Pitch Perfect

Wearable sensors are the secret weapon in big-league baseball’s arms race  P. 34
Challenge us.

What are your requirements for periodic signal detection?
Our mission: providing instrumentation, software, and advice to get you the best results with minimal time and effort.

MFLI 500 kHz Lock-in Amplifier starting at $6,210
IT’S NOT TOO SOON TO BE WARY OF AI

We need strategies to ensure that superintelligent machines will remain under control.

By Stuart Russell
Page 46

WHEN APPS RULE THE ROAD
Navigation apps are acting as traffic cops, but what they don’t know can cause chaos.

By Jane Macfarlane
Page 22

HELLO, SILICON-INTERCONNECT FABRIC
Swap printed circuit boards for silicon and you’ll get smaller, more powerful systems.

By Puneet Gupta & Subramanian S. Iyer
Page 28

THE NEW SCIENCE OF BIOBALL
With biometric sensors, baseball pitchers are gaining insights into injury risk and performance.

By Will Carroll & Ben Hansen
Page 34

TURNING THE ELECTRIC MOTOR INSIDE OUT
Pointing the magnetic flux along the axis, instead of the radius, increases the power.

By Daan Moreels & Peter Leijnen
Page 40
When Benjamin Hansen was playing baseball in high school, around 2006, technologies to monitor athletes’ bodies and performance weren’t yet commonplace. Yet Hansen wanted to collect data any way he could. “I would sit on the bench with a calculator and a stopwatch, timing the pitchers,” he says. He clicked the stopwatch when the pitcher released the baseball and again when the ball popped into the catcher’s mitt, then factored in the pitcher’s height in calculating the pitch velocity.

Hansen’s coach, however, was not impressed. “My coach should have embraced it,” he says, wistfully. “But instead he made me run laps.” Hansen kept playing baseball through college, pitching for his team at the Milwaukee School of Engineering [above]. But he was plagued by injuries. He well remembers a practice game in which he logged 15 straight outs—then felt a sharp pain in his elbow. He had partially torn his ulnar collateral ligament (UCL) and had to sit out the rest of the season. “I always asked the question: Why is this happening?” he says.

Today, Hansen is the vice president of biomechanics and innovation for Motus Global, in St. Petersburg, Fla., a startup that produces wearable sports technology. In this issue, he describes Motus’s product for baseball pitchers, a compression sleeve with sensors to measure workload and muscle fatigue [p. 34]. From Little League to Major League Baseball, pitchers are using Motus gear to understand their bodies, improve performance, and prevent injuries.

Traditional wisdom holds that pitcher injuries result from faulty form. But data from Motus’s wearable indicates that it’s the accumulated workload on a player’s muscles and ligaments that causes injuries like UCL tears, which have become far too common in baseball. By displaying measurements of fatigue and suggesting training regimens, rehab workouts, and in-game strategies, the wearable can help prevent players from pushing themselves past their limits. It’s a goal that even Hansen’s old coach would probably endorse. ■
Punpee Gupta

Gupta is an associate professor of electrical engineering at the University of California, Los Angeles. He and UCLA colleague Subramanian S. Iyer design computer systems that can take advantage of silicon-interconnect fabric technology, as they describe in this issue [p. 28]. “There is a huge class of data-intensive applications, like graph problems and machine learning, where such a tightly knit fabric would be extremely advantageous,” says Gupta.

Jane Macfarlane

Macfarlane, director of the Smart Cities Research Center at the University of California, Berkeley’s Institute of Transportation Studies, works on data analytics for emerging transportation issues. In the late 1990s, as advanced-technology director for the in-car navigation system OnStar, she was happy to let OnStar guide her car. These days she likes to challenge navigation algorithms by not following directions. In this issue, she discusses how those algorithms are increasing traffic congestion [p. 22].

Daan Moreels

Moreels is an aeronautical engineer by training and cofounder of Magnax, a Belgian company that has developed a particularly compact electric machine, called a yokeless axial-flux motor. “Initially, we thought our technology would be an ideal fit as a generator in wind turbines, but the market drove us in the direction of motors for electric vehicles,” he says. He and Magnax founder Peter Leijnen tell the tale in “Turning the Electric Motor Inside Out” [p. 40].

Chris Philpot

Philpot is an illustrator based in Santa Fe, N.M., who describes his clean style as “airline safety card art.” He created the opening art for “When Apps Rule the Road” [p. 22], which depicts a smartphone as an unhelpful traffic cop, creating traffic snarls and chaos. “I’m usually encouraged to bring levity to my illustrations,” Philpot says. “This image shows how we personify our devices, getting mad at them even though they’re just plastic and metal. That’s a great source of humor.”

Stuart Russell

Russell, a computer scientist, founded and directs the Center for Human-Compatible Artificial Intelligence at the University of California, Berkeley. This month, Viking Press is publishing Russell’s new book, Human Compatible: Artificial Intelligence and the Problem of Control, on which he writes, “It’s Not Too Soon To Be Wary of AI” [p. 46]. Russell’s “It’s also active in the movement against autonomous weapons, and he instigated the production of the highly viewed 2017 video “Slaughterbots.”
Drone Pilots Beware

Can I fly here? You probably shouldn’t rely on the FAA’s B4UFLY app to decide

Over the summer, I went home to Oregon to visit my family, and I brought my Parrot Anafi drone along. The plan was to go river rafting, hiking, and kayaking, and I figured I’d try to find some interesting opportunities to fly my drone along the way.

Finding somewhere to legally and safely fly a drone can be tricky, because the rules governing recreational drone operations often aren’t common sense and aren’t at all easy to figure out.

To help with this, the U.S. Federal Aviation Administration (FAA) has developed an app called B4UFLY, which will tell you, based on your location, whether there are any drone flight restrictions in place. It’s a wonderful idea, and I imagine it would be very effective—if it didn’t have some significant issues. Although the FAA presents the app as a tool that recreational flyers can use to find out “whether it is safe to fly their drone,” B4UFLY does not currently include information about many local, state, or even federal rules that apply to drone operators. Consequently, the app’s indications that pilots are “good to go” may end up giving you the wrong idea entirely.

I asked the FAA to comment on this, and the agency provided the following statement:

The B4UFLY app provides information regarding airspace access for recreational drone flyers. It provides land use information for takeoffs and landings for National Park Service lands, but it does not provide information regarding [where] takeoffs and landings are allowed on other federal, state, and locally managed lands and parks. Operators are expected to make themselves aware of any additional land use or police restrictions that may exist in the area where they wish to fly.

What the FAA seems to be saying is that the B4UFLY app primarily provides information about airspace. The FAA doesn’t regulate anything on the ground, which is where most other drone regulations are applied. However, the app does include drone restrictions in national parks, which is land-use information, so it’s unclear why places like wilderness areas can’t also be added to the app.

The more fundamental issue is that recreational drone pilots trust the FAA to tell them where it’s okay to fly. If the FAA is presenting the B4UFLY app as a tool that informs pilots whether it is safe to fly or not, that’s exactly what the app should do. Instead, it provides only one very limited type of information about recreational drone safety, and users may not understand that it’s on them to somehow dig up the rest of the information that may affect their flight. Based on my experience in Oregon, this can be a frustrating process that’s often inconclusive, and even the most diligent drone pilots may not be able to figure out all the relevant land use restrictions on their own.

Drones are so cheap and pervasive now that the only realistic way to make sure that people fly them safely is for the rules to be clear, concise, and easy to follow. The FAA seems to be trying to do this, but so far, the B4UFLY app is simply not good enough.

—Evan Ackerman

A version of this article appears in our Automaton blog.

POST YOUR COMMENTS at https://spectrum.ieee.org/B4UFLY1019

ILLUSTRATION BY Nate Kitch
Simulation + testing = optimized loudspeaker designs

A global leader in electronics rose to the top of the audio industry by adding multiphysics simulation to their design workflow. COMSOL Multiphysics® enables audio engineers to couple acoustics analyses and other physical phenomena to address design challenges inherent to loudspeaker and soundbar designs.

The COMSOL Multiphysics® software is used for simulating designs, devices, and processes in all fields of engineering, manufacturing, and scientific research. See how you can apply it to your loudspeaker designs.

comsol.blog/loudspeaker-design

Acoustic pressure within a speaker box and the sound pressure level in the surrounding domain.
U.S. TRUCKERS RACE TO DEPLOY ELECTRONIC LOGGING DEVICES

Early data suggests the technology is making the roads safer

As time runs out for U.S. truckers to upgrade to electronic logging devices to track how long they’re on the road, data from drivers who’ve already made the switch indicates that the controversial systems are working as intended.

