce a regular heartbeat.



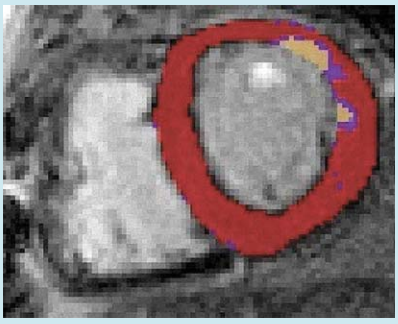
1 **TAKE MRI SCANS** of the patient's heart.



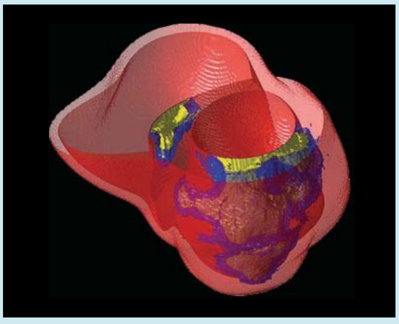
2 **USE IMAGE-PROCESSING TOOLS** to locate the walls of the heart's chambers.



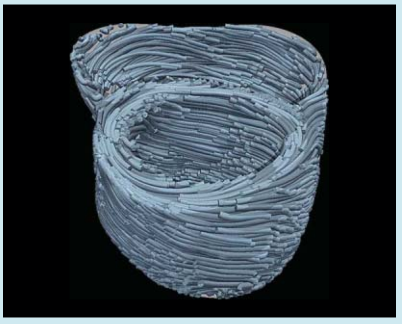
3 **WITH THAT DATA,** construct a 3-D model depicting that heart's unique anatomy.



4 **USE IMAGE-PROCESSING TOOLS** to identify the heart's scar tissue [tan] and the semifunctional adjacent tissue [purple].



5 **OVERLAY THAT UNIQUE PATTERN** of scar tissue on the 3-D model.



6 **USING ANOTHER IMAGE-ANALYSIS** program, determine the orientation of the heart's muscle fibers.

To validate our method and get this test to the clinic, our team is now creating individualized virtual hearts for post-heart-attack patients who have an ejection fraction greater than 35 percent (who therefore don't qualify for an implanted device). Clinical recommendations for these patients are sparse, but we can run our simulations and make our predictions. If we discern patients in that group who are at high risk for a lethal arrhythmia, we can recommend that they receive implants despite their relatively high ejection fractions. We're working toward a day when cardiologists routinely order these virtual tests as a noninvasive way of screening their patients and gauging their risk of sudden cardiac death.

SO HOW DO WE MAKE A VIRTUAL heart? To be clinically useful, our model must represent the individual's unique anatomy and the pattern of scar tissue from the heart attack. We start with the patient's magnetic resonance imaging (MRI) or computed tomography (CT) scans, which produce images representing slices of the heart. We use image-processing techniques to identify the muscle tissue in the walls of the heart's chambers and to map the damaged heart's scar tissue. Then we use that information to build a geometric model. For the final step we use the images to estimate the orientation of the muscle fibers, which determines how electrical signals propagate through the tissue.

Once we have this patient-specific geometric structure, we overlay a computational model of the inner workings of a generic heart. We need to represent activity at the cellular and molecular levels, where ionic exchanges across cardiac-cell membranes trigger contractions and where currents flow from cell to cell. The result is a personalized computer model that can be likened to Google Earth–think of it as "Google Heart"–which allows us to zoom in on a disease component and then zoom out to explore the phenomena at the organ level.

In another application of virtual-heart technology, we're looking at a treatment for arrhythmia that goes a step beyond the implanted defibrillator described above. Those devices can lower patients' risk of dying from sudden cardiac arrest, but they don't "cure" patients by preventing arrhythmias altogether. So for some patients with dangerous arrhythmias, such as people who receive frequent and painful shocks from their implanted defibrillators, doctors set out to find sources of the problems and fix them.

Let's imagine that our patient, Jim, is a candidate for this treatment. First, his doctors must study the electrical pulses that are creating his irregular heartbeat. These pulses sweep through Jim's cardiac muscle in patterns that look like spiraling electrical tornadoes. If the doctors can locate the spot where these disruptions originate, they can burn it away (ablate it, in medical speak) and restore a regular rhythm to Jim's heart.

Sounds sensible–but the task isn't easy. To find that critical spot, they bring Jim to an electrophysiology lab and sedate him. Specialists insert a catheter into his leg and slowly guide it through a vein until it enters the heart's chambers. Then they begin the painstaking process of "interrogating" the heart with the electrode on the catheter's tip. They slowly navigate the tool around the inner surface of the heart to measure the electric signals in the tissue, trying to piece together a map showing how the irregular electric signal moves through Jim's heart.

This painstaking procedure typically takes between 4 and 12 hours, and it carries numerous risks, including the possibility that the electrode will pierce the heart wall. The dangers are justified by Jim's medical condition, but unfortunately this intervention may not help him much. Maps constructed by this point-by-point interrogation method have poor resolution and are sometimes inaccurate. When the doctors use these maps to plan their ablation procedures, they simply don't have the best information.

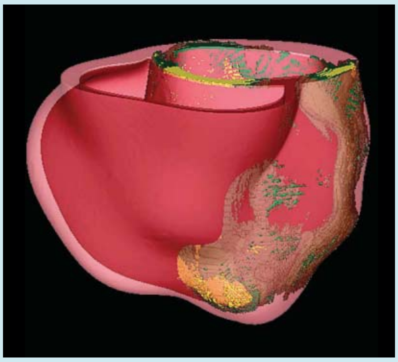
For arrhythmias originating in the heart's primary pumps–the ventricles–ablation isn't always successful. Doctors may scorch the wrong tissue, damaging parts of the heart that aren't responsible for the faulty electric pulse. In one clinical study of patients with an accelerated rhythm called ventricular tachycardia, researchers found that ablation stopped the arrhythmia in only 54 percent of patients, and 8 percent of patients experienced complications.

For people in Jim's situation, a virtual heart could offer a better way. Indeed, at Johns Hopkins my colleagues and I are now testing the first clinical application of our models in post-heart-attack patients who have developed ventricular tachycardia, which can be life threatening. We want to determine whether our models can help physicians make better decisions about which tissue to burn away–and let them make those decisions without long sessions of probing patients' hearts.

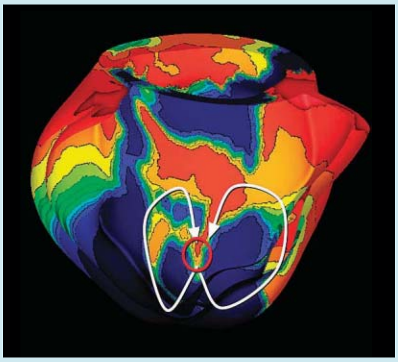
Using our system on Jim, we'd build a three-dimensional model of his heart, which would display its unique structural quirks and the specific patches

Pinpointing the Problem

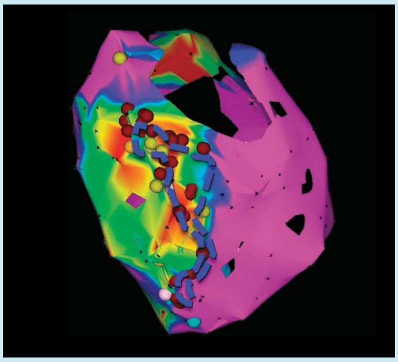
Some patients who've had heart attacks develop life-threatening arrhythmias, which doctors try to stop by burning away problematic tissue. A computer model can precisely identify the target.



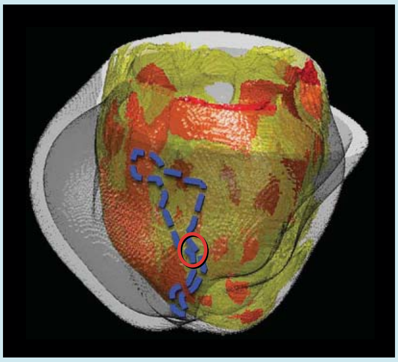
1 **THE PERSONALIZED 3-D MODEL** of a patient's heart shows its unique anatomy and pattern of scar tissue, which determine how electrical signals move through the heart.



2 **DOCTORS CAN SIMULATE** an electrical signal that produces an abnormal heartbeat and can thus cause cardiac arrest. By observing how it moves through the tissue, they can determine where the signal must originate.



3 **IN THE STANDARD TREATMENT,** doctors use a catheter to probe for tissue with abnormal electrical activity. They then burn away a large patch of that tissue [blue dotted line] in hopes of destroying the point of origin.



4 **HOWEVER,** the computer model reveals that just one small piece of tissue [red circle] is the key to the faulty signal. If doctors base their treatment on the model, they can burn less tissue and leave more of the heart intact.

JOHNS HOPKINS UNIVERSITY/HEART RHYTHM (4) of dead tissue causing electrical interference. We would then run programs on the model to analyze all possible arrhythmias that could develop in his heart and to locate the tissue responsible for the faulty electric pulses. We could seek ablation targets that provide the most efficient fix, stopping the arrhythmia with the fewest and smallest burns. Then the doctor could navigate the ablation tool to those precise locations in Jim's heart and destroy the minimum amount of tissue needed to do the job. We believe this would significantly shorten the ablation procedure, decrease complications, and increase the rate of success.

My team has already conducted a retrospective study, in which we used our virtual hearts to study patients who had undergone the traditional treatment. We identified small and precise target spots for ablation, which our simulations showed would eliminate the patients' arrhythmias. When we compared our targets with the regions that doctors had actually burned away, we found that our targets did indeed fall within those destroyed regions but were much smaller.

In upcoming clinical trials, we'll identify targets for patients who haven't yet undergone ablation treatment. The doctors will burn away just our small suggested targets and will then try to induce an arrhythmia with electrical stimulation. If they can't do it, that will be a clear victory for our method.

IMPLANTED DEFIBRILLATORS HAVE proved their ability to save the lives of patients with arrhythmias, leading cardiologists to authorize their use in an increasingly diverse range of patients. When doctors began implanting defibrillators in children and babies with congenital heart defects, however, they soon ran into difficulties. Here, too, virtual hearts may come in handy.

In a patient with normal heart size and anatomy, the defibrillator is implanted in a standard configuration: A battery sits beneath the collarbone, and a catheter snakes through a vein into the heart's right ventricle. But existing devices weren't designed for children's small bodies, and doctors frequently have to implant the bulky battery down in the child's abdomen. What's more, in children with malformed or diminutive hearts, the catheter often can't get through the tiny veins or reach the proper target inside the ventricle. Surgeons often have to place the electrodes outside the heart instead.

> There may come a time when all patients with heart conditions, from babies to octogenarians, have their virtual hearts tucked into their electronic medical records

Pediatric hearts with congenital defects are so variable and structurally complex that defibrillator implantation is a highly individualized art. Currently there's no reliable way to predict the ideal locations for the defibrillator components in a given child, and an imperfect setup can have serious repercussions. For example, poor positioning of the battery can cause the leads that twist through the child's body to bend and stress, creating fractures in the insulating material. Such cracks can make the defibrillator discharge unnecessarily or, worse, fail to deliver a shock when needed.

The exact location of the electrodes outside the heart is also a question of great importance. Doctors set the defibrillator's voltage based on how much cardiac tissue the current must flow through and the orientation of the muscle fibers in that tissue. High voltages can damage tissues and can also cause great pain, because the current stimulates nerve fibers. So doctors are motivated to find the locations that deliver an effective shock at the lowest voltage.

In a proof-of-concept study, we took the MRI scans from a pediatric patient with a congenital heart defect, in which the right ventricle was dramatically undersized. We created a 3-D model of the child's heart and the surrounding torso, and we experimented with different locations for the battery and the electrode tips. Our simulations eventually identified the configuration that should produce an arrhythmia-stopping shock at the minimum voltage. If doctors adopt such models, it may take the guesswork out of device positioning and spare young patients from repeat procedures to reposition their devices.