Trucking companies and independent truckers operating Class 8 commercial vehicles were required to start using electronic logging devices (ELDs) by December 2017. A U.S. Department of Transportation (DOT) division that monitors the industry mandated the devices to ensure companies comply with hours-of-service rules that limit drivers to working 14 hours in a day, with no more than 11 hours of driving.

Many small fleets and independent drivers installed ELDs when the regulation took effect. But regulators gave others, primarily midsize and larger fleets, extra time to comply because they had previously installed older-generation electronic tracking systems called automatic on board recording devices, or AOBRDs. The grace period for AOBRD users ends 16 December 2019.

More than half of the 3.5 million trucks required to install ELDs still hadn’t switched as of May, according to Trucks.com. Preliminary data shows that ELD adoption already has led to fewer truckers driving when they’re not supposed to. From December 2017 to June 2019, truck-driver inspections that
ON THE ROAD: There were 4,657 large trucks involved in fatal crashes in the United States in 2017. In 60 cases, the truck driver was asleep or fatigued.

resulted in at least one hours-of-service violation dropped significantly, from 1.19 percent to 0.57 percent, according to the Federal Motor Carrier Safety Administration (FMCSA), the DOT’s trucking regulator.

“I think they’re okay,” says Michelle Kitchin, a veteran trucker from Grand Rapids, Mich., who drives for a company in the process of making the switch. “If used correctly, they can protect the driver.”

ELDs plug into a truck’s engine control module through the J1939 vehicle bus to synchronize with the engine and record required data on engine power status, engine hours, vehicle motion, and miles driven. The devices also track the identity of the driver, vehicle, and trucking company. Drivers must also input their duty status to reflect their time spent driving, waiting at a loading dock, sleeping, or on a break. The driver uses the device, which is generally about the size of a sandwich, to transfer the data when requested to the trucking company and vendor.

A typical ELD system consists of a hardware unit and a companion app. The older-generation, AOBRD, systems recorded some but not all of the same data. Many also had display screens that were hardwired to a truck, which meant drivers had to be in the cab to use them.

In the months before the ELD regulation took effect, groups representing small trucking fleets and independent drivers lobbied unsuccessfully to stop it and warned that it would lead drivers to quit rather than switch.

For the most part, that didn’t happen. “There was so much ridiculous panic that it would force people out of the industry and drivers couldn’t earn a living,” says Brian Fielkow, chief executive at Jetco Delivery, a Houston trucking and logistics company. Instead, he says, it forced carriers to charge shippers and receivers more appropriate rates.

Some trucking companies have delayed switching until the last minute, partly to wait for vendors to work out any bugs and partly to wait for prices to drop. Units can cost from several hundred dollars for bare-bones models to US $1,000 or more. Users may pay additional monthly subscription fees for data storage and analytics.

Jetco, which has 150 drivers and about the same number of trucks, switched from a hardwired system to a tablet-based system several years ago, so moving to ELDs earlier this year was relatively simple, Fielkow says. “The tablet-based system is much more practical given that drivers switch trucks,” he says.

The FMCSA allowed suppliers to self-certify their equipment, which resulted in a flood of vendors. As of early September, the agency’s database listed more than 470 registered units, with some vendors selling multiple units for different truck types.

As the December deadline approaches, trucking companies that have yet to upgrade can order devices directly from vendors or online through sites such as Amazon.com. Vendors are also selling ELDs at truck stops. Transflo, for example, stocks units at Pilot Flying J Travel Centers and Love’s Travel Stops, among others, according to Doug Schrier, the company’s vice president of product and innovation.

The company that Kitchin drives for, Van Eerden Trucking, operates a 150-truck fleet based in Byron Center, Mich., and is just now switching to ELDs. Van Eerden, which hauls office furniture to the East and West coasts and produce to Michigan on return trips, has figured out that driver relays are the key to keeping freight on the road and drivers within hours-of-service boundaries, Kitchin says. That means that after she drops off a load in California and is on her return trip, Kitchin drives as far as her hours of service will permit. If she has to stop, another driver or driver team meets her and takes her trailer, and she waits for instructions from dispatch about her next load.

“It’s keeping us moving, which makes us get more freight,” Kitchin says. “We pull more loads because we’re doing it this way, which makes everyone more money.” —MICHELLE V. RAFFER

An extended version of this article appears in our Cars That Think blog.
FINALLY, A FUNCTIONAL CARBON-NANOTUBE CPU

Three breakthroughs make commercial nanotube processors possible

Engineers at MIT and Analog Devices have created the first fully programmable 16-bit carbon-nanotube microprocessor. It’s the most complex integration of carbon-nanotube-based CMOS logic so far, with nearly 15,000 transistors, and it was done using technologies proven to work in a commercial chip-manufacturing facility. The processor, called RV16X-Nano, is a milestone in the development of beyond-silicon technologies, its inventors say.

Unlike silicon transistors, nanotube devices can easily be made in layers with dense 3D interconnections. The Defense Advanced Research Projects Agency is hoping this 3D aspect will lead to commercial carbon-nanotube (CNT) chips with the performance of today’s cutting-edge silicon but without the high costs of design and manufacturing.

Some of the same researchers created a modest one-bit, 178-transistor processor back in 2013. In contrast, the new one, which is based on the open-source RISC-V instruction set, is capable of working with 16-bit data and 32-bit instructions. Naturally, the team, led by MIT assistant professor Max Shulaker, tested the chip by running a version of the obligatory “Hello, World!” program.

Shulaker’s team, along with engineers at Analog Devices and, later, SkyWater Technology Foundry, developed three commercially viable techniques to create the RV16X-Nano:

1. When CNT transistors are made, the nanotubes are first put into a solution and spread across a silicon wafer. Most of the nanotubes lie uniformly on the silicon, but some ball up into bundles of a thousand or more. These bundles can’t form transistors. When building small-scale test circuits, this was no big deal, Shulaker explains, because even if a bundle killed one circuit, another would work. But for a large-scale integration such as the RV16X-Nano, these nanotube pileups would happen often enough to mess up the whole processor.

To cleanse that contamination, the researchers developed a technique called RINSE. It relies on the fact that individual nanotubes are stuck to the substrate by van der Waals forces more strongly than bundles are. By first coating the nanotube-covered substrate with a photoresist and then carefully washing it away—under just the right conditions—the process selectively removes the bundles but leaves the individual CNTs.

2. While RINSE dealt with one type of impurity, another nearly crashed the whole project. CNTs come in two basic flavors: metallic and semiconducting. Having some metallic nanotubes in a CNT-based logic gate means the circuit will waste power and produce a noisy signal. But how many metallic nanotubes is too many when you’re trying to build a full-scale processor?

The answer Shulaker’s team came up with was “pretty depressing.” The best that today’s commercial processes could produce is 99.99 percent semiconducting nanotubes and 0.01 percent metallic. But what’s needed is 99.999999 percent purity—impossibly far out of reach.

“We thought, if we can’t process our way out of this...then somehow we had to design our way around it,” says Shulaker. The team found that, by far, the main driver for the needed purity was not the power issue but the noise. Among the many logic circuits they’d made, they noticed that some combinations were much more susceptible to the noise problem than others. “So the solution at that point was simple: We’ll just design circuits with the good combinations of logic gates and avoid using the bad combinations,” he says. DREAM, the set of design rules that postdoctoral researcher Gage Hills came up with, allows large-scale integration using carbon nanotubes you can purchase off the shelf.
Quantum technologies are at the vanguard of many engineering fields today. Yet one of the earliest quantum applications still appears very far indeed from any kind of widespread, commercial rollout.

Despite decades of research, there’s no viable road map for how to scale quantum cryptography to secure real-world data and communications for the masses. That’s not to say that quantum cryptography lacks commercial applications. Quantum crypto, which uses delicate quantum states of individual photons to transmit information that can’t be accessed without detection, is a niche industry today. A handful of companies now operate or pay for access to networks secured using quantum cryptography in Austria, China, Japan, and the United States. But these early customers may never provide enough demand for vendors to scale these services.

“There are very high security players…but there are so few of them,” says Prem Kumar, professor of physics and electrical and computer engineering at Northwestern University, in Evanston, Ill. “The vast majority of people…don’t really want to pay anything [for their cryptography].”

From a practical standpoint, then, it doesn’t appear that quantum cryptography will be anything more than a physically elaborate, costly, and for many applications, largely ignorable method of securely delivering cryptographic keys in the near future.

This is in part because traditional cryptography, relying as it does on existing computer networks and hardware, costs very little to implement. Conversely, quantum crypto requires an entirely new infrastructure of delicate single-photon detectors and sources, and dedicated fiber-optic lines. So its high price tag must be offset by a proven security benefit, which has remained theoretical at best.