There may come a time when all patients with heart conditions, from babies to octogenarians, have their virtual hearts tucked into their electronic medical records, which doctors can then use to plan their treatments. I look forward to that day, for I have great hope that these simulated hearts will be able to prevent some real human hearts from breaking. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/virtualheart1114

HOW FORD INVENTED THE SQUI

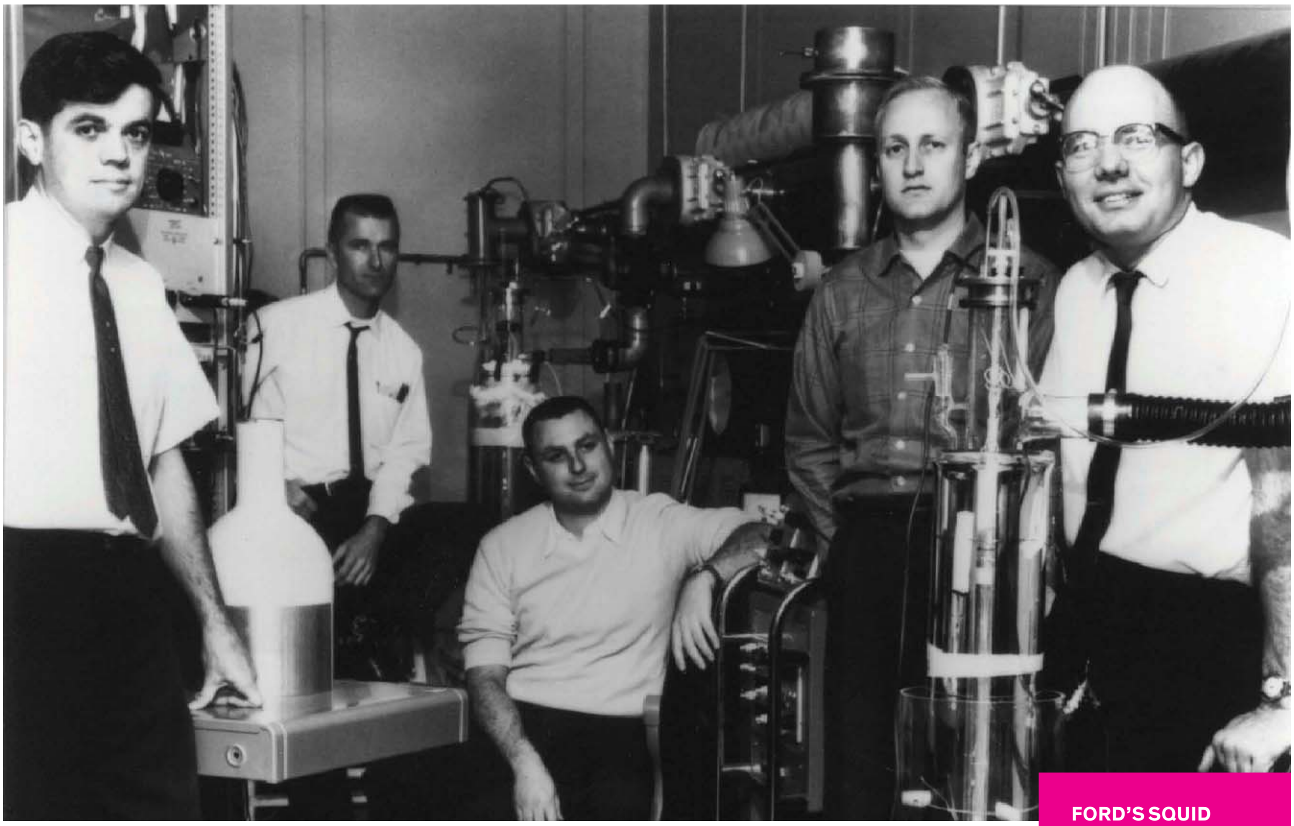
In the 1960s, researchers at the car company scored this key breakthrough in superconductivity

BY ANN JOHNSON

COOLED TO A FEW DEGREES ABOVE ABSOLUTE ZERO, a superconducting quantum interference device, or SQUID, can do something amazing: detect a magnetic field only a millionth as strong as the human brain's, or less than 5 quintillionths of a tesla. • Measuring such minute magnetic fields turns out to be useful for many things, including geophysical and archeological surveys, detection of the cosmic microwave background, nondestructive testing of materials and devices, and imaging the brain, heart, and other body parts. Invented some 50 years ago, the SQUID now comes in dozens of varieties, with different materials and circuitries, and operating temperatures both high (at the liquid-nitrogen range of around 77 kelvins) and low (less than 10 K, in the realm of liquid helium). • Exquisite though they are, SQUIDs seem to have been invented almost accidentally. During the 1950s and 1960s, industrial and academic labs pursued superconductors with nearly the same zeal they were devoting to semiconductors. Bell Telephone Laboratories, General Electric, IBM, RCA, and Westinghouse all had programs in superconductivity. • And yet, the SQUID did not come from any of these august groups. It was invented instead at the Ford Motor Co., whose scientific lab was then a relative upstart on the corporate research scene. Created in 1951 in Dearborn, Mich., the lab operated according to a philosophy that was established by AT&T's Bell Labs and IBM's Thomas J. Watson Research Center and that has now been essentially abandoned. These great institutions pursued research topics not because they were likely to contribute to the parent company's bottom line anytime soon but because the corporation believed that research for research's sake was something a real company did.

SUPERCONDUCTIVE QUANTUM INTERFERENCE DEVICE UTILIZING A SUPERCONDUCTIVE INDUCTIVE REACTIVE ELEMENT SHUNTED BY A SINGLE JUNCTION

Original Filed April 2, 1965 2 Sheets-Sheet 1



FORD'S SQUID TEAM: The researchers who invented the SQUID were [from left] John Lambe, James Zimmerman, Arnold Silver, Robert Jaklevic, and James Mercereau.

"We had the freedom to do what we were interested in," says Arnold Silver, who worked in the Ford lab in its heyday. "We could follow our noses—and particularly, we could follow the data." In 1963, Silver was a member of the talented team of scientists and engineers who noticed a curious phenomenon in a sample of supercooled phosphorous-doped silicon and then followed it to its logical conclusion.

Like the discovery of the cosmic microwave background at Bell Labs in 1964 and the exposition of fractal geometry at IBM in 1982, the invention of the SQUID at Ford offered no obvious benefit to the company's principal business. And yet all of these breakthroughs eventually revolutionized major categories of science and brought the company enormous prestige. The SQUID story, like those of the other breakthroughs, also speaks to the question of where, in a radically more restrained corporate research environment, these serendipitous and fundamental discoveries will come from. The question is all the more important when it concerns a device—like the SQUID—that takes decades to find widespread use.

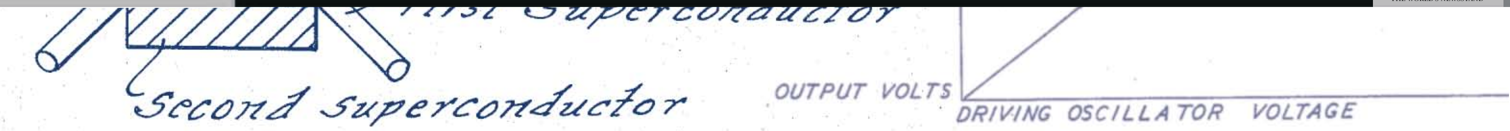
THE SEEDS FOR THE SQUID WERE PLANTED WELL before the work in Dearborn. Back in 1911, the Dutch physicist Heike Kamerlingh Onnes first observed superconductivity when he succeeded in cooling mercury to a few degrees above absolute zero. At this temperature, atomic vibrations in the material are reduced to the point where they no longer produce any resistance to the flow of electrons. So a current can be sustained in the supercooled material indefinitely and without needing a voltage to push it—that is, it becomes superconducting.

Research in superconductivity continued on the margins of physics until the 1950s. One high point came in 1957 when John Bardeen (a co-inventor of the transistor), Leon Cooper, and Robert Schrieffer published an atomic explanation of the phenomenon, which became known as the BCS theory. The three later shared the Nobel Prize in physics for their work.

Even as Bardeen, Cooper, and Schrieffer were refining their theoretical explanation, work elsewhere focused on making useful superconducting devices. Indeed, much like nanotechnology at the turn of this century, superconductivity in the 1950s and '60s was considered to be the next big thing. Superconductors, it was thought, would revolutionize computers and computation and transform the power grid by eliminating resistive losses in transmission and distribution. Even more fantastic were the proposed uses of superconductors in space colonization and levitating cars. In an influential 1968 article, "Economic Aspects of Superconductivity," physicists Roland W. Schmitt and W. Adair Morrison suggested that superconductors might succeed the bipolar transistor and eventually duplicate the market

PREVIOUS PAGES: DRAWINGS: U.S. PATENT AND TRADEMARK OFFICE; PHOTOS, CLOCKWISE FROM TOP: NIST; FORD; ARNOLD SILVER/FORD

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®



success of semiconductors. No surprise, then, that every sizable tech-oriented company in the world had a superconductivity group.

A giant step toward commercializing superconductivity came in 1962 when Brian Josephson, a graduate student at the University of Cambridge, theorized that a superconducting current, or supercurrent, could tunnel through an insulating barrier between two superconductors without any resistance, thereby completing a superconducting circuit. Once the supercurrent exceeded a certain critical current, however, an AC voltage would develop across the junction, with a frequency approaching 500 gigahertz. The following year, Philip W. Anderson and John M. Rowell at Bell Labs built the first such circuit, subsequently named the Josephson junction. A commercially viable Josephson junction then became the goal of many industry researchers. An electronic circuit fashioned from Josephson junctions would be capable of switching at very high speeds–particularly desirable for computer logic chips.

Ford's Dearborn lab wasn't caught up in the fervor surrounding superconductivity, but much like the more established corporate labs, it had a research program in cryogenics and nuclear magnetic resonance. Lab managers had been very successful at recruiting top scientific talent, who were well funded and relatively unfettered in their investigations. When later asked what magnetic resonance research had to do with cars, Terry Cole, a member of the Ford magnetics group, replied, "It really didn't matter." Indeed, none of the Ford researchers responsible for the SQUID–a group that included Robert Jaklevic, John Lambe, James Mercereau, Arnold Silver, and James Zimmerman–was drawn to the work because of its possible commercial applications.

Lambe made the first crucial observation, which came about like many a noteworthy discovery: by accident. In 1963, he was studying nuclear double resonance–the interaction between the nuclear and electron spins of an atom–in silicon-29. After placing the silicon sample in his magnetic resonance instrument, he cooled it to 4 K and then watched the signals on an oscilloscope. Normally, magnetic resonance is helpful in studying the physical and chemical properties of a material in the presence of a powerful magnet. A given material will emit a distinctive pattern of signals, or spectra. In this case, though, the sample began emitting signals immediately, while the magnet was still off.

Cole later gave this account in an oral history interview: "Suddenly, before they even turned the magnet on, they began to see what looked like magnetic resonance spectra coming out of their apparatus. They noticed that even with the power off, if they rotated the magnet, these lines seemed to move around, move back and forth in the spectral domain. They turned the magnet on. They were seeing not dozens of lines, which was not unusual, but thousands, tens of thousands of lines. A mystery! They had looked at the spectrum in a nearly identical sample just before. How could something change that much?"

Puzzled, Lambe consulted with some colleagues. The silicon sample had indium solder contacts, and so the team "decided it had something to do with superconductivity, because they began to appear temperature-wise at about the transition temperature of indium," Silver later recalled.

They then experimented with different thin-film samples. When the samples had no cracks or other flaws, no lines appeared. But when they were damaged even slightly, the effect returned. "Eventually we patterned the films...we cut little notches in them," Silver said. The oscilloscope readings from these intentionally notched films were even stronger than those from the original sample.

Mercereau, a Caltech Ph.D. who had worked on diffraction waves in liquid helium for his thesis, had a possible explanation for this puzzling phenomenon. He had just come back from a low-temperature physics conference, where he had met Brian Josephson. He suggested that they had in fact created a Josephson junction.

Realizing that their creation was sensitive to tiny magnetic fields, the researchers set about fashioning a Josephson-junction device that could actually measure the intensity of those fields–an interferometer, in other words.

To build the device, Jaklevic started by depositing a film of tin onto a glass microscope slide; he patterned the film by passing it through a stainless steel mask, which he had cut with a razor blade. Next he painted on a mask of Formvar (a type of plastic) and deposited a second tin film to cover the first film. The plastic mask was now the insulator between the two films, and the junction was created through an opening in the plastic between the bottom film, which oxidized in air, and the top film. The device was placed in liquid helium, a coil was inserted to apply magnetic fields to the device, and the resulting signals were viewed on an oscilloscope. The result was the world's first functioning SQUID, as described by the team in an article in *Physical Review Letters* in early 1964. This type of SQUID would subsequently be referred to as a DC SQUID

BACK TO BASICS: An aerial shot of the Ford Motor Co.'s Scientific Research Laboratory in Dearborn, Mich., in 1967, where the SQUID had been invented four years earlier.

OPPOSITE PAGE: ARNOLD SILVER/FORD. THIS PAGE: FORD

HEART OF THE MATTER: Even after leaving Ford, Zimmerman [third from left] continued to champion the SQUID. With biomagnetism expert David Cohen [second from left], he recorded the first low-noise magnetocardiogram in December 1969, using Cohen's shielded room at MIT. Also shown are the Naval Research Lab's Edgar Edelsack and a woman identified only as "Laurie."

DAVID COHEN

because its current stays constant. Interestingly, the Ford researchers were hesitant about using the term "SQUID" in official publications, even though, according to Silver, it soon came into common use around the lab; he credits Zimmerman with coining the term.

Thin-film junctions proved very time consuming and difficult to reproduce. "Months would go by when we could not make junctions," Silver later wrote. So Zimmerman focused instead on making the circuits from niobium wire, which he happened to have on hand. Niobium thereafter became the superconducting element of choice in subsequent SQUIDs at Ford and elsewhere.

Zimmerman, working with Silver, continued to simplify the devices, which were still hard to reproduce, in no small part because niobium is an especially tricky metal to machine. Finally in 1965 the pair succeeded in making a SQUID consisting of a superconducting ring with just a single Josephson junction interrupting it. Silver used a 27-megahertz radio-frequency detection system from his magnetic resonance lab to measure the SQUID's signals. When an external oscillating flux was applied to the ring, this low-noise detector captured the change in the internal flux. The researchers dubbed this device an RF SQUID. It was cheaper and easier to produce and became the basis for commercializing the SQUID.

However, as mentioned earlier, the SQUID had nothing to do with cars, and the Ford team made no serious attempts to profit from it. Zimmerman would later recount how team members watched the oscilloscope signal change as steel chairs were moved around the apparatus, minutely altering the surrounding magnetic fields. The lab's SQUID was "an extremely sensitive detector of lab chairs," he quipped. The fruits of their intellectual labors were 25 academic papers and nine U.S. patents related to SQUIDs and superconductivity. Even before the team broke up in 1967 or 1968, some members had already moved on to other topics.

What finally put a stop to Ford's SQUID work, though, was an internal dispute over who had actually developed the device. Mercereau had spent much of 1965 and 1966 touting the team's work at science conferences—so much so that Phil Anderson at Bell Labs began referring to superconducting quantum interference as the "Mercereau effect." But within the Ford team, he was not considered the sole or even the main contributor to the SQUID's invention. To ease tensions, Jacob E. "Jack" Goldman, director of the Ford labs, transferred Mercereau to Aeroneutronic, a lab in Newport Beach, Calif., that had been purchased by Ford.

THE STORY OF THE SQUID THEN TAKES A NEW direction, with Zimmerman emerging as the protagonist. Within a year of Mercereau's move in 1967, Zimmerman also joined Aeroneutronic, though not to work with his former colleague. In his new position, Zimmerman led the lab's cryogenics division and worked on advancing the RF SQUID toward a marketable product.

He was temperamentally suited to the task. His varied background included a stint in Australia during and shortly after World War II, working on radar and on photometry. Later, after earning his Ph.D. from the Carnegie Institute of Technology (now Carnegie Mellon University) in 1951, he took a position with the Smithsonian Institution at the Table Mountain Observatory in California. There, he worked on measuring the electromagnetic radiation emitted by the sun, otherwise known as the solar constant, and he continued that research at the Montezuma Observatory in Chile's Atacama Desert. The flexibility of mind that allowed Zimmerman to shift easily from radar to cryogenics to astronomy and back to cryogenics would serve him well in his quest to commercialize the SQUID.

In 1969, while still working for Aeroneutronic, Zimmerman cofounded—with physicist John Wheatley and several others—a company in San Diego called Superconducting Helium Electronics. SHE's main focus was on manufacturing RF SQUIDs and the helium-refrigeration units needed to operate the devices. Initially, the company sold niobium devices like the ones that Zimmerman had designed in Dearborn. Eventually, that design evolved into a niobium-aluminum oxide-niobium device, which was much easier to make, although it had an inferior signal-to-noise ratio. SHE's devices were the world's first commercially successful SQUIDs.

| CONTINUED ON PAGE 49

LET THEM SEE YOU Swea

Your sweat may bring medical diagnostics to Fitbits and Fuelbands • *By* JASON HEIKENFELD

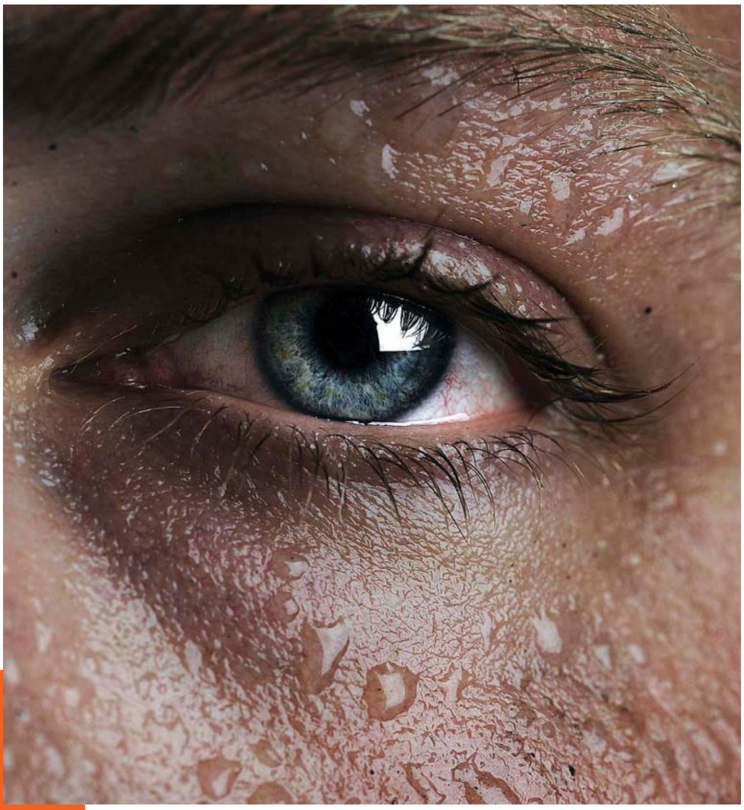
Sweat, ick. It betrays our nervousness, leaves unsightly blotches on our clothes, drips down our faces, and makes us stink. Sure, it cools us when we overheat, but most of the time we think of it purely as an inconvenience.

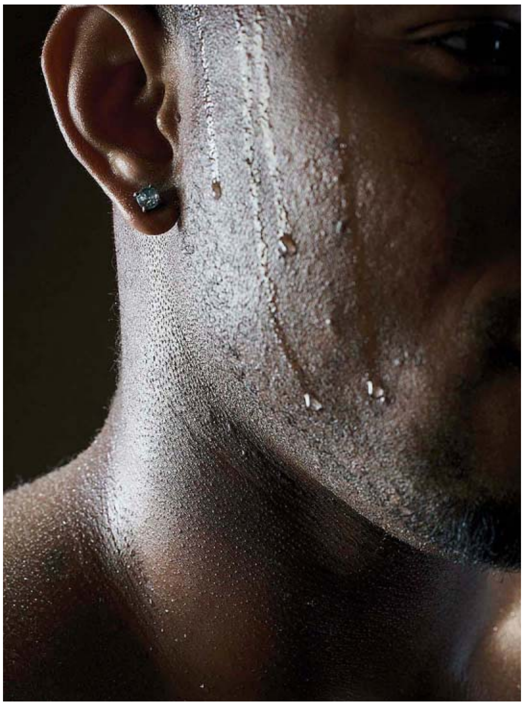
We may soon, however, learn to like our sweat a lot more—or at least what it can reveal about our health. We'd certainly prefer giving a doctor a little sweat to being punctured for a blood test—or even providing a urine sample—as long as we didn't have to run a mile or sit in a sauna to do it. And if sweat could provide constant updates about our bodies' reactions to a medication, or track head trauma in athletes, we might just start to appreciate it.

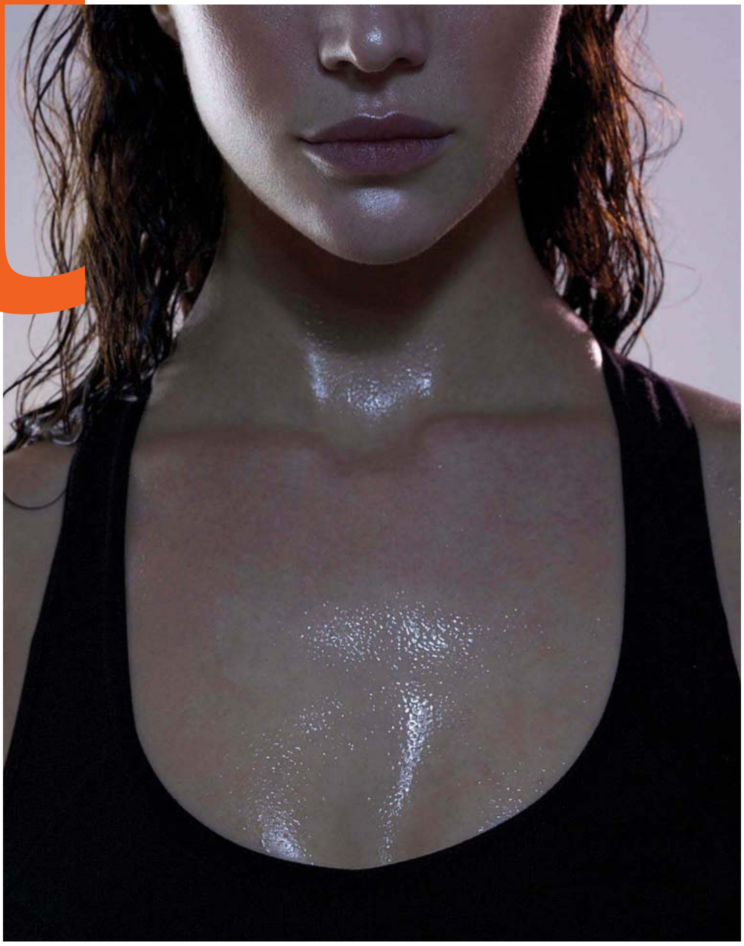
Sweat contains a trove of medical information and can provide it in almost real time. And now you can monitor your sweat with a wearable gadget that stimulates and collects it using a small patch and analyzes it using a smartphone—that is, if you visit my lab.

Using sweat to diagnose disease is not new. For decades, doctors have screened for cystic fibrosis in newborns by testing their sweat. And in the 1970s several studies tried using sweat to monitor drug levels inside the body. But in the early days of sweat diagnostics, the process of collecting it, transporting it, and measuring it was vastly more complicated than an ordinary blood test, so the technology didn't catch on.

That's about to change. Researchers have discovered that perspiration may carry far more information and may be easier to stimulate, gather, and analyze than previously thought.

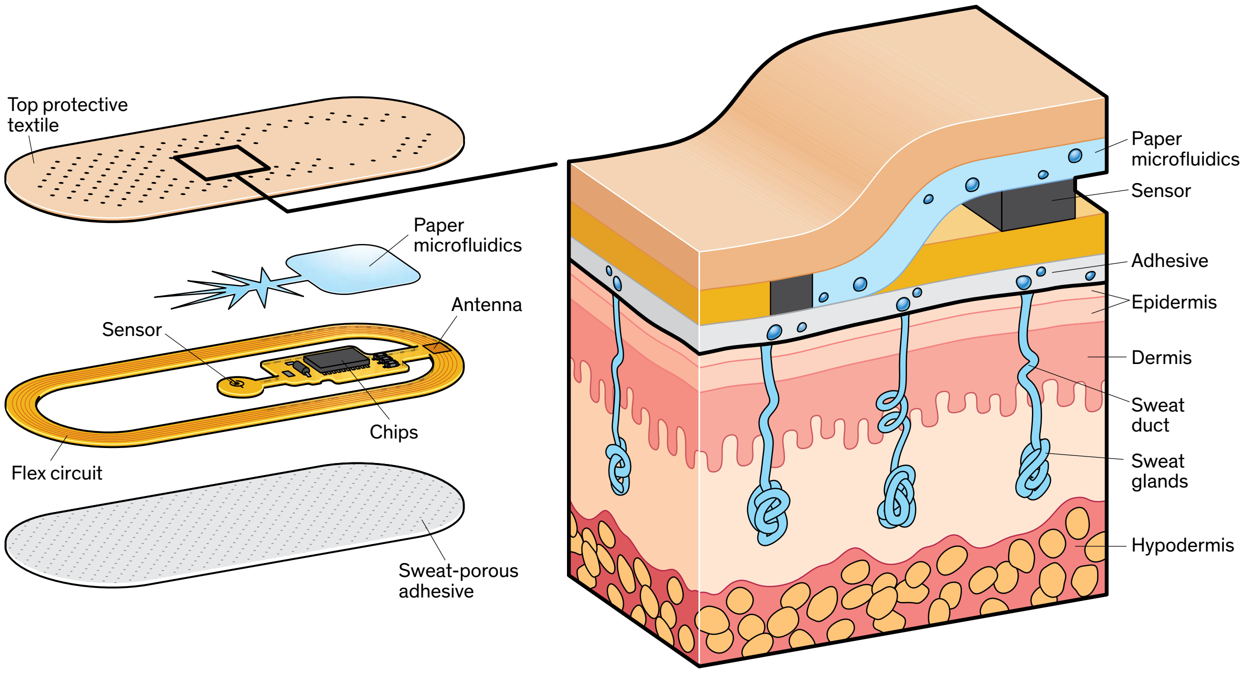






GETTY IMAGES (5)

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®



PERSPIRATION DETECTIVE: This patch, developed at the University of Cincinnati, uses paper microfluidics to wick sweat from the skin through a membrane that selects for a specific ion, such as sodium. Onboard circuitry calculates the ion concentration and sends the data to a smartphone. The electronics within the patch are externally powered, as in an RFID chip.

My group at the University of Cincinnati, working with Joshua Hagen and other scientists at the U.S. Air Force Research Laboratory, at Wright-Patterson Air Force Base, in Ohio, began five years ago to look for a convenient way to monitor an airman's response to disease, medication, diet, injury, stress, and other physical changes during both training and missions. In that quest, we developed patches that stimulate and measure sweat and then wirelessly relay data derived from it to a smartphone. In 2013 the Air Force expanded on my group's work and that of our collaborators by sponsoring the Nano-Bio-Manufacturing Consortium, in San Jose, Calif., created to accelerate the commercialization of biomonitoring devices such as sweat sensors.

My colleagues and I started by looking for something sweat could reveal that would be useful to a large number of people. We settled on monitoring physical fatigue—in particular, alerting athletes if they were about to "crash" because of overexertion or dehydration. This problem may sound mundane, but it is hard to predict. Even million-dollar athletes regularly leave competitions because of cramping, and warning of an approaching imbalance in electrolytes could prompt an athlete to take in fluids to avoid such a mishap.

With the testing of athletes in mind, we started by measuring the substances dissolved in sweat. You probably know, thanks to decades of commercials for Gatorade, that sweat is rich with electrolytes, electrically charged ions of elements like sodium, chlorine, and potassium, with concentrations from ones to tens of millimoles per liter. (In biological terms, that is actually a lot: Normally, blood has a 3.5 to 5.2 millimolar concentration of potassium. That is, it contains 3.5 to 5.2 millimoles of potassium per liter.) Ideally, we wanted to figure out the balance of electrolytes in sweat and how it correlates to the balance of electrolytes in the blood, because it is an imbalance of electrolytes in the blood that causes severe symptoms of dehydration like muscle cramping.

Measuring the saltiness of sweat doesn't turn out to be particularly useful for monitoring athletes, because levels of sodium and chloride in sweat don't correlate with any particular changes in blood levels. That's because the cell membranes lining the sweat gland act as "salt pumps." When messages from the central nervous system trigger the membranes to push negatively charged chloride ions out, they drag positively charged sodium ions with them, maintaining a neutral charge in the sweat duct. The insides of the cells become less salty than their exteriors. This imbalance draws water through the cell membranes into the sweat duct, until the sodium and chloride concentrations again match; as a result, the cells shrink until they can replenish themselves by pulling in water and salt from adjacent cells. The process repeats to create more and more sweat.