This is not how the story was expected to play out. In the
One night around 7 p.m. last August, Michael Lundquist was at his home in Tucson when his cellphone rang. He knew from the ringtone that it was a robocall. So he took it immediately. He lives for moments like this.

“LIGO/Virgo alert has been received,” the automated voice told him (generated by a Python script that he’d written). The Laser Interferometer Gravitational-Wave Observatory, or LIGO, in Louisiana and Washington state had picked up a ripple in space-time. Lundquist opened his email to see the details.

The gravitational wave front from a collision of two neutron stars some 115 million light-years away had just passed through the earth. And it looked like this potential “kilonova” event could be visible in Tucson that night. (The alert arrived, as it happened, perfectly timed to kick off the evening’s telescope observations.)

Lundquist is one of a handful of pioneers of what’s called “multimessenger” astronomy, using in this case gravitational-wave detections to trigger astronomical observations via an optical telescope. His group’s SAGUARO system (standing for Searches After Gravitational-waves Using ARizona Observatories) has automated access

1980s and ‘90s, quantum physics appeared poised to deliver the ultimate punch and counterpunch to conventional, math-based cryptography. Quantum computers were on the road to defeating public-key crypto algorithms like RSA.

But quantum physics would also, it was thought, come to the rescue. Quantum cryptography offered a physics-based crypto system that might replace mathematical cryptography, which otherwise would be in deep trouble in a world of crypto-defeating quantum computers.

Math may get the last laugh, though. An emerging subfield with the somewhat misleading name “post-quantum cryptography” now appears better situated to deliver robust and broadly scalable cryptosystems that can withstand attacks from quantum computers. (Post-quantum crypto, in fact, has nothing to do with quantum cryptography. It’s about developing conventional, mathematical cryptography that cannot be solved by quantum computers.)

“To me [quantum cryptography] seems like a solution to a problem that we don’t really have,” says Ben Perez, a security engineer at Trail of Bits, a New York City–based cybersecurity firm. “I don’t see quantum cryptography being a game changer going forward.”

That said, Trail of Bits CEO Dan Guido says even speculative post-quantum crypto implementations are far ahead of where many commercial clients are today.

“I don’t think this is on a lot of people’s radars, and I don’t think it needs to be,” Guido says.

Even if companies were ready to adopt it today, quantum cryptography is nowhere near capable of scaling up to supplant traditional crypto’s essential role in commerce, finance, banking, government, business, and Internet operations, says Lee Bassett, assistant professor of electrical and systems engineering at the University of Pennsylvania, in Philadelphia.

“Quantum cryptography is not going to replace classical cryptography anytime soon,” Bassett says. “There is just so far to go technologically until we can even provide the sort of networking backbone that’s needed.”

However, he adds, the same quantum-cryptography systems under a different name may well be crucial to some of the next steps needed to roll out future quantum computers.

“The same technologies that will allow you to do [quantum cryptography] will also allow you to build networked quantum computers,” Bassett says. “Or allow you to have modular quantum computers that have different small quantum processors that all talk to each other. The way they talk to each other is through a quantum network, and that uses the same hardware that a quantum-cryptography system would use.”

So ironically, the innards of quantum “cryptography” may one day help string smaller quantum computers together to make the kind of large-scale quantum information processor that could defeat classical cryptography.

In which case, “post-quantum cryptography” had better be ready. Because this time, the physicists may really mean it.

—MARK ANDERSON

An extended version of this article appears in our Tech Talk blog.

POST YOUR COMMENTS at https://spectrum.ieee.org/quantumcrypto1019
to a 1.5-meter survey telescope in the Catalina mountains outside Tucson.

Within an hour of receiving notification of the gravitational-wave candidate event S190822c, Lundquist and others began plotting their night’s observing run of the region of the sky where the source of this gravitational wave might be found. The LIGO data-analysis programs had concluded from the shape of the gravitational-wave front that two in-spiraling and ultimately colliding neutron stars had produced the space-time blip. LIGO is also well tuned to detect neutron star–black hole collisions and black hole–black hole collisions, the predominant, vanilla flavor in LIGO-land.

A single gravitational-wave interferometer provides precious little information about where the candidate wave originated. However, with two LIGO interferometers in different regions of the United States and one European gravitational-wave interferometer (Virgo) outside Pisa, Italy, careful timing of the wave front’s arrival at multiple detectors allows astronomers to triangulate the direction of the signal.

Ultimately, S190822c was retracted as a false alarm. Detecting changes in laser-beam path length down to fractions of the width of a proton—which is how much space-time wobbles when a gravitational wave passes through—is often a game of false positives.

Yet, as Lundquist and his coauthors describe in a recent paper published in Astrophysical Journal Letters, they have had three candidate gravitational-wave events on which to test their increasingly automated system.

The closest they’ve yet come to discovering the optical counterpart to a gravitational-wave source was on 25 April of this year. In that case, the source was in a galaxy some 500 million light-years distant.

Lundquist says that as soon as the SAGUARO system’s algorithms know where to look, they get telescope time to take pictures of between 12 and 24 tiled segments of the sky.

The team already has on file previous images from that same telescope of 5,069 patches of sky, covering most of the sky that’s visible from Tucson’s latitude. So the algorithm automatically aligns and then subtracts that archived image from the new image, which creates a picture that only registers any changes in stars or galaxies (or asteroids or comets or planets) in the frame. Through this process, the 25 April event, Lundquist says, generated 2,711 candidate sources. Such data would be impossible to sort by hand in any reasonable time frame, when the optical flare-up in the distant galaxy might be visible only for a day or two after the gravitational-wave signal arrives.

So Lundquist has also set up a machine-learning pipeline that automatically considers each potential candidate source for more trivial explanations—a known variable star, for instance, or an oversaturated image that caused noisy pixel data. This way, the team can whittle the list of possible gravitational-wave sources down to one or two dozen objects that could then be reasonably followed up on by astronomers.

The thing they’re ultimately looking for looks like a supernova in a faraway galaxy, only brighter. Called a kilonova, this recently discovered astronomical event is now believed to be the source of most of the universe’s heavy elements. That gold in your watch or ring is very likely the by-product of two neutron stars that collided sometime before or around the time when our solar system formed.

“We have it in a nice spot where we’re waiting for a really good event,” Lundquist says. “But in the meantime we’re just trying to improve the machine learning as much as possible—to make it just that much easier to find the kilonova.” —MARK ANDERSON

A version of this article appears in our Tech Talk blog.
EVER CONSIDER how much energy is consumed during a weekend music festival? Try tens of thousands of kilowatt-hours, or enough to run a small town. In a bid to eventually get rid of the exhaust-belching diesel generators that supply this electricity, engineers at Eindhoven University of Technology, in the Netherlands, have developed a 21-meter-high renewable energy tower. The Green Energy Mill, which can be erected or folded down for transport in an afternoon, is covered with 40 colorful luminescent solar concentrator panels that absorb light and direct it to solar cells at the edges of the panes. The cherry on top is a vertical wind turbine that, along with the solar panels, shunts electricity to a battery pack with a capacity of 90 kilowatt-hours. The tower will undergo several tests before debuting at festivals next year.
DAVID SCHNEIDER

A young friend recently spent a week learning about radio astronomy at the Green Bank Observatory in West Virginia. His experience prompted me to ask: How big a radio antenna would you need to observe anything interesting? It turns out the answer is a half meter across. For less than US$150 I built one that size, and it can easily detect the motions of the spiral arms of the Milky Way galaxy. Wow!

My quest began with a used satellite-TV dish and a “cantenna” waveguide made from a coffee can placed at the dish’s focus. Unfortunately, I had to abandon this simple approach when I figured out that a coffee can was too small to work for the wavelength I was most interested in: 21 centimeters. That is the wavelength of neutral hydrogen emissions, a favorite of radio astronomers because it can be used to map the location and motion of clouds of interstellar gas, such as those in the spiral arms of our galaxy.

Some research revealed that amateur radio astronomers were having success with modest horn antennas. So I copied the example of many in an online group called Open Source Radio Telescopes and purchased some aluminized foam-board insulation as antenna construction material. But I was troubled when my multimeter showed no evidence that the aluminized surface could conduct electricity. To make sure the material would have the desired effect on radio waves, I built a small box out of this foam board and put my cellphone inside it. It should have been completely shielded, but my cellphone received calls just fine.