On the other hand, measuring levels of sodium and chloride in sweat is essential in diagnosing cystic fibrosis. The cells lining the upper portion of the sweat ducts normally reabsorb most of the salt that is produced by the sweat creation. (The body is smart; we need to retain those electrolytes.) But for patients with cystic fibrosis, the cells that handle that reabsorption don't work properly, and simple benchtop equipment in a doctor's office can detect the presence of saltier-than-normal sweat.

ILLUSTRATION BY James Provost

With sodium and chloride off the table, we looked at a number of other substances in the blood whose levels increase when the body gets dehydrated and that diffuse into sweat in a more orderly way, meaning that when they appear in high concentration in sweat, they must be at a high concentration in the blood. Like sodium and chloride, these are small ionic solutes in sweat–ones that I can't specify here, unfortunately, because of confidentiality agreements.

Although we couldn't use them directly to gauge dehydration, we weren't quite done with sodium and chloride. We found that the faster the sweating, the saltier the sweat (because there is less time for the body to reabsorb the sodium and chloride). Correlating the levels of electrolytes in sweat with their levels in blood isn't exactly straightforward. That's because their diffusion from blood into sweat is slow. So as the rate of sweating increased, the telltale substances we were tracking in the sweat became more diluted. By monitoring sodium and chloride levels, too, we could correct our sweat measurements accordingly.

Detecting sodium and chloride ions requires two things: an electrode coated with an ion-selective membrane, and a reference electrode, typically made of silver chloride. The coating for the ion-selective membrane is a standard polymer–like the plastic used to make plumbing pipes–through which ions have great difficulty penetrating, along with a special ionophore molecule that allows the passage of only one type of ion. If the ionophore is for sodium, sodium is able to easily penetrate into the polymer coating, and because sodium is a positively charged ion, a voltage of several millivolts builds up. Because the voltage of the reference electrode does not change, you can measure the total voltage of a circuit by connecting the two electrodes with a meter, calculating the voltage induced by the ion-selective membrane, and from that calculating the ion concentration. As sodium and chloride generation by sweat are interrelated, you also obtain a simple measurement of chloride.

That's how we can find out how much salt is in sweat. Trickier is capturing the sweat quickly, getting it to the sensors, and then disposing of it, because you don't want to hang on to old sweat and mix it with new. We decided to use paper microfluidics, the lowest-cost form of plumbing we could find that would move fluid along the patch. Pregnancy-test sticks use paper microfluidics in this way.

In our patch, the paper wicks sweat in a tree-root pattern, maximizing the collection area while minimizing the volume of paper. To keep the sweat pumping along after it passes through the sensors, these microfluidic channels direct the sweat to a superabsorbent hydrogel, such as the filler used in diapers, which pulls the sweat out of the paper and stores it. The patch can pull sweat along for several hours with the hydrogel swelling only 2 to 3 millimeters, enlarging it to hundreds of times its original volume.

We built a sodium sensor, the voltage meter, a communications antenna, the microfluidics, and a controller chip onto a patch that's externally powered (like an RFID chip) by a smartphone. We printed it onto a flexible substrate and, with the help of researchers at the 3M Co., coated it with a sweat-porous adhesive so that it could stick to the skin. In tests, this patch performed as well as the benchtop electrolyte-sensing systems used by doctors to test for cystic fibrosis. We have had a couple of people in our research group wearing the patches for as long as a week.

Right now our industry partners are preparing to use standard flexible-electronic manufacturing processes to produce several hundred patches for more extensive human trials, which are expected to start before the end of the year. We're also adding about a half dozen other sensors that will detect additional ions besides sodium and chloride and use them to predict things like exertion level and muscle injury or damage. The initial results look promising, and if the upcoming human trials go well, it's not a far stretch to imagine using the patch in conjunction with the RFID-reading mats that already record marathoners' split times to also identify runners at risk of a dangerous electrolyte imbalance.

This kind of passive patch should work great for athletes, who are usually pumping out plenty of sweat. But my colleagues and I also wanted to measure sedentary people–for example cystic fibrosis patients, who normally don't sweat much.

The solution is to use an electrical process, called iontophoresis, which stimulates skin to produce sweat. Iontophoresis works by placing an electrically charged medication on the skin and using an electrode and a low current–less than 1 milliampere per square centimeter–to draw the medication into the skin.

Doctors have used iontophoresis for years to push anti-inflammatory drugs through the skin to reach injured tissue. And they have used it in a cystic fibrosis test for newborns to infuse pilocarpine, a medication that stimulates sweat glands, into the skin.

We've built the components needed to add this same capability to our patch. By carefully controlling the current that drives the iontophoresis, and therefore the absorption of pilocarpine, we can keep sweat flowing on as big or as small a spot as we want for hours, and possibly even days, at a time.

Electrolytes are by far the easiest component of sweat to measure. But metabolites–like lactate, creatinine, and glucose–shouldn't be too much harder.

The lactate level is a great indicator of a person's ability to cope during rigorous exercise or while on life support. Lactate, or lactic acid, is a by-product of burning glucose

WHAT'S IN Sweat?

Biomarkers contained in sweat can give indications about the physical state of the body. They include electrolytes, metabolites, proteins, and amino acids. Here's a sampling:

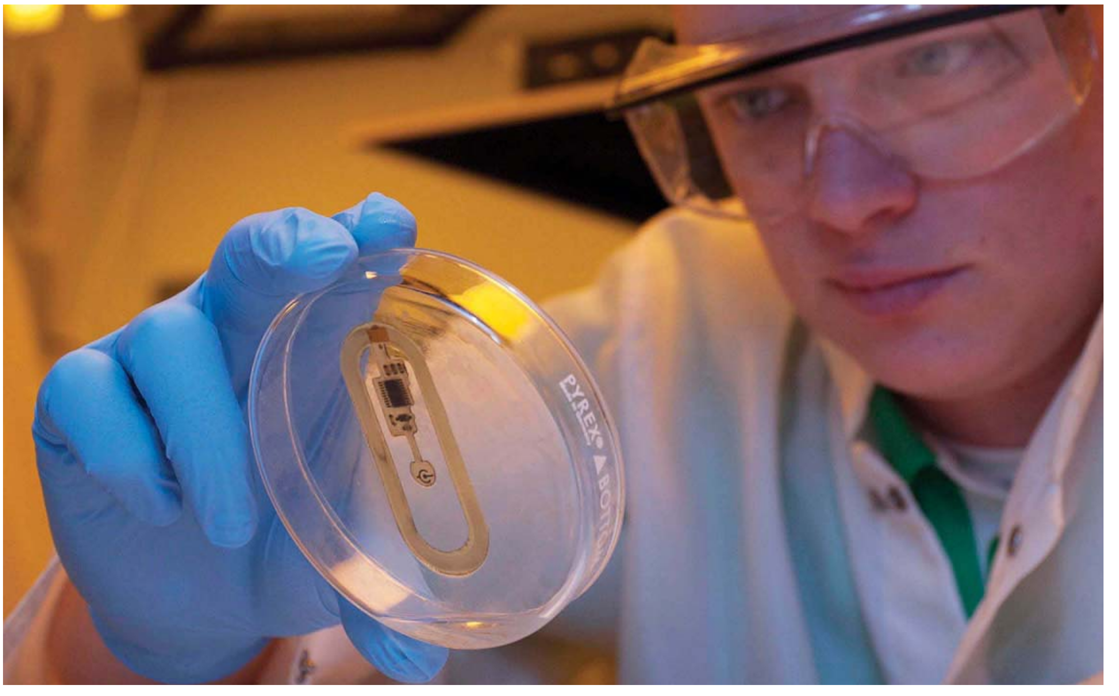
Electrolytes
- Sodium
- Chloride
- Potassium
- Calcium

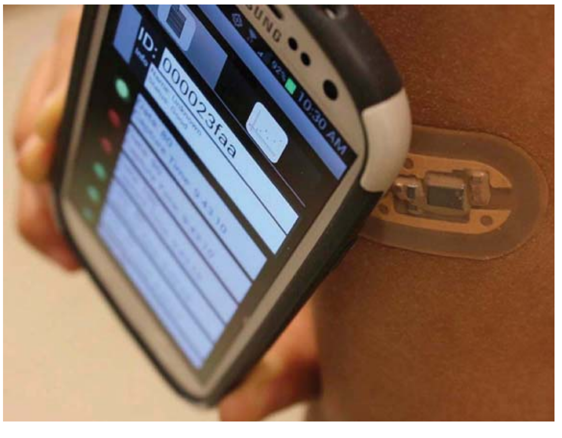
Metabolites
- Lactate
- Creatinine
- Glucose
- Uric acid

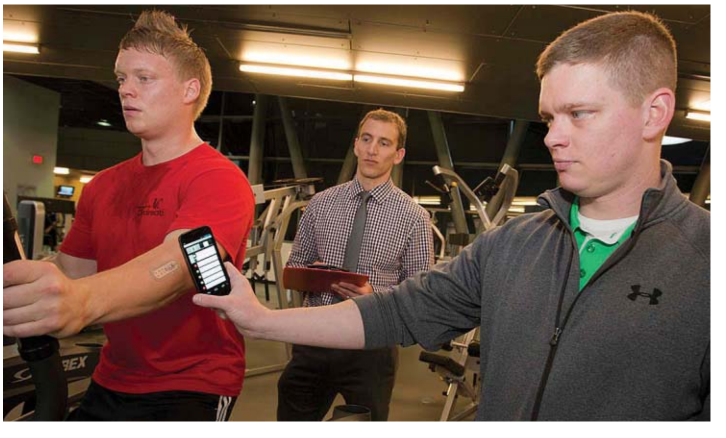
Small Molecules
- Amino acids
- DHEA
- Cortisol

Proteins
- Interleukins
- Tumor necrosis factor
- Neuropeptides

SWEAT SEEKERS: University of Cincinnati Ph.D. student Daniel Rose holds a petri dish containing the raw electronics [top] of the sweat-sensing patch he helped create, then tests the patch on his brother, Roger Rose, during a workout [bottom right]. A smartphone app displays data sent from the patch [bottom left].







DOTTIE STOVER/UNIVERSITY OF CINCINNATI (3)

without oxygen. Therefore, when the body is not getting enough oxygen, it generates more lactate. Higher concentrations of creatinine and urea indicate an unhealthy kidney struggling to clear waste products from the body. In people with chronic kidney disease, so much urea is excreted with sweat that the accumulation of uric acid crystals makes the skin look frosted. And glucose monitoring, of course, is key to managing diabetes.

As yet, we have not found a way to predict exact blood levels by measuring these metabolites in sweat. So using sweat to monitor glucose levels, as desirable as that would be, is still out of reach. But being able to sense a general increase or decrease in metabolites, even without knowing their exact concentrations, can still be valuable, as Joseph Wang and his colleagues at the University of California, San Diego, recently demonstrated.

Wang's team built a tattoolike electronic sweat sensor and had test subjects wear it during a vigorous cycling routine. Measuring a change in lactate, Wang found, might be sufficient to warn that an athlete was going to "hit the wall." Joshua Windmiller, a former student of Wang's, has started a company, Electrozyme, to commercialize the technology.

Metabolites like lactate in sweat are in the micromolar to millimolar range, still a relatively high biological concentration and easily measurable with a simple circuit. You again coat an electrode, but here the coating includes an enzyme specific to a particular metabolite, such as glucose oxidase or lactate oxidase. (Enzymes lower the amount of energy needed to cause a reaction.) Lactate oxidase, for example, breaks lactate into pyruvate and peroxide. The energized electrode steals two electrons from each molecule as it breaks the peroxide into oxygen and two hydrogen protons. Because lactate oxidase affects only lactate, only more lactate can generate more electrons, so any change in lactate concentration shows up as a change in current through a sensing circuit.

More work in developing this type of sensor is needed, though, because when sweat glands work really hard, they also generate their own lactate, which can skew the data. The measurement of some other metabolites with this technique, however, isn't subject to this problem. For example, the sensors that measure current also work well for other molecules that react in the presence of an enzyme, including urea, which in addition to signaling kidney health shows a substantial increase in both blood and sweat when dehydration reaches a dangerous point.

Compared with ions and metabolites, many of the biomarkers that doctors rely on for diagnosis of stress, disease, poor nutrition, injury, and other conditions are far harder to detect because they are found in blood and sweat in mere nanomolar to picomolar concentrations (a mere billionth or trillionth by weight). But detecting their presence in sweat is nevertheless possible.

Lately, some of the hardest-to-measure biomarkers–small-protein cytokines–are generating the most excitement. Cells release cytokines under a number of circumstances, including trauma, infection, and cancer. For example, the concentration of a cytokine called interleukin 6 (IL-6) can increase up to a thousandfold during an infection.

Esther Sternberg and her colleagues at the University of Arizona recently demonstrated that several cytokines, including IL-6, have the same concentration in sweat as they do in blood. This means doctors could use sweat to diagnose a wide variety of physical and mental stresses. Right now, though, the tools needed to measure the nanomolar to picomolar concentrations of cytokines in sweat are as big as a refrigerator, or at best a suitcase. The trick here is getting the technology down to the size of a wearable gadget. My colleagues and I think that's possible and are working toward that goal.

The basic problem is this: These biomarkers are present at such low concentrations that they can't generate enough voltage or current themselves to overcome noise. A better strategy would be to coat an electrode with a biorecognition element–basically a biochemical puzzle piece custom designed to selectively match up to, grab, and hold the biomarker we are trying to sense. We would then apply an alternating electrical signal to the electrode. As biomarkers gather on the electrode, they should act as a barrier to electrical current, increasing the electrical impedance in a measurable way.

A more exotic and sensitive approach would be to add a molecule called a redox couple to the top of the biorecognition element. A redox couple inserted in an electrochemical process makes it easier for electrons to move from a solution to an electrode. When the biomarker binds to the biorecognition element, it changes the shape of the element, bringing the redox couple closer to the electrode, close enough to allow it to dramatically increase the flow of current. With support from the National Science Foundation and a biochemist in my lab, we recently demonstrated sensing cytokines down to a level of less than a 1-picomolar concentration using this technique.