That experiment still perplexes me, because people definitely do build radio telescopes out of aluminized foam board. In any case, I abandoned the board and for $13 purchased a roll of 20-inch-wide (51-centimeter-wide) aluminum flashing—the thin sheet metal used to weatherproof tricky spots on roofs. The width of my roll determined the aperture of my horn’s wide end. The roll was 10 feet (3 meters) long, which limited the length of the four sides to 75 cm. An online calculator showed that a horn of those dimensions would have a respectable directional gain of 17 decibels. Some hours with snips and aluminized HVAC tape ($8) resulted in a small horn antenna. Attaching a square of ordinary foam board (not the aluminized kind) to the open end made it plenty robust.

I also purchased a 1-gallon can of paint thinner ($9) and gave away its contents.

**THE SKY ELECTRIC:** The author made a horn antenna [left] out of aluminum flashing and a metal can. The antenna can detect emissions from the hydrogen gas in nearby arms of the galaxy: Dark green [above] represents the signal from the sky; light green indicates a comparison baseline system response with no signal.
empty can serves as a waveguide feed at the base of the horn antenna. A handy online waveguide calculator told me this feed would have an operating range that nicely brackets the neutral-hydrogen line frequency of 1420 megahertz.

Some folks contributing to Open Source Radio Telescopes were using similar cans. But none of the projects’ documentation showed exactly how to construct the feed’s “pin”: the part that picks up signals inside the waveguide and passes them to the telescope’s receiver. Many cantenna tutorials say to make the pin a quarter of a wavelength long, which in this case works out to 53 millimeters. The tricky part is figuring out where to place it in the can—it needs to be a quarter of a wavelength from the base. However, in this case the relevant wavelength isn’t 21 centimeters but what’s called the guide wavelength, which corrects for the difference between how the signal propagates in free space versus inside the waveguide. An online tutorial and another calculator showed the appropriate distance from the base to be 68 mm. So that’s where I drilled a hole to accommodate an N-type coaxial bulkhead connector that I had purchased on Amazon.com for $5, along with an N-to-SMA adapter ($7).

For my receiver, I went with a USB dongle that contains a television tuner plus a free software-defined radio application called HDSDR. (The software was chosen on the basis of a report from two amateur radio astronomers in Slovenia who had used it to good effect.)

I purchased the dongle from Nooelec.com ($37) because that company had also recently started selling a gizmo that seemed perfect for my application: It contains two low-noise amplifiers and a surface-acoustic-wave (SAW) filter centered on 1420 MHz ($38). The dongle itself provides power for the amplifier through the coaxial cable that connects them, a 30-cm (12-inch) length of coax purchased on Amazon.com ($9). The dongle just sits on the ground next to my horn and is attached to a Windows laptop through a USB extension cable.

At my instrument’s “first light,” I was able to detect the neutral-hydrogen line with just a little squinting. After getting more familiar with the HDSDR software, I figured out how to time-average the signal and focus on the spectral plot, which I adjusted to display average power.

This plot distinctly showed a hydrogen “line” (really a fat bump) when I pointed my horn at the star Deneb, which is a convenient guide star in the constellation of Cygnus. Point at Cygnus and you’ll receive a strong signal from the local arm of the Milky Way very near the expected 1420.4-MHz frequency. Point it toward Cassiopeia, at a higher galactic longitude, and you’ll see the hydrogen-line signal shift to 1420.5 MHz—a subtle Doppler shift indicating that the material giving off these radio waves is speeding toward us in a relative sense. With some hunting, you may be able to discern two or more distinct signals coming from different spiral arms of the Milky Way.

Don’t expect to hear E.T., but being able to map the Milky Way in this fashion feels strangely empowering. It’ll be $150 well spent.

—DAVID SCHNEIDER

POST YOUR COMMENTS at https://spectrum.ieee.org/telescope1019
launched last year, IEEE Spectrum’s Consumer Electronics Hall of Fame celebrates the gadgets, tools, and devices that brought technology into people’s homes and transformed everyday life over the course of the last 50 years. Starting later this month, IEEE members can read about a new set of inductees on Spectrum’s website, and enter a related competition to win prizes such as home theater audio gear. Here’s one to get you started.

It’s not often that one circuit revolutionizes a huge product category, but the Philips Universal class-D (UcD) module did just that for audio amplifiers. Before the UcD, there had been a few quirky and short-lived commercial class-D amps, which differed from previous amplifiers by using an intermediate stage in which transistors are rapidly switched on and off, versus directly trying to amplify a signal linearly.

But with its stunning combination of small size, light weight, low cost, high efficiency, and remarkable performance, the UcD showed what class-D amps could do. Consequently, it is a virtual certainty that you own at least one class-D unit, in your home, car, smartphone, or smart speaker.

Philips’s UcD was the brainchild of a single engineer, Bruno Putzeys, who grew up in a home where audio electronics held sway. “There was always something happening in the house that had to do with amplifiers or speakers,” Putzeys recalls of his childhood. When he first learned about class-D amps, he was hooked: “I’d read about them in a French magazine when I was 15 and was fascinated by the technique.” In college, his thesis was on class-D amps. It was that work that landed him a job at Philips.

In a nutshell, a class-D amplifier works by converting the input signal into a train of square pulses of varying width but fixed amplitude. This technique is called pulse-width modulation: The pulse width of this square wave represents the level of the analog signal. These pulses switch transistors on and off, thereby boosting the amplitude of the wave train. The resulting output is passed through a low-pass filter to reconstitute the analog signal at higher volume.

Class-D amps can be extremely efficient because the switching transistors are almost always either on or off and therefore waste little or no power; they can be more than 90 percent efficient, much higher than earlier amplifier types. Because they are so efficient and small, class-D amps can make the most of limited battery power and can be inserted in tight spaces, making them suitable for smart speakers and cellphones, where opportunities to dissipate heat are pretty meager.

Not all of these advantages were widely appreciated in 1995, when Philips hired Putzeys. He says that after he signed on, Philips lost interest in class-D amps, but he managed to get the go-ahead to build one anyway. That first device sparked enough interest to earn Putzeys the R&D budget to keep trying to improve his designs. After several unfruitful years, a manager pushed Putzeys to produce a class-D amp Philips could actually use in a product. It wouldn’t have to be perfect, he was told; just build something quick and dirty. “It was supposed to be simple and cheap, but it turned out to be something more than that,” Putzeys says.

The result was the UcD amplifier module, which could outperform any amplifier in its price range. Still, Philips chose not to incorporate the amp into any of its own products, a fact that still irritates Putzeys all these years later. So he and his colleagues began selling it under license to other manufacturers, which incorporated it into speakers, home theater systems, and more.

And though class-D audio has had a meteoric ascendance, with many more sophisticated modules coming onto the market (several created by Putzeys at other companies in his post-Philips career), the UcD has endured. Seventeen years after the first UcDs were built at Philips, one of the original licenses, Hypex, still sells a direct descendant: the UcD180HG.

—BRIAN SANTO
As of press time, the United Kingdom was scheduled to leave the European Union on 31 October. However, there has been chaos in the British parliament, and it is still uncertain if the U.K. will exit on that date, or if it does, on what terms. One thing that has become clear is that Brexit will inflict significant hardship on small- and medium-size enterprises (SMEs).

"All the stories about Brexit in the Financial Times have been about big multinational companies," says Ross Brown, a professor at the University of St. Andrews, in Scotland, and coauthor of a paper on the potential impact of Brexit on SMEs. Brown says that small companies are unable to implement...
This is a great fear, especially for companies in a sector like video games that is heavily reliant on Eastern European employees. “For a big company to open up a plant in Eastern Europe is fine, but for a small company of maybe 10 people to open another overseas office is really quite a major undertaking,” says Brown, who believes that many such small companies may downsize rather than take on this kind of additional risk.

—DEXTER JOHNSON

POST YOUR COMMENTS at https://spectrum.ieee.org/brexit1019

For a FREE 60-day evaluation, go to OriginLab.Com/demo and enter code: 8547

Over 75 New Features & Apps in Origin 2019!

Over 500,000 registered users worldwide in:

- 6,000+ Companies including 20+ Fortune Global 500
- 6,500+ Colleges & Universities
- 3,000+ Government Agencies & Research Labs
WHERE’S MY STUFF?

**WE ALL LOSE THINGS.** Think about how much time you’ve spent searching for your keys or your wallet. Now imagine how much time big companies spend searching for lost items. In a hospital, for example, the quest for a crash cart can slow a response team during an emergency, while on a construction site, the hunt for the right tool can lead to escalating delays. According to a recent study funded by Microsoft, roughly 33 percent of companies utilizing the Internet of Things are using it for tracking their stuff. Quality location data is important for more than tracking misplaced tools; it’s also necessary for robotics in manufacturing and in autonomous vehicles, so they can spot nearby humans and avoid them. The growing interest in locating things is reflected in updated wireless standards. The Bluetooth Special Interest Group estimates that with the updated 5.1 standard, the wireless technology can now locate devices to within a few inches. Elsewhere, Texas Instruments has built a radar chip using 60-gigahertz signals that can help robots “see” where things are in a factory by bouncing radio waves off its surroundings. But for me, the real excitement is in a newcomer to the scene. In August, NXP, Bosch, Samsung, and access company Assa Abloy launched the FiRa Consortium to handle location tracking using ultrawideband radios (FiRa stands for “fine-ranging”). This isn’t the ultrawideband of almost 20 years ago, which offered superfast wireless data transfers over short distances much like Wi-Fi does today. FiRa uses a wide band of spectrum in the 6- to 9-GHz range and relies on the new IEEE 802.15.4z standard. The base standard is used for other IoT network technologies, including Zigbee, Wi-SUN, 6LoWPAN, and Thread radios, but the z formulation is designed specifically for securely ascertaining the location of a device.

FiRa delivers location data based on a time-of-flight measurement—the time it takes a quick signal pulse to make a round trip to the device. This is different from Bluetooth’s method, which opens a connection between radios and then broadcasts the location. Charles Dachs, vice chair of the FiRa Consortium and vice president of mobile transactions at NXP, says FiRa’s pulselike data transmissions allow location data to be gleaned for items within 100 to 200 meters of a node without sucking up a lot of power. Time-of-flight measurements allow for additional security, since they make it harder to spoof a location, and they’re so accurate, it’s obvious that a person is right there, not even a few meters away. Also, because the radio transmissions aren’t constant, it’s possible for hundreds of devices to ping a node without overwhelming it. By comparison, Bluetooth nodes can handle only about 50 devices.

FiRa’s location-tracking feature is likely to be the application that entices many companies to adopt the standard, but it can do more. The consortium also hopes that automotive companies will use it for securely unlocking car doors or front doors wirelessly. However, there is a downside: Widespread FiRa use for locks would require either a separate fob or new radios on our smartphones. I think it’s far more likely that FiRa will find its future in enterprise and industrial asset tracking. Historically, Bluetooth has struggled in this space because of the limited number of connections that can be made. Other radios have been a bit too niche, or not well designed for enterprise use. As for location tracking for us consumers? Apple and Google are both betting on Bluetooth, so that’s where I’d place my bets, too.
IN 1896, SVANTE ARRHENIUS, OF SWEDEN, became the first scientist to quantify the effects of man-made carbon dioxide on global temperatures. He calculated that doubling the atmospheric level of the gas from its concentration in his time would raise the average midlatitude temperature by 5 to 6 degrees Celsius. That’s not too far from the latest results, obtained by computer models running more than 200,000 lines of code. • The United Nations held its first Framework Convention on Climate Change in 1992, and this was followed by a series of meetings and climate treaties. But the global emissions of carbon dioxide have been rising steadily just the same. • At the beginning of the 19th century, when the United Kingdom was the only major coal producer, global emissions of carbon from fossil fuel combustion were minuscule, at less than 10 million metric tons a year. (To express them in terms of carbon dioxide, just multiply by 3.66.) By century’s end, emissions surpassed half a billion metric tons of carbon. By 1950, they had topped 1.5 billion metric tons. The postwar economic expansion in Europe, North America, the U.S.S.R., and Japan, along with the post-1980 economic rise of China, quadrupled emissions thereafter, to about 6.5 billion metric tons of carbon by the year 2000. • The new century has seen a significant divergence. By 2017, emissions had declined by about 15 percent in the European Union, with its slower economic growth and aging population, and also in the United States, thanks largely to the increasing use of natural gas instead of coal. However, all these gains were outbalanced by Chinese carbon emissions, which rose from about 1 billion to about 3 billion metric tons—enough to increase the worldwide total by nearly 45 percent, to 10.1 billion metric tons. • By burning huge stocks of carbon that fossilized ages ago, human beings have pushed carbon dioxide concentrations to levels not seen for about 3 million years. The sampling of air locked in tiny bubbles in cores drilled into Antarctic and Greenland ice has enabled us to reconstruct carbon dioxide concentrations going back some 800,000 years. Back then the atmospheric levels of the gas fluctuated between 180 and 280 parts per million (that is, from 0.018 to 0.028 percent). During the past millennium, the concentrations remained fairly stable, ranging from 275 ppm in the early 1600s to about 285 ppm before the end of the 19th century. Continuous measurements of the gas began near the top of Mauna Loa, in Hawaii, in 1958: The 1959 mean was 316 ppm, the 2015 average reached 400 ppm, and 415 ppm was first recorded in May 2019.

Emissions will continue to decline in affluent countries, and the rate at which they grow in China has begun to slow down. However, it is speeding up in India and Africa, and hence it is unlikely that we will see any substantial global declines anytime soon.

The Paris agreement of 2015 was lauded as the first accord containing specific national commitments to reduce future emissions, but even if all its targets were met by 2030, carbon emissions would still rise to nearly 50 percent above the 2017 level. According to the 2018 study by the Intergovernmental Panel for Climate Change, the only way to keep the average world temperature rise to no more than 1.5 °C would be to put emissions almost immediately into a decline steep enough to bring them to zero by 2050.

That is not impossible—but it is very unlikely. The contrast between the expressed concerns about global warming and the continued releases of record volumes of carbon could not be starker.
The proliferation of navigation apps is causing traffic chaos. It’s time to restore order.

Miguel Street is a winding, narrow route through the Glen Park neighborhood of San Francisco. Until a few years ago, only those living along the road traveled it, and they understood its challenges well. Now it’s packed with cars that use it as a shortcut from congested Mission Street to heavily traveled Market Street. Residents must struggle to get to their homes, and accidents are a daily occurrence. The problem began when smartphone apps like Waze, Apple Maps, and Google Maps came into widespread use, offering drivers real-time routing around traffic tie-ups. An estimated 1 billion drivers use such apps in the United States alone. Today, traffic jams are popping up unexpectedly in previously quiet neighborhoods around the country and the world. Along Adams Street, in the Boston neighborhood of Dorchester, residents complain of speeding vehicles at rush hour, many with drivers who stare down at their phones to determine their next maneuver. London shortcuts, once a secret of black-cab drivers, are now overrun with app users. Israel was one of the first to feel the pain because Waze was founded there; it quickly caused
such havoc that a resident of the Herzliya Bet neighborhood sued the company.

The problem is getting worse. City planners around the world have predicted traffic on the basis of residential density, anticipating that a certain amount of real-time changes will be necessary in particular circumstances. To handle those changes, they have installed tools like stoplights and metering lights, embedded loop sensors, variable message signs, radio transmissions, and dial-in messaging systems. For particularly tricky situations—an obstruction, event, or emergency—city managers sometimes dispatch a human being to direct traffic.

But now online navigation apps are in charge, and they’re causing more problems than they solve. The apps are typically optimized to keep an individual driver’s travel time as short as possible; they don’t care whether the residential streets can absorb the traffic or whether motorists who show up in unexpected places may compromise safety. Figuring out just what these apps are doing and how to make them better coordinate with more traditional traffic-management systems is a big part of my research at the University of California, Berkeley, where I am director of the Smart Cities Research Center.

**Here’s how the apps evolved.** Typically, the base road maps used by the apps represent roads as five functional classes, from multilane freeways down to small residential streets. Each class is designed to accommodate a different number of vehicles moving through per hour at speeds that are adjusted for local conditions. The navigation systems—originally available as dedicated gadgets or built into car dashboards and now in most smartphones—have long used this information in their routing algorithms to calculate likely travel time and to select the best route.

Initially, the navigation apps used these maps to search through all the possible routes to a destination. Although that worked well when users were sitting in their driveways, getting ready to set out on a trip, those searches were too computationally intensive to be useful for drivers already on the road. So software developers created algorithms that identify just a few routes, estimate the travel times of each, and select the best one. This approach might miss the fastest route, but it generally worked pretty well. Users could tune these algorithms to prefer certain types of roads over others—for example, to prefer highways or to avoid them.

The digital mapping industry is a small one. Navteq (now Here Technologies) and TomTom, two of the earliest digital-map makers, got started about 30 years ago. They focused mainly on building the data sets, typically releasing updated maps quarterly. In between these releases, the maps and the routes suggested by the navigation apps didn’t change.

When navigation capabilities moved to apps on smartphones, the navigation system providers began collecting travel speeds and locations from all the users who were willing to let the app share their information. Originally, the system providers used these GPS traces as historical data in algorithms designed to estimate realistic speeds on the roads at different times of day. They integrated these estimates with the maps, identifying red, yellow, and green routes—where red meant likely congestion and green meant unrestricted flow.