The Air Force is interested in the possibility of measuring cytokine biomarkers to monitor extreme stresses on pilots. And it is even more interested in neuropeptide biomarkers that can give clues to the state of the brain, like one called Orexin-A, a neuropeptide biomarker that measures alertness.

In an attempt to push the limits of detection of biomarkers even further, investigators at the Air Force Research Laboratory led by Rajesh Naik are coating nanowires, nanotubes, and graphene electrodes as part of a field-effect transistor with biorecognition elements. These researchers have already built sensors capable of measuring biomarkers present at only a 1/100-picomolar concentration in simulated sweat. The issue here, for now, is that nanowires and graphene are still a bit exotic and not yet easily manufacturable.

Ultimately, sweat-sensing patches will measure multiple electrolytes, metabolites, and other biomarkers at the same time. Their designers will no doubt have to devise some clever algorithms to account for differences in the way various electrolytes, metabolites, and biomarkers migrate into sweat. But it will be worth the effort. Being able to measure multiple biomarkers might allow physicians to conduct cardiac stress tests on a treadmill without drawing blood. They could also measure the impact of drugs on the body so that dosages could be determined more precisely, as opposed to the crude estimates we use now based merely on age and body weight.

There is still work to do on the digital signal processing and algorithms needed to analyze the raw electrical measurements of biomarkers in sweat. But a physical-exertion sensor patch is a near reality, about to be tried on hundreds of people. If all goes well, we could have sweat-sensing patches–at least sensors for athletics–on the market in low volume next year. These do not have to go through a lengthy approval process with the U.S. Food and Drug Administration because they are not meant to be used for diagnosis or treatment of disease.

The second-generation patch we're now working on in the lab is nearly complete. It includes secure Bluetooth communication, data storage, and a small microcontroller to detect higher-frequency and more complex signals from the electronic sensors on the patch. Analysis of these more sophisticated waveforms is critical for the detection of the really low-concentration biomarkers, like cytokines. Ultimately, sweat analysis will offer minute-by-minute insight into what is happening in the body, with on-demand sampling in a manner that is convenient and unobtrusive.

Researchers have understood the richness of the information carried in sweat for some 50 years, but they have been unable to take advantage of it because of the difficulty of collecting, transporting, and analyzing the samples. With the many recent advances in sensing, computing, and wearable technology providing inspiration–and with more than a little perspiration in the laboratory–we are on the verge of a true revolution in wearable diagnostics. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/sweat1114

THE TRANSPARENT COCKPIT

BY SUSUMU TACHI, MASAHIKO INAMI & YUJI UEMA

A SEE-THROUGH CAR BODY fills in a driver's blind spots, in this case by revealing ever more of a bicycle as a car overtakes it [shown left to right, top and bottom]. A projector directs processed images at the correct viewing angle by reflecting them off a special material on the inside of the car.

Augmented reality will banish drivers' blind spots and give them a bird's-eye view

You're traveling down the highway with the road flashing by beneath your feet and the scenery looming everywhere—fore and aft, left and right, above and below. Gone are the usual blind spots created by your vehicle's doors, window frames, roof, and floor. You're as free as a bird and just as aware of your surroundings.

We call this form of augmented reality a transparent cockpit because it would make the driver of a car feel like he's piloting an airplane—another place where this technology might be used. We have implemented it in test cars using cameras, imaging software, projector displays, and reflective surfaces. Thus equipped, human beings could drive very safely while still enjoying the open road—more open, indeed, than ever before.

A CAR MADE OF GLASS would be an attractive prospect if glass weren't structurally inferior to steel. As things stand, metal posts and doors block the driver's view. To allow the driver to see beyond these blind spots, we train cameras on the car's surroundings, process the imagery to match the viewpoint of the driver, and then display it on the vehicle's interior, causing the doors, backseats, and floor either to disappear or fade to a ghostly aspect.

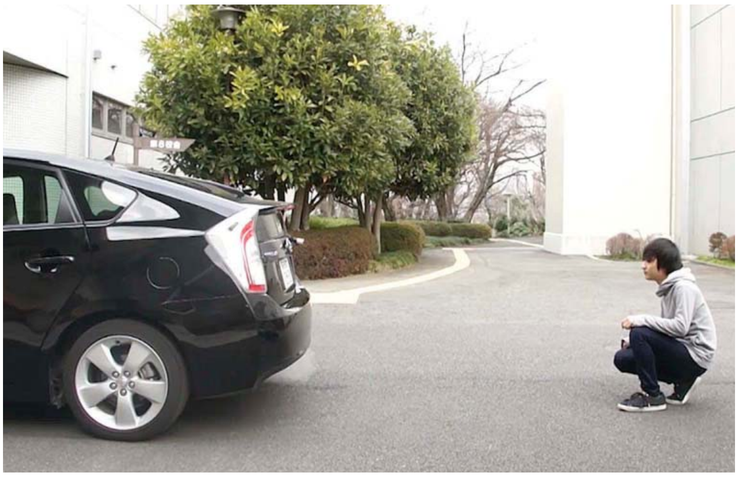
You could use one of two types of display systems to achieve this effect: one that gives off its own light or one that reflects light from a projector. A self-illuminated display can be made of backlit LCDs, LEDs, or organic LEDs and installed right on the seats, the doors, and other interior components. But it would be hard to customize such displays to fit the varied shapes. And seats, which are usually covered with fabric, couldn't really accommodate such a display. Instead we chose a projector system in which the car's interior is made of a material that can either serve as a screen or allow such a screen to be placed over it.

Any conventional projection system would fail for obvious reasons. The projected image wouldn't be bright enough to match the scenery outdoors, at least in the daytime. Images projected on a complex shape would be distorted and would have to be corrected accordingly. A special stereoscopic visor would be needed to view outdoor scenery in three dimensions, and only the driver could enjoy the display in its proper perspective.

ALL PHOTOS: TACHI LABORATORY/INAMI LABORATORY

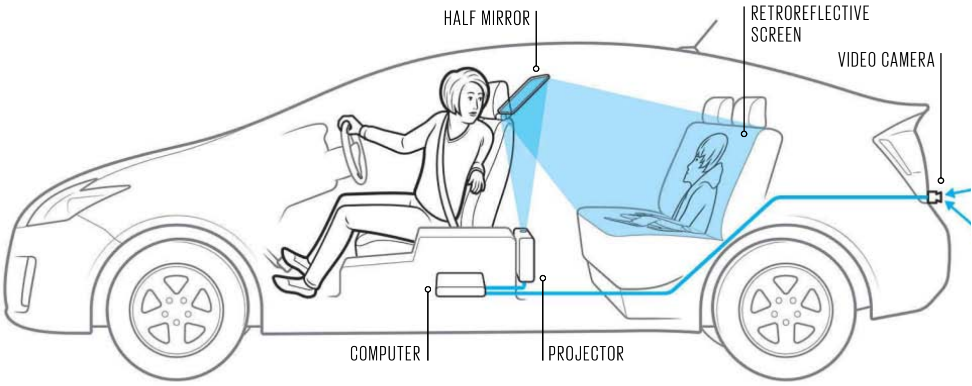
We have solved all these problems with a new projector system that reflects light precisely back along the path it has just taken. By doing this, we can project the correct image, in its proper apparent position, directly at the observer–provided that the projector is close enough to the observer's eyes. In order to do this, we can place it on the person's head or mount the projector on the ceiling and have it track the person's movements.

Our retroreflective projection technology, or RPT, uses a screen coated in 50-micrometer glass beads, which produces a very bright reflection. What's more, the system uses one projector for each eye, so it can create a stereoscopic effect



How to make a rolling theater in the round

A CROUCHING BOY becomes visible to a driver when she looks back. In this, the latest refinement of the authors' system, the projector is placed on the floor rather than the ceiling and projects an image of the boy up to a half mirror. Some of the rays bounce to a special, retroreflective screen on the backseat, which returns them directly to the driver's eye. Some rays (not shown, for simplicity's sake) also proceed upward to produce a copy of the image on a ceiling retroreflector. This image is also reflected by the half mirror to the driver's eye, ensuring that she will see the boy even if someone is sitting in the backseat.

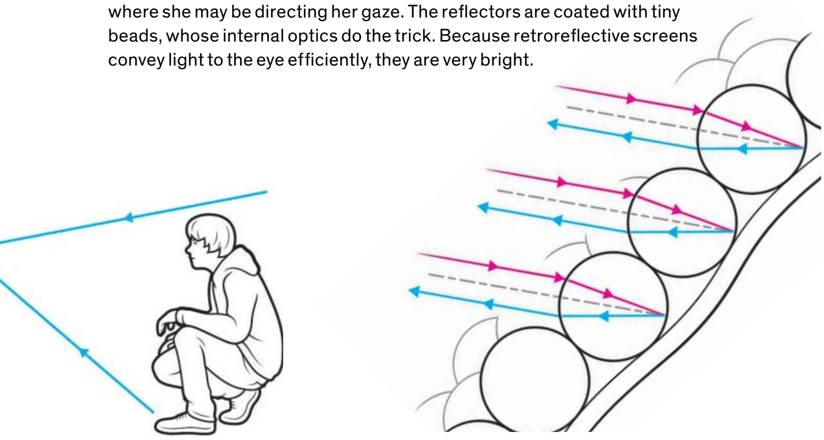


with a single screen. No shutter glasses or any other movie-house 3-D equipment are required.

HERE'S HOW IT WORKS: The projector directs the outgoing beam to a half mirror in front of the observer. Part of the beam goes on to illuminate the special screen, which reflects most of it directly back through the half mirror and straight into the observer's eyes.

The reflection is bright because the tiny beads that make up the retroreflective coating work very efficiently. When illuminated by 1 lux of light, the reflective brightness is roughly 500 candelas per lux per square meter. Multiplying this value by 0.25 to account for the reduction caused by passing to and fro through the half mirror gives a final

RETROREFLECTORS return an incident ray of light directly to its source, allowing a projector to display the appropriate image to the driver no matter where she may be directing her gaze. The reflectors are coated with tiny beads, whose internal optics do the trick. Because retroreflective screens convey light to the eye efficiently, they are very bright.



brightness of around 125 cd/lx/m². A similarly illuminated movie screen, by comparison, would typically have a reflective brightness on the order of 1 cd/lx/m².

In other words, our RPT system's projection is at least 100 times as bright as that achieved using normal screens. And because the reflection is along the axis of projection, there is no distortion of the image even when it's projected on a screen of a complex shape.

This system can also work as a kind of optical camouflage, one that could make a person disappear into the background, for instance. The military might not come running, though, because this trick works only if the person being camouflaged is wearing clothes covered in retroreflective beads. Also, the observer must peer through a half mirror while the projector is fed data from a video camera behind the camouflaged person. A computer uses image-based rendering techniques to calculate the appropriate perspective and to transform the captured image into the image to be projected onto the subject, who then blends seamlessly into the background. It is quite an amusing effect.

Another possible use of the RPT system is to capture data from an X-ray machine or an MRI scan, render it into an image, and then superimpose it onto a patient undergoing surgery. This would be particularly useful for minimally invasive surgery, the kind conducted through a "keyhole" in the body. By superimposing ultrasonic data, the projector could also display the body's inner organs in real time.

In a factory, a skilled craftsman might wear a glove made of retroreflective material. An image could be projected onto the glove showing tiny objects—such as those involved in the testing of circuits—that would otherwise be obscured by the craftsman's hand. The possibilities of our see-through technology abound.

SO FAR WE HAVE BEEN describing a system that caters to just one person. But there is no reason not to equip all the people in a car with this apparatus. Indeed, it is quite possible to project multiple images on the same screen.

ILLUSTRATION BY James Provost

GHOST OR GHOUL? The man with upraised arms [top] has disappeared into the scenery—a trick known as optical camouflage. He first had to don retroreflective material; the observer had to put the projection system on his head. The man in the bottom photo is wearing the reflective material under his shirt, so his bones seem to be bursting from his chest.

To do this, you could give a projector and the associated half mirror to each person, to be worn on the head or installed over it. The other method is to make an autostereoscopic 3-D display that produces a hologram-like image in the round by using a large number of viewpoints, created by an array of RPT projectors. To present motion as smooth as a movie's panning shot, you would need several dozen projectors. However, because commercially available projectors are bulky, it would be hard to pack them closely, and so their various viewpoints would necessarily be very different from one another. When you viewed the resulting 3-D image in the round, it would lurch from one perspective to the next in herky-jerky fashion instead of moving smoothly.

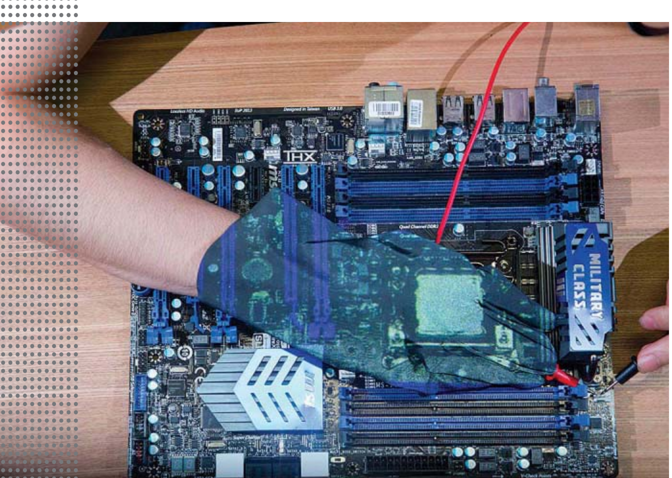
We therefore developed a workaround that consists of a projector, a lens array, a half mirror, and a retroreflective screen. We also included an additional lens to ensure that each lens in the array is equally well illuminated. Projected light forms an image on the field lens. Each lens of the array works as a single projector, and they are placed so that their projected areas overlap. As a result, the number of lenses in the array is equivalent to the number of projection sources and, in turn, the number of viewpoints.

We implemented our basic, one-observer system in a car by applying retroreflector screens to the passengers' doors and to the dashboard. In our initial experiment we used only one camera and fixed the projector to the ceiling, just above the driver's head. Even though we hadn't corrected the image to accurately reflect the distance of the camera from the driver's eye, this stripped-down system made blind spots clearly visible and the car's structures virtually transparent. Furthermore, the displayed image was sufficiently bright to see even in the daytime.

Next we built a setup specifically for a Toyota Prius that made the backseat virtually transparent, so that the driver could see everything behind the car when driving in reverse. In this application, the system had one projector and six lenses, allowing the driver to act naturally without the system's having to track the movements of the driver's head. The result is a panoramic view that the driver can use intuitively–quite unlike the current, counterintuitive system, which sends output from a rearview camera to a display mounted on the dashboard. We are now collaborating with several automakers and automotive electronics companies in turning our concept into a commercial system.

Besides making cars safer and driving more enjoyable, this technology could be used in the cockpit of an airplane to make the floor transparent during landing, enabling the pilot to see the runway in full view. In a cruise ship, it could provide an outdoor view for windowless rooms by making the walls appear invisible. That way, even the innermost cabins could have virtual portholes. It could work in office buildings, too, offering the denizen of every cubicle a wonderful wide-angle view.

With our RPT system, these forms of augmented reality are practical right now. As engineers continue to improve active displays, such as OLEDs, by making them brighter and by manipulating them so that they conform to complex surfaces, our technology may find wider application–wherever we need to see through things. ■



MORE PRACTICAL APPLICATIONS include retroreflective gloves that allow assembly workers to see fine work that their own hands would otherwise obscure.

POST YOUR COMMENTS at http://spectrum.ieee.org/transparent1114

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

CONTINUED FROM PAGE 36 | In late 1969, Zimmerman was contacted by physicist David Cohen, who had become intrigued by biomagnetism and was experimenting with measuring electrical fields of the human heart and brain using copper coils. To do this, Cohen built a large magnetically shielded room and took hundreds of passes of each subject, using signal averaging to eke out a decent signal-to-noise ratio. "I badly needed a better detector and had heard about Zimmerman and his SQUID," Cohen recently recalled.

In late December 1969, Zimmerman visited the Francis Bitter National Magnet Laboratory at MIT to meet with Cohen. Zimmerman had with him a portable SQUID demonstrator that he'd built; it consisted of an RF SQUID in a small helium-filled Dewar vessel and an RF amplifier in a small aluminum box. On New Year's Eve, they tested it. Cohen later offered this account: "Finally we were ready to look at the easiest biomagnetic signal: the signal from the human heart, because it was large and regular. Jim stripped down to his shorts, and it was *his* heart that we first looked at. The resulting MCG [magnetocardiogram] signal exceeded my best expectations. It was as clear as a conventional ECG [electrocardiogram], and several orders of magnitude better than the MCG from a coil detector. Although I didn't realize it, a new era had arrived in biomagnetism."

Cohen likened his own effort with the copper coils to "trying to explore a new continent...using a rowboat." The SQUID, he said, gave him "a powerboat."

Cohen and Zimmerman's experiment was the first use of a SQUID on a living subject. Though the apparatus wasn't ready for clinical use, the results turned both men into true believers about the medical applications of the SQUID. Cohen next began using SQUIDs for measuring the tiny magnetic fields in the brain–even trickier to detect than those from the heart. Meanwhile, in San Diego, SHE shifted its focus to designing SQUIDs specifically for medical use; eventually, the company changed its name to Biomagnetic Technologies and sold SQUIDs for performing magnetoencephalograms, or MEGs.

Around the time of his visit with Cohen, Zimmerman was offered a job at the National Bureau of Standards (now the National Institute of Standards and Technology) at its facility in Boulder, Colo. He resigned from SHE due to a possible conflict of interest, but he never let up on making the SQUID more portable and responsive. He also helped create the first arrays of SQUIDs, for taking measurements over a wider area. With Martin Reite at the Colorado Health Sciences Center, for instance, he designed a SQUID array for MEGs; Reite used the apparatus to study the brain's auditory response.

If Zimmerman's work on SQUIDs was groundbreaking, his keen interest in refrigeration was equally important. The lack of good cooling technology, he realized, was one of the main things holding back the adoption of the SQUID in industry, medicine, and elsewhere. Available commercial refrigerators were too big and, worse, contained magnetic components, which could overwhelm the faint signals the SQUID was supposed to detect. Zimmerman spent more than a decade designing portable cryogenic systems, including an ingenious Stirling-cycle refrigerator no bigger than a bicycle pump. Made largely of plastic, it could still cool a niobium SQUID to 8.5 K. Later, after he retired in 1985, he and his grandson devised a liquid-helium cryostat that could maintain temperatures of 1 millikelvin. Now known as the Z cryostat ("Z" for Zimmerman), it is a standard piece of equipment in many high-temperature superconductivity labs.

FIFTY YEARS AFTER ITS INVENTION, THE SQUID IS ONLY now coming into its own. Two companies currently manufacture the devices, and dozens of research groups around the world are investigating new applications for them. The Swedish company Elekta, for instance, makes neurological "stations" that each incorporate 306 SQUID circuits for verifying the abnormal magnetic activity associated with epilepsy and other conditions. Aided by high-speed computer processing, the apparatus yields a three-dimensional magnetic field map of a patient's brain that can be used to guide surgical treatment of the condition.

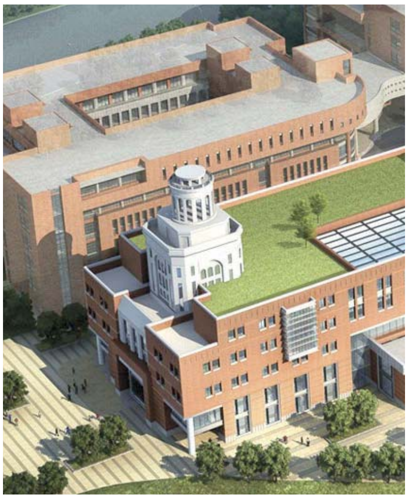
The SQUID is also a principal building block for numerous electronics applications, including analog-to-digital converters and both traditional and quantum computing. In nondestructive testing, the devices have been used to detect aluminum corrosion in aircraft. Such anomalies would otherwise be nearly impossible to detect without dismantling or otherwise damaging the components, and the magnetic fields produced by such corrosion are exceedingly weak compared with those from other components on the plane, such as the steel fasteners.

Researchers are also considering the SQUID as a tool for measuring the effectiveness of magnetically activated drug delivery; this technique involves dispersing drugs through the blood using magnetic nanoparticles. SQUID arrays offer a way to noninvasively detect where the nanoparticles have dispersed and where the drug has been delivered. There have even been reports of nanoSQUIDs, which their inventors claim can measure the magnetic field of a single atom.

If the SQUID continues on its way to a glorious future, it will be a testament to Zimmerman's energy and persistence. Building on those fragile lab curiosities devised in Dearborn, he doggedly refined and improved them over the course of several decades. Along the way, he spread the SQUID gospel, collaborating eagerly with researchers outside his own discipline and enthusiastically tackling the hard engineering problems to ensure its success. What the story of the SQUID elegantly shows is that the moment of invention—however surprising, revelatory, and exciting—is but the first small step in the long road to reality. It is also a poignant reminder of what's been lost. As today's corporations move away from unfettered basic research, we should not forget the crucial role of the 20th century's industrial labs and the ingenious ideas and inventions that emerged from them. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/fordsquid1114

Joint Institute of Engineering



FACULTY POSITIONS AVAILABLE IN ELECTRICAL/COMPUTER ENGINEERING

Sun Yat-sen University & Carnegie Mellon University are partnering to establish the **SYSU-CMU Joint Institute of Engineering (JIE)** to innovate engineering education in China and the world. The mission of the JIE is to nurture a passionate and collaborative global community and network of students, faculty and professionals working toward pushing the field of engineering forward through education and research in China and in the world.

JIE is seeking **full-time faculty** in all areas of electrical and computer engineering (ECE). Candidates should possess a doctoral degree in ECE or related disciplines, with a demonstrated record and potential for research, teaching and leadership. The position includes an initial year on the Pittsburgh campus of Carnegie Mellon University to establish educational and research collaborations before locating to Guangzhou, China.

This is a worldwide search open to qualified candidates of all nationalities, with an internationally competitive compensation package for all qualified candidates.

PLEASE VISIT: **jie.cmu.edu** for details

SHUNDE INTERNATIONAL

Joint Research Institute

RESEARCH STAFF POSITIONS AVAILABLE IN ELECTRICAL/COMPUTER ENGINEERING

SYSU-CMU Shunde International Joint Research Institute (JRI) is located in Shunde, Guangdong. Supported by the provincial government and industry, the JRI aims to bring in and form high-level teams of innovation, research and development, transfer research outcomes into products, develop advanced technology, promote industrial development and facilitate China's transition from labor intensive industries to technology intensive and creative industries.

The JRI is seeking **full-time research faculty** and **research staff** that have an interest in the industrialization of science research, which targets electrical and computer engineering or related areas.

Candidates with industrial experiences are preferred.

Applications should include a full CV, three to five professional references, a statement of research and teaching interests, and copies of up to five research papers.

Please submit the letters of reference and all above materials to the address below.

Application review will continue until the position is filled.

EMAIL APPLICATIONS OR QUESTIONS TO: **sdjri@mail.sysu.edu.cn**

SUN YAT-SEN UNIVERSITY Carnegie Mellon University

ShanghaiTech Faculty Search

ShanghaiTech University invites *highly qualified* candidates to fill multiple tenure-track/tenured faculty positions as its core team in the School of Information Science and Technology (SIST). Candidates should have exceptional academic records by international standards or demonstrate strong potential in cutting-edge research areas of information science and technology. English fluency is required and overseas academic experience is highly desired. ShanghaiTech aims to become a world-class research university for training future scientists, entrepreneurs, and technological leaders. Located in Zhangjiang High-Tech Park in the cosmopolitan Shanghai, we shall trail-blaze a new education system in China. Besides establishing and maintaining a world-class research profile, faculty candidates must also contribute substantially to graduate and undergraduate education.

Academic Disciplines:
We welcome candidates in all cutting edge areas of information science and technology. Our recruitment focus includes, but is not limited to: computer architecture and software, cloud and high performance computing, computational foundations, data mining and analysis, visualization, computer vision, machine learning, data sciences and statistics, IC designs, solid-state electronics, high speed and RF circuits, embedded systems, intelligent and signal processing systems, smart energy/power devices and systems, next-generation networking, control systems, robotics, sensor networks as well as inter-disciplinary areas involving information science and technology.

Compensation and Benefits:
Salary and startup funds are highly competitive, commensurate with experience and academic accomplishment. We also offer a comprehensive benefit package to employees and eligible dependents, including housing benefits. All regular faculty members will join our new tenure-track system commensurate with international practice for tenure evaluation and promotions.

Qualifications:
- A well articulated research plan and demonstrated record/potentials;
- Ph.D. (Electrical Engineering, Computer Engineering, Computer Science, Statistics, or related field);
- A minimum relevant research experience of 4 years.

Applications:
Submit (in English, PDF) *a cover letter, a 2-page research plan, a CV plus copies of 3 most significant publications, and names of three referees* to: ***sist@shanghaitech.edu.cn*** by December 31st, 2014 (or until positions are filled). *More information is at* ***http://www.shanghaitech.edu.cn***.

THE CHINESE UNIVERSITY OF HONG KONG

Applications are invited for:-

Faculty of Engineering
Professors / Associate Professors / Assistant Professors

(Ref. 1415/039(370)/2)

The Faculty invites applications for several faculty posts at Professor / Associate Professor / Assistant Professor levels, with prospect for substantiation, in the interdisciplinary area of 'Big Data Analytics', which is a new strategic research initiative supported by the University's Focused Innovations Scheme and will complement current/planned strengths in different Departments under the Faculty. To lead the big data research initiative, senior professors in this area are particularly welcome. Currently, the Faculty is seeking candidates in the following areas:

- Theoretical, mathematical and algorithmic aspects in large data analytics;
- Large scale software systems and architecture in large data analytics;
- Combining big data analytics with statistical modelling and operations research methods for optimal decision making;
- Application areas in large data analytics (including information systems and the Web, bioinformatics, financial engineering, logistics and supply chain management, public health, social networks, etc.)

Applicants should have (i) a PhD degree; and (ii) a strong scholarly record demonstrating potential for teaching and research excellence. The appointees will be expected to (a) teach undergraduate and postgraduate courses; (b) develop a significant independent research programme with external funding; and (c) supervise postgraduate students. Appointments will normally be made on contract basis for three years initially, which, subject to performance and mutual agreement, may lead to longer-term appointment or substantiation later. Applications will be accepted until the posts are filled. Further information about the Faculty is available at http://www.erg.cuhk.edu.hk.

Salary and Fringe Benefits
Salary will be highly competitive, commensurate with qualifications and experience. The University offers a comprehensive fringe benefit package, including medical care, plus a contract-end gratuity for appointments of two years or longer, and housing benefits for eligible appointees. Further information about the University and the general terms of service for appointments is available at http://www.per.cuhk.edu.hk. The terms mentioned herein are for reference only and are subject to revision by the University.

Application Procedure
Please send full resume, copies of academic credentials, a publication list with abstracts of selected published papers, details of courses taught and evaluation results (if any), a research plan, a teaching statement, together with names of three to five referees, to the Dean, Faculty of Engineering by e-mail to recruit-bda@erg.cuhk.edu.hk. For enquiries, please contact Professor John C.S. Lui, the leader of the strategic initiative (e-mail: cslui@cse.cuhk.edu.hk). Applicants are requested to clearly indicate that they are applying for the posts under 'Big Data Analytics Initiative'. The Personal Information Collection Statement will be provided upon request. Please quote the reference number and mark 'Application - Confidential' on cover.