As the historical records of these GPS traces grew and the coverage and bandwidth of the cellular networks improved, developers started providing traffic information to users in nearly real time. Estimates were quite accurate for the more popular apps, which had the most drivers in a particular region.

And then, around 2013, Here Technologies, TomTom, Waze, and Google went beyond just flagging traffic jams ahead. They began offering real-time rerouting suggestions, considering current traffic on top of the characteristics of the road network. That gave their users opportunities to get around traffic slowdowns, and that’s how the chaos began.

On its face, real-time rerouting isn’t a problem. Cities do it all the time by changing the signal, phase, and timing of traffic lights or flashing detour alerts on signs. The real problem is that the traffic management apps are not working with existing urban infrastructures to move the most traffic in the most efficient way.

First, the apps don’t account for the peculiarities of a given neighborhood. Remember the five classes of roads along with their estimated free-flow speeds I mentioned? That’s virtually all the apps know about the roads themselves. For example, Baxter Street in Los Angeles—also a scene of increased accidents due to app-induced shortcutting—is an extremely steep road that follows what originally was a network of goat paths. But to the apps, this road looks like any other residential road with a low speed limit. They assume it has parking on both sides and room for two-way traffic in between. It doesn’t take into account that it has a 32 percent grade and that when you’re at the top you can’t see the road ahead or oncoming cars. This blind spot has caused drivers to stop unexpectedly, causing accidents on this once-quiet neighborhood street.
A sporting event at a nearby stadium [A] causes a traffic backup on the highway that bypasses the center of this imaginary urban area. That’s a problem for our hypothetical driver trying to get home from work, so she turns to a navigation app for help. The shortest—and, according to the app, the fastest—alternate route [blue line] winds through a residential neighborhood with blind turns, a steep hill [B], and a drawbridge [C], which can create unexpected delays for those unfamiliar with its scheduled openings. The red route cuts through the city center [D] and in front of an elementary school [E]; the app doesn’t know school just let out for the day. Fortunately, our driver knows the area, so she selects the purple route, even though the app indicates that it isn’t the fastest option. Drivers unfamiliar with the area and looking for a shortcut to the stadium could find themselves in chaotic—even hazardous—situations.

WHAT THE TRAFFIC APPS DON’T KNOW

The algorithms also may not consider other characteristics of the path they choose. For example, does it include roads on which there are a lot of pedestrians? Does it pass by an elementary school? Does it include intersections that are difficult to cross, such as a small street crossing a major thoroughfare with no signal light assistance?

I recently experienced what such cluelessness can cause. I was in congested traffic on a multilane road when an app offered to get me out of the traffic by sending me into a residential neighborhood. It routed me right past an elementary school at 8:15 a.m. There were crossing guards, minivans double parked, kids jumping out of cars, and drivers facing the bright morning sun having a hard time seeing in the glare. I only added to the chaos.

On top of all these problems, these rerouting apps are all out for themselves. They take a selfish view in which each vehicle is competing for the fastest route to its destination. This can lead to the router creating new traffic congestion in unexpected places.

Consider cars crossing a thoroughfare without the benefit of a signal light. Perhaps the car on the smaller road has a stop sign. Likely, it was designed as a two-way stop because traffic on the larger road was typically light enough that the wait to cross was comfortably short. Add cars to that larger road, however, and breaks in the traffic become few, causing the line of cars waiting at the stop sign to flow onto neighboring streets. If you’re in the car on the larger road, you may be zipping along to your destination. But if you’re on the smaller road, you may have to wait a very long time to cross. And if the apps direct more and more cars to these neighborhood roads, as may happen when a nearby highway is experiencing abnormal delays, the backups build and the likelihood of accidents increases.

To compound the “selfish routing” problem, each navigation application provider—Google, Apple, Waze (now owned by Google)—operates independently. Each provider receives data streamed to its servers only from the devices of its users, which means that the penetration of its app colors the system’s understanding of reality. If the app’s penetration is low, the system may
GOATS ONLY? The steep and narrow Baxter Street in Los Angeles, originally a network of goat paths, looked like any other residential road to the traffic apps, which rerouted drivers along it and caused chaos.

fall back on historical traffic speeds for the area instead of getting a good representation of existing congestion. So we have multiple players working independently with imperfect information and expecting that the entire road network is available to absorb their users in real time.

Meanwhile, city transportation engineers are busy managing traffic with the tools they have at their disposal, like those on-ramp metering lights, messaging signs, and radio broadcasts suggesting real-time routing adjustments that I mentioned previously. Their goal is to control the congestion, maintain a safe and effective travel network, and react appropriately to such things as accidents, sporting events, and, in emergency situations, evacuations.

The city engineers are also working in isolation, with incomplete information, because they have no idea what the apps are going to do at any moment. The city now loses its understanding of the amount of traffic demanding access to its roads. That’s a safety issue in the short term and a planning issue in the long term: It blinds the city to information it could use to develop better traffic-mitigation strategies—for example, urging businesses to consider different work shifts or fleet operators to consider different routes.

So you may have recently benefited from one of these shortcuts, but it’s doubtful that you’re winning the long game. To do that takes thinking about the system as a whole and perhaps even considering aggregate fuel consumption and emissions. Only then can we use these rerouting algorithms for the benefit of all citizens and our environment.

In the meantime, neighborhoods and citizens are fighting back against the strangers using their streets as throughways. In the early days of the problem, around 2014, residents would try to fool the applications into believing there were accidents tying up traffic in their neighborhood by logging fake incidents into the app. Then some neighborhoods convinced their towns to install speed bumps, slowing down the traffic and giving a route a longer base travel time.

A town in New Jersey, Leonia, simply closed many of its streets to through traffic during commute hours, levying heavy fines for nonresident drivers. Neighboring towns followed suit. And all faced the unintended consequence of their local businesses now losing customers who couldn’t get through the town at those hours.

The city of Los Angeles recently responded to the issues on Baxter Street by recasting the street as one-way: downhill only. It’s still not ideal; it means longer trips for residents coming and going from their homes, but it reduced the chaos.

Last year, an unfortunate situation in Los Angeles during the 2017 wildfires clearly demonstrated the lack of congruence among the rerouting apps and traditional traffic management: The apps directed drivers onto streets that were being closed by the city, right into the heart of the fire. This is not the fault of the algorithms; it is simply extremely difficult to maintain an up-to-date understanding of the roads during fast-moving events. But it does illustrate why city officials need a way to connect with or even override these apps. Luckily, the city had a police officer in the area, who was able to physically turn traffic away onto a safer route.

These are mere stopgap measures; they serve to reduce, not improve, overall mobility. What we really want is a socially optimum state in which the average travel time is minimized everywhere. Traffic engineers call this state system optimum equilibrium, one of the two Wardrop principles of equilibrium. How do we merge the app-following crowds with an engineered flow of traffic that at least moves toward a socially optimized system, using the control mechanisms we have on hand? We can begin by pooling everyone’s view of the real-time state of the road network. But getting everybody in the data pool won’t be easy. It is a David and Goliath story—some players like Google and Apple have massive back-office digital infrastructures to run these operations, while many cit-
ies have minimal funding for advanced technology development. Without the ability to invest in new technology, cities can’t catch up with these big technology providers and instead fall back on regulation. For example, Portland, Ore., Seattle, and many other cities have lowered the speed limits on residential streets to 20 miles per hour.

There are better ways. We must convince the app makers that if they share information with one another and with city governments, the rerouting algorithms could consider a far bigger picture, including information from the physical infrastructure, such as the timing schedule for traffic lights and meters and vehicle counts from static sensors, including cameras and inductive loops. This data sharing would make their apps better while simultaneously giving city traffic planners a helping hand.

As a first step, we should form public-private partnerships among the navigation app providers, city traffic engineering organizations, and even transportation companies like Uber and Lyft. Sharing all this information would help us figure out how to best reduce congestion and manage our mobility.

**We have a number** of other hurdles to overcome before all the apps and infrastructure tools can work together well enough to optimize traffic flow for everyone.

The real challenge with traffic control is the enormous scale of the problem. Using the flood of data from app users along with the data from city sensors will require a new layer of data analytics that takes the key information and combines it, anonymizes it, and puts it in a form that can be more easily digested by government-operated traffic management systems.