BAYLOR UNIVERSITY

Faculty Positions

The Electrical and Computer Engineering Department of Baylor University seeks faculty applicants for three tenured/tenure-track Faculty Positions at all levels. Any area of expertise will be considered but applicants in computer engineering will be given special consideration. Applicants for assistant professor must demonstrate potential for sustained, funded scholarship and excellent teaching; applicants for associate or full professor must present evidence of achievement in research and teaching commensurate with the desired rank. The ECE department offers B.S., M.S., M.E. and Ph.D. degrees and is rapidly expanding its faculty size. Facilities include the Baylor Research and Innovation Collaborative (BRIC), a newly-established research park minutes from the main campus.

Chartered in 1845 by the Republic of Texas, Baylor University is the oldest university in Texas. Baylor has an enrollment of over 15,000 students and is a member of the Big XII Conference. Baylor's mission is to educate men and women for worldwide leadership and service by integrating academic excellence and Christian commitment within a caring community. The department seeks to hire faculty with an active Christian faith; applicants are encouraged to read about Baylor's vision for the integration of faith and learning at **www.baylor.edu/profuturis/**.

Applications received by **January 1, 2015** will be assured full consideration. Applications must include:

1) a letter of interest that identifies the applicant's anticipated rank,

2) a complete CV,

3) a concise statement of teaching and research interests,

4) the names and contact information for at least four professional references.

Additional information is available at www.ecs.baylor.edu. Send materials via email to Dr. Ian Gravagne at Ian_Gravagne@baylor.edu. Please combine all submitted material into a single pdf file.

Baylor University is affiliated with the Baptist General Convention of Texas. As an Affirmative Action/Equal Employment Opportunity employer, Baylor encourages candidates of the Christian faith who are minorities, women, veterans, and persons with disabilities to apply.

Carnegie Mellon University

College of Engineering

Faculty Positions

Carnegie Mellon University, a world leader in information and communication technology, has extended its global reach into Africa with its Center of Excellence in Information and Communication Technology. Focused on one of the fastest growing economic regions of the world, the Center of Excellence is creating a new generation of graduates able to take advantage of Africa's unique opportunities.

Based in Rwanda, the Center of Excellence benefits from the country's bold ICT strategy and CMU's culture of innovation to provide a platform for students to become technology thought leaders through its Master of Science in Information Technology and Master of Science in Electrical and Computer Engineering.

We are seeking highly qualified candidates who share this vision and wish to join a dynamic world-class faculty. Faculty members are expected to collaborate with regional and multi-national industry in technology innovation and entrepreneurship and deliver innovative, interdisciplinary graduate teaching and research programs for the African context.

Areas of interest include:
•software engineering;
•mobile computing;
•cloud computing;
•big data analytics;
•communications;
•information and cyber security;
•intelligent infrastructures;
•wireless networking;
•mHealth;
•energy systems;
•eLearning; and
•mobile applications.

Candidates should possess a Ph.D. in a related discipline and an outstanding record in research, teaching and leadership. Applications should include a comprehensive resume including a complete list of publications, 3-5 professional references, a statement of research and teaching interests (less than 2 pages each), and copies of 2 research papers (journal or conference papers).

APPLICATIONS SHOULD BE SENT TO:
Director, Carnegie Mellon University in Rwanda
rwanda-coe@cit.cmu.edu

Application review starts Dec. 1

www.cmu.edu/rwanda

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Position in Electrical Engineering

at the Ecole polytechnique fédérale de Lausanne (EPFL)

The Institute of Electrical Engineering at EPFL invites applications for a **tenure track assistant professor** in **Electrical Engineering.** Recruitment to a tenured senior position may be considered in exceptional cases.

Applicants should demonstrate strong competences in the broad area of electrical engineering. Areas of interest include, but are not limited to, embedded computing and communication systems, radio-frequency circuits and antennas, nano-circuits and devices, electrical sensors and interfaces, displays, energy-efficient design and energy distribution systems. The Institute welcomes applications from candidates in new emerging areas that do not fit the above groups but that relate to Electrical Engineering at large.

As a faculty member of the School of Engineering, the successful candidate is expected to initiate independent, creative research programs and actively participate in undergraduate and graduate teaching.

Significant start-up resources and state-of-the-art research infrastructure will be available. Salaries and benefits are internationally competitive.

EPFL, with its main campus located in Lausanne, Switzerland, is a dynamically growing and well-funded institution fostering excellence and diversity. A technical university covering essentially the entire palette of engineering and science, EPFL has a highly international environment that is multi-lingual and multi-cultural, with English often serving as a common interface.

Applications should include a cover letter with a statement of motivation, curriculum vitae, list of publications and patents, concise statement of research and teaching interests, and the names and addresses of at least five referees. Applications must be uploaded in PDF format to: **http://go.epfl.ch/iel-search**

Formal evaluation of candidates will begin on **December 1st, 2014.**

Enquiries may be addressed to:
Prof. Pierre Vandergheynst
Search Committee Chair
E-mail: **iel-search@epfl.ch**

For additional information on EPFL, please consult the web sites: **www.epfl.ch, sti.epfl.ch** and **iel.epfl.ch.**

EPFL is committed to increasing the diversity of its faculty, and strongly encourages women to apply.

THE UNIVERSITY OF CHICAGO

The Department of Computer Science at the **University of Chicago** invites applications from exceptionally qualified candidates for faculty positions at the rank of **Assistant Professor** in the area of Artificial Intelligence (AI). Outstanding researchers working in Artificial Intelligence, which include both the theory of machine learning and applications to areas such as natural language processing, computer vision, and computer systems are encouraged to apply.

The University of Chicago has the highest standards for scholarship and faculty quality, and encourages collaboration across disciplines. We encourage strong connections with researchers across campus in areas such as the biological and physical sciences.

The Department of Computer Science (**cs.uchicago.edu**) is the hub of a large, diverse computing community of two hundred researchers focused on advancing foundations of computing and driving its most advanced applications. Long distinguished in theoretical computer science and artificial intelligence, the Department is now building strong systems and machine learning groups. The larger community in these areas at the University of Chicago includes the Computation Institute, the Toyota Technological Institute at Chicago (TTIC), the Department of Statistics, and the Mathematics and Computer Science Division of Argonne National Laboratory.

The Chicago metropolitan area provides a diverse and exciting environment. The local economy is vigorous, with international stature in banking, trade, commerce, manufacturing, and transportation, while the cultural scene includes diverse cultures, vibrant theater, world-renowned symphony, opera, jazz, and blues. The University is located in Hyde Park, a Chicago neighborhood on the Lake Michigan shore just a few minutes from downtown.

Applicants must have completed all requirements for the PhD at time of appointment. The PhD should be in Computer Science or a related field such as Mathematics or Statistics. All applicants must apply through the University's Academic Jobs website at **http://tinyurl.com/muzweou**.

To be considered as an applicant, the following materials are required:

- cover letter
- curriculum vitae including a list of publications,
- statement describing past and current research accomplishments and outlining future research plans, and
- description of teaching philosophy, and
- three reference letters, one of which must address the candidate's teaching ability.

Reference letter submission information will be provided during the application process.

Review of application materials will begin on January 15, 2015 and continue until all available positions are filled.

All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, age, protected veteran status or status as an individual with disability.

The University of Chicago is an **Affirmative Action / Equal Opportunity** */ Disabled / Veterans Employer.*

NANYANG TECHNOLOGICAL UNIVERSITY

Faculty Positions at School of Chemical and Biomedical Engineering [SCBE]

The School of Chemical and Biomedical Engineering (**http://www.scbe.ntu.edu.sg**), Nanyang Technological University of Singapore invites applicants to apply for tenure-track faculty positions at the Associate/Assistant Professor level. Applicants should hold a Ph.D. in Chemical Engineering, Bioengineering, Biomedical Engineering, Food Science Technology and Engineering or a related field by the beginning of the appointment period. Candidates with post-doctoral training would be preferred.

The School is particularly interested in:

1) Chemical Engineering candidates with interests in Biochemical Engineering, Synthetic Biology, Food Engineering, Chemical Engineering Process, and Fluids and Colloids.
2) Bioengineering candidates with research interests in Biomaterials, Bioimaging, Biosensors, Biodevices, Bionanotechnologies, Tissue Engineering (musculoskeletal, neuron regeneration, etc), Rehabilitation Neuro-Biomechanics and Translational Biomedical Engineering.

The candidate should have a demonstrated excellence in original research, with good publication records and the ability to teach core Chemical/Food Engineering and Bioengineering courses. Entrepreneurial qualities are also sought after.

Responses received by 30th November 2014 would be given priority.

Emoluments and General Terms and Conditions of Service
The commencing salary will depend on the candidate's qualifications, experience and the level of appointment offered. Information on emoluments and general terms and conditions of service is available at: **http://www.ntu.edu.sg/ohr/CareerOpportunities/TermsandConditions/Pages/FacultyPositions.aspx**.

Application Procedure
Qualified candidates are invited to submit an application. Guidelines for Submitting an Application for Faculty Appointment are available at: **http://www.ntu.edu.sg/ohr/CareerOpportunities/SubmitanApplication/Pages/FacultyPositions.aspx**.
The post applied for should be clearly stated. Electronic submission of application is encouraged and can be forwarded to:

Chairman, Search Committee, School of Chemical and Biomedical Engineering
NANYANG TECHNOLOGICAL UNIVERSITY
E-mail: scbe_recruit@ntu.edu.sg

www.scbe.ntu.edu.sg

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under the grant agreement no. 621386

University of Zilina, Slovakia

European Research Area (ERA) Chair
in Intelligent Transport Systems (ITS)

Excellent scientists are invited to apply for the ERA Chair position established at the University Science Park of the University of Zilina within the prestigious European grant awarded to only 11 European research institutions within the Seventh Framework Programme. The project aims to enhance research and innovation aspects of the University Science Park and the University of Zilina in the field of Intelligent Transport Systems (ITS).

The ERA Chair holder is expected to represent research excellence in the field of Intelligent Transport Systems, specifically in the area of Information and Communication Technologies in connection with transport and services development towards advanced ITS. He/She should be "Leading Researcher" (R4) according to the European Framework for Research Careers. Previous experiences with development and implementation of ITS will be evaluated during the selection process. Additionally, the ERA Chair holder will have an opportunity to influence the scientific development as the scientific advisor to the rector of the University of Zilina.

Applications should include Curriculum Vitae with a special focus on high-impact publications, research funding management and soft skills, a statement of research interest, three professional references and motivation letter.

Applications should be sent by e-mail to
erachair@uniza.sk before 15th November, 2014.

Information and updates regarding the ERA Chair Holder position are available at:
http://www.erachair.uniza.sk/

university science park
University of Zilina

ŽILINSKÁ UNIVERZITA V ŽILINE
UNIVERSITAS SOLNENSIS

THE UNIVERSITY OF CHICAGO

The Department of Computer Science at the **University of Chicago** invites applications from exceptionally qualified candidates for faculty positions at the rank of **Associate Professor** in the area of Artificial Intelligence (AI). Outstanding researchers working in Artificial Intelligence, which include both the theory of machine learning and applications to areas such as natural language processing, computer vision, and computer systems are encouraged to apply.

The University of Chicago has the highest standards for scholarship and faculty quality, is dedicated to fundamental research, and encourages collaboration across disciplines. We encourage strong connections with researchers across campus in areas such as the biological and physical sciences.

The Department of Computer Science (**cs.uchicago.edu**) is the hub of a large, diverse computing community of two hundred researchers focused on advancing foundations of computing and driving its most advanced applications. Long distinguished in theoretical computer science and artificial intelligence, the Department is now building strong systems and machine learning groups. The larger community in these areas at the University of Chicago includes the Department of Statistics, the Computation Institute, the Toyota Technological Institute at Chicago (TTIC), and the Mathematics and Computer Science Division at Argonne National Laboratory.

The Chicago metropolitan area provides a diverse and exciting environment. The local economy is vigorous, with international stature in banking, trade, commerce, manufacturing, and transportation, while the cultural scene includes diverse cultures, vibrant theater, world-renowned symphony, opera, jazz, and blues. The University is located in Hyde Park, a Chicago neighborhood on the Lake Michigan shore just a few minutes from downtown.

Applicants must have a doctoral degree in Computer Science or a related field such as Mathematics or Statistics and be several years beyond the Ph.D. Applicants are expected to have established an outstanding research program and will be expected to contribute to the department's undergraduate and graduate teaching programs. All applicants must apply through the University's Academic Jobs website at **http//tinyurl.com/pfatjhn**.

To be considered as an applicant, the following materials are required:

- cover letter,
- curriculum vitae including a list of publications,
- statement describing past and current research accomplishments and outlining future research plans, and
- description of teaching philosophy, and
- a reference contact list consisting of three people.

Review of complete applications will begin January 15, 2015 and will continue until all available positions are filled.

All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, age, protected veteran status or status as an individual with disability.

The University of Chicago is an **Affirmative Action / Equal Opportunity** */ Disabled / Veterans Employer.*

THE UNIVERSITY OF TEXAS AT AUSTIN
Electrical and Computer Engineering

The University of Texas at Austin ECE Faculty Searches

The Department of Electrical and Computer Engineering at The University of Texas at Austin invites applications for the following tenure-track and tenured faculty positions:

Dula D. Cockrell Centennial Chair in Engineering

The Department of Electrical and Computer Engineering at The University of Texas at Austin invites applications for the Dula D. Cockrell Centennial Chair in Engineering in microelectronics, with preference given to nanoscale technology, science and manufacturing, for applications in energy, cloud and mobile computing, biology, health care, integrated man-machine interfaces, or related areas. Candidates should have an internationally recognized record of research and scholarship, and possess the qualities necessary for academic leadership. The successful applicant will be expected to supervise graduate students, teach undergraduate and graduate classes, and be involved in service to the university and profession. This appointment offers outstanding scope for the appointee's individual and collaborative research talents and provides an opportunity for leadership in developing sponsored research programs. Applicants for this tenured position should have an earned PhD in electrical engineering or a related discipline.