We also need to develop simulation software that can use all this data to model the dynamics of our mobility on an urban scale. Developing this software is a key topic of current research sponsored by the U.S. Department of Energy’s Energy Efficient Mobility Systems program and involving Here Technologies and three national laboratories: Lawrence Berkeley, Argonne, and Pacific Northwest. I am involved with this research program through the Berkeley lab, where I am a guest scientist in the Sustainable Transportation Initiative. To date, a team supported by this program, led by me and staffed by researchers from the three labor-

DURING THE 2017 WILDFIRES, THE APPS DIRECTED DRIVERS ONTO STREETS THAT WERE BEING CLOSED BY THE CITY, RIGHT INTO THE HEART OF THE FIRE.

DURING THE 2017 WILDFIRES, THE APPS DIRECTED DRIVERS ONTO STREETS THAT WERE BEING CLOSED BY THE CITY, RIGHT INTO THE HEART OF THE FIRE.

DURING THE 2017 WILDFIRES, THE APPS DIRECTED DRIVERS ONTO STREETS THAT WERE BEING CLOSED BY THE CITY, RIGHT INTO THE HEART OF THE FIRE.

DURING THE 2017 WILDFIRES, THE APPS DIRECTED DRIVERS ONTO STREETS THAT WERE BEING CLOSED BY THE CITY, RIGHT INTO THE HEART OF THE FIRE.

hour in the evening congestion period; an incident on a highway, of course, would cause these numbers to jump.

This simulation demonstrates how much traffic planners can do to rebalance traffic flow, and it provides numbers that, right now, are not directly available. The next question is how much of the road network you want to use, trading off highway congestion for some additional traffic on neighborhood roads.

Our next step will be to modify our algorithm to consider neighborhood constraints. We know, for example, that we don’t want to reroute traffic into school zones during drop-off and pickup times, and that we should modify navigation algorithms appropriately.

We hope to soon put these tools in the hands of government transportation agencies.

**That’s what we’re** trying to do with technology to address the problem. But there are nontechnical hurdles as well. For example, location data can contain personal information that cannot be shared indiscriminately. And current business models may make for-profit companies reluctant to give away data that has value.

Solving both the technical and nontechnical issues will require research and public-private partnerships before we can assemble this cooperative ecosystem. But as we learn more about what drives the dynamics of our roads, we will be able to develop effective routing and traffic controls that take into account neighborhood concerns, the business objectives of fleet owners, and people’s health and convenience.

I am confident that most people, when well informed, would be open to a little inconvenience in the furtherance of the common good. Wouldn’t you be willing to drive a few extra minutes to spare a neighborhood and improve the environment?”
The need to make some hardware systems tinier and tinier and others bigger and bigger has been driving innovations in electronics for a long time. The former can be seen in the progression from laptops to smartphones to smart watches to hearables and other “invisible” electronics. The latter defines today’s commercial data centers—megawatt-devouring monsters that fill purpose-built warehouses around the world. Interestingly, the same technology is limiting progress in both arenas, though for different reasons.

• The culprit, we contend, is the printed circuit board. And the solution is to get rid of it. • Our research shows that the printed circuit board could be replaced with the same material that makes up the chips that are attached to it, namely silicon. Such a move would lead to smaller, lighter-weight systems for wearables and other size-constrained gadgets, and also to incredibly powerful high-performance computers that would pack dozens of servers’ worth of computing capability onto a dinner-plate-size wafer of silicon.

Goodbye, Motherboard.

Hello, Silicon-Interconnect Fabric

By Puneet Gupta & Subramanian S. Iyer
This all-silicon technology, which we call silicon-interconnect fabric, allows bare chips to be connected directly to wiring on a separate piece of silicon. Unlike connections on a printed circuit board, the wiring between chips on our fabric is just as small as wiring within a chip. Many more chip-to-chip connections are thus possible, and those connections are able to transmit data faster while using less energy.

Silicon-interconnect fabric, or Si-IF, offers an added bonus. It’s an excellent path toward the dissolution of the (relatively) big, complicated, and difficult-to-manufacture systems-on-chips that currently run everything from smartphones to supercomputers. In place of SoCs, system designers could use a conglomeration of smaller, simpler-to-design, and easier-to-manufacture chiplets tightly interconnected on an Si-IF. This chiplet revolution is already well under way, with AMD, Intel, Nvidia, and others offering chiplets assembled inside of advanced packages. Silicon-interconnect fabric expands that vision, breaking the system out of the package to include the entire computer.

To understand the value of eliminating the printed circuit board, consider what happens with a typical SoC. Thanks to Moore’s Law, a 1-square-centimeter piece of silicon can pack pretty much everything needed to drive a smartphone. Unfortunately, for a variety of reasons that mostly begin and end with the printed circuit board, this sliver of silicon is then put inside a (usually) plastic package that can be as much as 20 times as large as the chip itself.

The size difference between chip and package creates at least two problems. First, the volume and weight of the packaged chip are much greater than those of the original piece of silicon. Obviously, that’s a problem for all things that need to be small, thin, and light. Second, if the final hardware requires multiple chips that talk to one another (and most systems do), then the distance that signals need to travel increases by more than a factor of 10. That distance is a speed and energy bottleneck, especially if the chips exchange a lot of data. This choke point is perhaps the biggest problem for data-intensive applications such as graphics, machine learning, and search. To make matters worse, packaged chips are difficult to keep cool. Indeed, heat removal has been a limiting factor in computer systems for decades.

If these packages are such a problem, why not just remove them? Because of the printed circuit board.

The purpose of the printed circuit board is, of course, to connect chips, passive components, and other devices into a working system. But it’s not an ideal technology. PCBs are difficult to make perfectly flat and are prone to warpage. Chip packages usually connect to the PCB via a set of solder bumps, which are melted and resolidified during the manufacturing process. The limitations of solder technology combined with surface warpage mean these solder bumps can be no less than 0.5 millimeters apart. In other words, you can pack no more than 400 connections per square centimeter of chip area. For many applications, that’s far too few connections to deliver power to the chip and get signals in and out. For example, the small area taken up by one of the Intel Atom processor’s dies has only enough room for a hundred 0.5-mm connections, falling short of what it needs by 300. Designers use the chip package to make the connection—per-unit-area math work. The package takes tiny input/output connections on the silicon chip—ranging from 1 to 50 micrometers wide—and fans them out to the PCB’s 500-μm scale.

Recently, the semiconductor industry has tried to limit the problems of printed circuit boards by developing advanced packaging, such as silicon interposer technology. An interposer is a thin layer of silicon on which a small number of bare silicon chips are mounted and linked to each other with a larger number of connections than could be made between two packaged chips. But the interposer and its chips must still be packaged and mounted on a PCB, so this arrangement adds complexity without solving any of the other issues. Moreover, interposers are necessarily thin, fragile, and limited in size, which means it is difficult to construct large systems on them.

We believe that a better solution is to get rid of packages and PCBs altogether and instead bond the chips onto a relatively thick (500-μm to 1-mm) silicon wafer. Processors, memory dies, analog and RF chiplets, voltage-regulator modules, and even passive components such as inductors and capacitors can be bonded directly to the silicon. Compared with the usual PCB material—a fiberglass and epoxy composite called FR-4—a silicon wafer is rigid and can be polished to near perfect flatness, so warping is no longer an issue. What’s more, because the chips and the silicon substrate expand and contract at the same rate as they heat and cool, you no longer need a large, flexible link like a solder bump between the chip and the substrate.

Solder bumps can be replaced with micrometer-scale copper pillars built onto the silicon substrate. Using thermal compression—which basically is precisely applied heat and force—the chip’s copper I/O ports can then be directly bonded to the pillars. Careful optimization of the thermal-compression bonding can produce copper-to-copper bonds that are far more reliable than soldered bonds, with fewer materials involved.

Eliminating the PCB and its weaknesses means the chip’s I/O ports can be spaced as little as 10 μm apart instead of 500 μm. We can therefore
pack 2,500 times as many I/O ports on the silicon die without needing the package as a space transformer.

Even better, we can leverage standard semiconductor manufacturing processes to make multiple layers of wiring on the Si-IF. These traces can be much finer than those on a printed circuit board. They can be less than 2 µm apart, compared with a PCB’s 500 µm. The technology can even achieve chip-to-chip spacing of less than 100 µm, compared with 1 mm or more using a PCB. The result is that an Si-IF system saves space and power and cuts down on the time it takes signals to reach their destinations.

Furthermore, unlike PCB and chip-package materials, silicon is a reasonably good conductor of heat. Heat sinks can be mounted on both sides of the Si-IF to extract more heat—our estimates suggest up to 70 percent more. Removing more heat lets processors run faster.