Tenure-Track Faculty Positions

The Department of Electrical and Computer Engineering at The University of Texas Austin has four faculty openings with a start date of Fall 2015. Appointment will be at the assistant professor level. In special cases, a senior faculty appointment may be possible. Exceptional candidates in any area of electrical and computer engineering will be considered for three of the four positions. We especially encourage applicants whose research interests impact energy, cloud and mobile computing, health care and informatics, synthetic and systems biology, cyberphysical systems and security, integrated man-machine interfaces and systems. The last position is specifically targeted to candidates in the area of systems biology.

Applicants should have received or expect to receive a doctoral degree in electrical engineering, computer engineering, computer science or a related discipline prior to September 2015. Successful candidates are expected to supervise graduate students, teach undergraduate and graduate courses, develop a sponsored research program, collaborate with other faculty and be involved in service to the university and profession.

Application Instructions:

All applications must be submitted electronically at **http://www.ece.utexas.edu/faculty/openings**. Interested applicants should submit a cover letter, current vita, statement of research, and teaching philosophy. For Chair positions, applications should include a minimum of five references who will submit original letters of reference directly to the website. For tenure-track faculty positions, at least three references who will submit original letters of reference should be included.

For Chair positions, applications will be considered until the positions are filled. For tenure-track positions, applications should be submitted by **December 1, 2014** to ensure fullest consideration. Earlier submission is strongly encouraged.

The successful candidate will be required to complete an Employment Eligibility Verification form and provide documents to verify identity and eligibility to work in the U.S. A security sensitive background check will be conducted on the applicant selected. The University of Texas at Austin is an Equal Opportunity/Affirmative Action Employer.

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Position in Ultra High Precision Robotics & Manufacturing

at the Ecole polytechnique fédérale de Lausanne (EPFL)

The Institute of Microengineering (IMT) within the School of Engineering at EPFL invites applications for a faculty position at the level of **tenure track assistant professor** in **ultra-high precision robotics and manufacturing.** Recruitment to a tenured senior position may be considered in exceptional cases.

This new position is aimed at reinforcing the leading position of the Swiss microengineering industry by giving it the means to further strengthen its competitiveness by continuous innovation.

Specific areas include, but are not limited to:
- Design of innovative ultra-high precision machining, manipulation and metrology systems targeting additive manufacturing;
- New kinematics, quasi-perfect guidings, actuators, transmission systems, sensors and methods targeting ultra-high precision additive manufacturing;
- New calibration techniques and new metrology devices for nanometric precision and sub-tens of nanometers accuracy;
- Design of tools targeting high-precision with excellent cleanness, e.g. microfactories and vacuum chambers.

Experience in successful collaborative research programs with industry is highly desirable. The IMT-EPFL offers a particularly advantageous position thanks to its historically very strong links to the diverse and well-established local high-technology industry.

As a faculty member of the School of Engineering, the successful candidate will be expected to initiate an independent research program, participate in undergraduate and graduate teaching and establish strong links with industrial partners. Internationally competitive salaries, start-up resources and benefits are offered.

The EPFL is a dynamically growing and well-funded institution fostering excellence and diversity. It has a highly international campus at an exceptionally attractive location boasting first-class infrastructure. As a technical university covering essentially the entire palette of engineering and science, EPFL offers a fertile environment for research cooperation between different disciplines. The EPFL environment is multi-lingual and multi-cultural, with English often serving as a common interface.

Applications should include a curriculum vitae with a list of publications, a concise statement of research and teaching interests, and the names of at least five referees. Applications must be uploaded in PDF format to: **http://go.epfl.ch/imt-search**

Formal evaluation of candidates will begin on **December 1st, 2014.**

Enquiries may be addressed to:
Prof. Christian Enz
Search Committee Chair
e-mail: **imt-search@epfl.ch**

For additional information on EPFL, please consult the web sites: **www.epfl.ch**, **sti.epfl.ch** and **imt.epfl.ch.**

EPFL is committed to increasing the diversity of its faculty, and strongly encourages women to apply.

IUPUI

Assistant/Associate Professor of Electrical and Computer Engineering, Purdue School of Engineering and Technology, Indiana University-Purdue University Indianapolis (IUPUI), invites applications for one or more tenure-track faculty positions. A possible start date is January 5, 2015. Successful candidates should expect to teach undergraduate and graduate courses, supervise graduate students and conduct externally funded research. Applicants should have a Ph.D. in computer engineering, electrical engineering or computer science. Preference will be given to applicants in areas within computer engineering, and areas with applications related to "Big Data" analysis. For a complete job description and to apply: **http://et2.engr.iupui.edu/departments/ece/about/news/index.php**

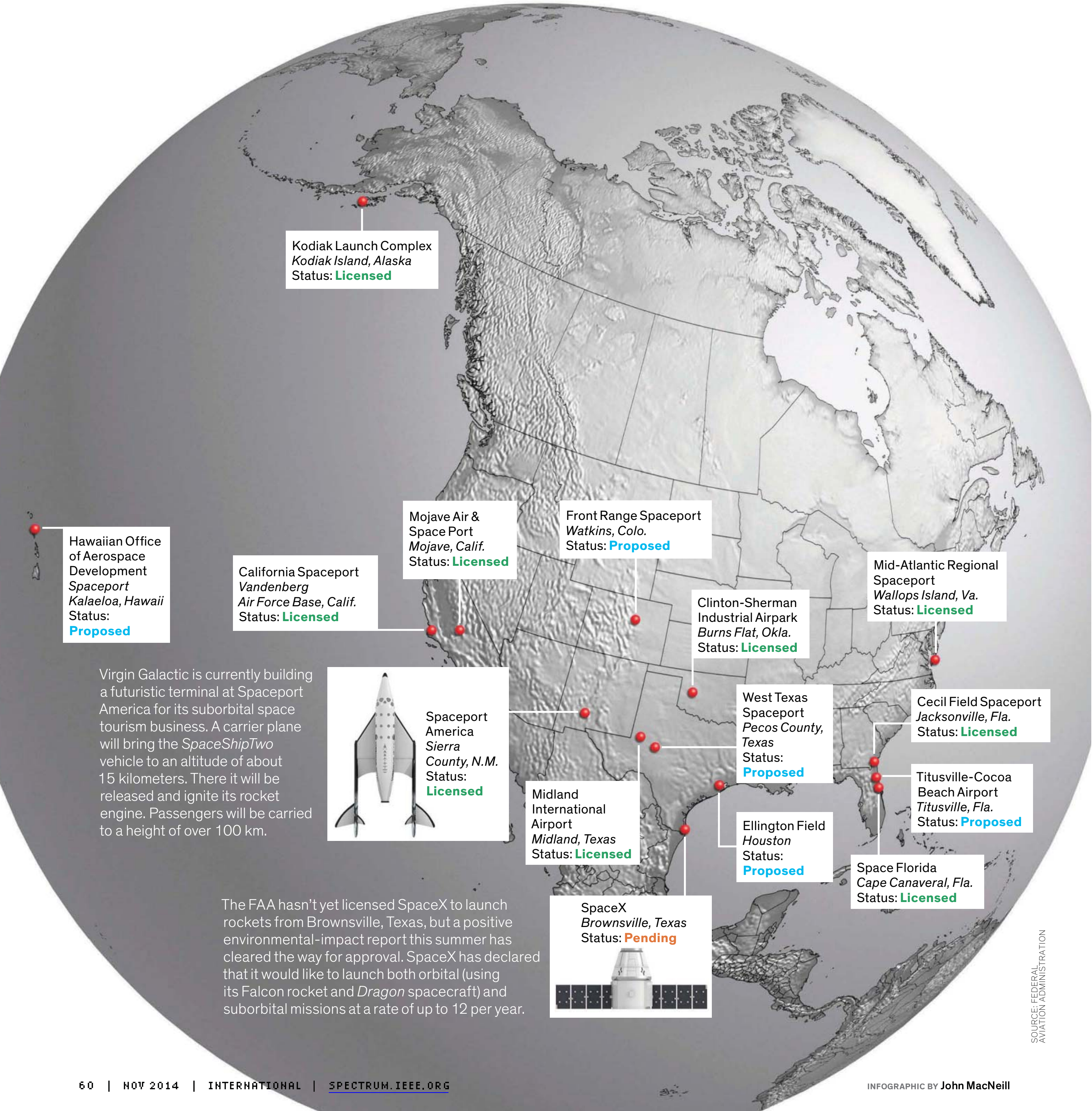
IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

DATAFLOW_

THE SPACE RUSH

LICENSED AND PROPOSED COMMERCIAL SPACEPORTS ARE POPPING UP ACROSS THE U.S.

Rocket and spacecraft company SpaceX recently announced its plans to open a spaceport in Texas, while Virgin Galactic is making noises that it expects to conduct a flight into space from the Mojave Air & Space Port in California in the next several months. But these aren't the only places where people are hoping to grab a piece of the nascent commercial space age. The United States' Federal Aviation Administration has already licensed a number of other spaceports, with several more locations also expressing interest in getting licensed. Just how big the commercial space market would have to be to support all these launch sites is an open question. **—STEPHEN CASS**

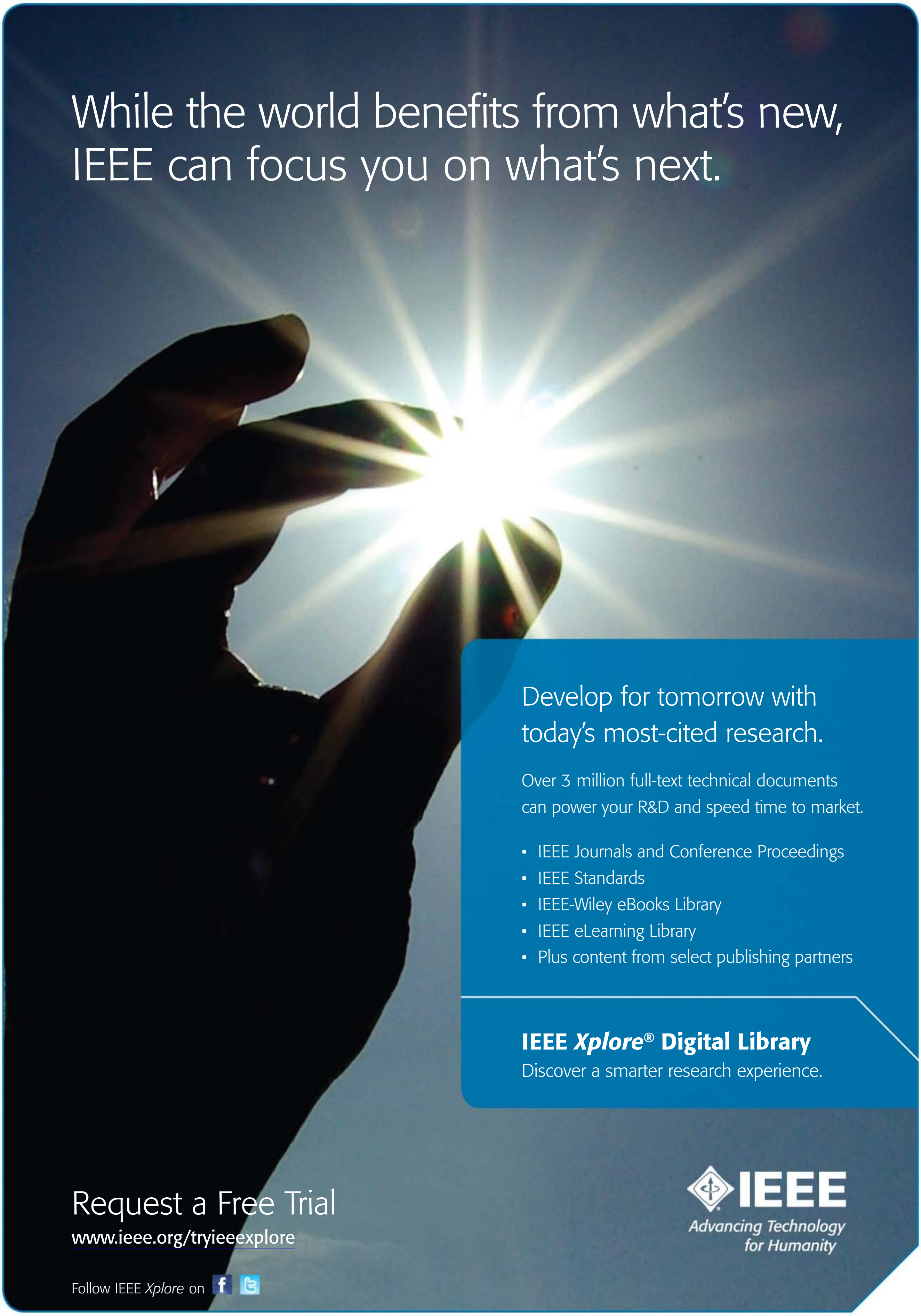


Virgin Galactic is currently building a futuristic terminal at Spaceport America for its suborbital space tourism business. A carrier plane will bring the *SpaceShipTwo* vehicle to an altitude of about 15 kilometers. There it will be released and ignite its rocket engine. Passengers will be carried to a height of over 100 km.

The FAA hasn't yet licensed SpaceX to launch rockets from Brownsville, Texas, but a positive environmental-impact report this summer has cleared the way for approval. SpaceX has declared that it would like to launch both orbital (using its Falcon rocket and *Dragon* spacecraft) and suborbital missions at a rate of up to 12 per year.

SOURCE: FEDERAL AVIATION ADMINISTRATION

INFOGRAPHIC BY John MacNeill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