Although silicon has very good tensile strength and stiffness, it is somewhat brittle. Fortunately, the semiconductor industry has developed methods over the decades for handling large silicon wafers without breaking them. And when Si-IF-based systems are properly anchored and processed, we expect them to meet or exceed most reliability tests, including resistance to shock, thermal cycling, and environmental stresses.

There’s no getting around the fact that the material cost of crystalline silicon is higher than that of FR-4. Although there are many factors that contribute to cost, the cost per square millimeter of an 8-layer PCB can be about one-tenth that of a 4-layer Si-IF wafer. However, our analysis indicates that when you remove the cost of packaging and complex circuit-board construction and factor in the space savings of Si-IF, the difference in cost is negligible, and in many cases Si-IF comes out ahead.

Let’s look at a few examples of how Si-IF integration can benefit a computer system.

In one study of server designs, we found that using package-less processors based on Si-IF can double the performance of conventional processors because of the higher connectivity and better heat dissipation. Even better, the size of the silicon “circuit board” (for want of a better term) can be reduced from 1,000 cm² to 400 cm². Shrinking the system that much has real implications for datacenter real estate and the amount of cooling infrastructure needed. At the other extreme, we looked at a small Internet of Things system based on an Arm microcontroller. Using Si-IF here not only shrinks the size of the board by 70 percent but also reduces its weight from 20 grams to 8 grams.

Apart from shrinking existing systems and boosting their performance, Si-IF should let system designers create computers that would otherwise be impossible, or at least extremely impractical.

A typical high-performance server contains two to four processors on a PCB. But some high-performance computing applications need multiple servers. Communication latency and bandwidth bottlenecks arise when data needs to move across different processors and PCBs. But what if all the processors were on the same wafer of silicon? These processors could be integrated nearly as tightly as if the whole system were one big processor.

This concept was first proposed by Gene Amdahl at his company Trilogy Systems. Trilogy failed because manufacturing processes couldn’t yield
enough working systems. There is always the chance of a defect when you’re making a chip, and the likelihood of a defect increases exponentially with the chip’s area. If your chip is the size of a dinner plate, you’re almost guaranteed to have a system-killing flaw somewhere on it.

But with silicon-interconnect fabric, you can start with chiplets, which we already know can be manufactured without flaws, and then link them to form a single system. A group of us at the University of California, Los Angeles, and the University of Illinois at Urbana-Champaign architected such a wafer-scale system comprising 40 GPUs. In simulations, it sped calculations more than fivefold and cut energy consumption by 80 percent when compared with an equivalently sized 40-GPU system built using state-of-the-art multichip packages and printed circuit boards.

Power turned out to be a major constraint. At a chip’s standard 1-volt supply, the wafer’s narrow wiring would consume a full 2 kilowatts. Instead, we chose to up the supply voltage to 12 V, reducing the amount of current needed and therefore the power consumed. That solution required spreading voltage regulators and signal-conditioning capacitors all around the wafer, taking up space that might have gone to more GPU modules. Encouraged by the early results, we are now building a prototype wafer-scale computing system, which we hope to complete by the end of 2020.

Silicon-interconnect fabric could play a role in an important trend in the computer industry: the dissolution of the system-on-chip (SoC) into integrated collections of dielets, or chiplets. (We prefer the term dielets to chiplets because it emphasizes the nature of a bare silicon die, its small size, and the possibility that it might not be fully functional without other dielets on the Si-IF.) Over the past two decades, a push toward better performance and cost reduction compelled designers to replace whole sets of chips with ever larger integrated SoCs. Despite their benefits (especially for high-volume systems), SoCs have plenty of downsides.

For one, an SoC is a single large chip, and as already mentioned, ensuring good yield for a large chip is very difficult, especially when state-of-the-art semiconductor manufacturing processes are involved. (Recall that chip yield drops roughly exponentially as the chip area grows.) Another drawback of SoCs is their high one-time design and manufacturing costs, such as the US $2 million or more for the photolithography masks, which can make SoCs basically unaffordable for most designs. What’s more, any change in the design or upgrade of the manufacturing process, even a small one, requires significant redesign of the entire SoC. Finally, the SoC approach tries to force-fit all of the subsystem designs into a single manufacturing process, even if some of those subsystems would perform better if made using a different process. As a result, nothing within the SoC achieves its peak performance or efficiency.

The packageless Si-IF integration approach avoids all of these problems while retaining the SoC’s small size and performance benefits and providing design and cost benefits, too. It breaks up the SoC into its component systems and re-creates it as a system-on-wafer or system-on-Si-IF (SoIF).

Such a system is composed of independently fabricated small dielets, which are connected on the Si-IF. The minimum separation between the dielets (a few tens of micrometers) is comparable to that between two functional blocks within an SoC. The wiring on the Si-IF is the same as that used within the upper levels of an SoC and therefore the interconnect density is comparable as well.
The advantages of the SoIF approach over SoCs stem from the size of the dielet. Small dielets are less expensive to make than a large SoC because, as we mentioned before, you get a higher yield of working chips when the chips are smaller. The only thing that’s large about the SoIF is the silicon substrate itself. The substrate is unlikely to have a yield issue because it’s made up of just a few easy-to-fabricate layers. Most yield loss in chipmaking comes from defects in the transistor layers or in the ultradense lower metal layers, and a silicon-interconnect fabric has neither. Beyond that, an SoIF would have all the advantages that industry is looking for by moving to chiplets. For example, upgrading an SoIF to a new manufacturing node should be cheaper and easier. Each dielet can have its own manufacturing technology, and only the dielets that are worth upgrading would need to be changed. Those dielets that won’t get much benefit from a new node’s smaller transistors won’t need a redesign. This heterogeneous integration allows you to build a completely new class of systems that mix and match dielets of various generations and of technologies that aren’t usually compatible with CMOS. For example, our group recently demonstrated the attachment of an indium phosphide die to an SoIF for potential use in high-frequency circuits.

Because the dielets would be fabricated and tested before being connected to the SoIF, they could be used in different systems, amortizing their cost significantly. As a result, the overall cost to design and manufacture an SoIF can be as much as 70 percent less than for an SoC, by our estimate. This is especially true for large, low-volume systems like those for the aerospace and defense industries, where the demand is for only a few hundred to a few thousand units. Custom systems are also easier to make as SoIFs, because both design costs and time shrink.

We think the effect on system cost and diversity has the potential to usher in a new era of innovation where novel hardware is affordable and accessible to a much larger community of designers, startups, and universities.

Over the last few years, we’ve made significant progress on Si-IF integration technology, but a lot remains to be done. First and foremost is the demonstration of a commercially viable, high-yield Si-IF manufacturing process. Patterning wafer-scale Si-IF may require innovations in “maskless” lithography. Most lithography systems used today can make patterns only about 33 by 24 mm in size. Ultimately, we’ll need something that can cast a pattern onto a 300-mm-diameter wafer.

We’ll also need mechanisms to test bare dielets as well as unpopulated Si-IFs. The industry is already making steady progress in bare die testing as chipmakers begin to move toward chiplets in advanced packages and 3D integration.

Next, we’ll need new heat sinks or other thermal-dissipation strategies that take advantage of silicon’s good thermal conductivity. With our colleagues at UCLA, we have been developing an integrated wafer-scale cooling and power-delivery solution called PowerTherm.

In addition, the chassis, mounts, connectors, and cabling for silicon wafers need to be engineered to enable complete systems.

We’ll also need to make several changes to design methodology to deliver on the promise of SoIFs. Si-IF is a passive substrate—it’s just conductors, with no switches—and therefore the interdielet connections need to be short. For longer connections that might have to link distant dielets on a wafer-scale system, we’ll need intermediate dielets to help carry data further. Design algorithms that do layout and pin assignments will need an overhaul in order to take advantage of this style of integration. And we’ll need to develop new ways of exploring different system architectures that leverage the heterogeneity and upgradability of SoIFs.

We also need to consider system reliability. If a dielet is found to be faulty after bonding or fails during operation, it will be very difficult to replace. Therefore, SoIFs, especially large ones, need to have fault tolerance built in. Fault tolerance could be implemented at the network level or at the dielet level. At the network level, interdielet routing will need to be able to bypass faulty dielets. At the dielet level, we can consider physical redundancy tricks like using multiple copper pillars for each I/O port.

Of course, the benefit of dielet assembly depends heavily on having useful dielets to integrate into new systems. At this stage, the industry is still figuring out which dielets to make. You can’t simply make a dielet for every subsystem of an SoC, because some of the individual dielets would be too tiny to handle. One promising approach is to use statistical mining of existing SoC and PCB designs to identify which functions “like” to be physically close to each other. If these functions involve the same manufacturing technologies and follow similar upgrade cycles as well, then they should remain integrated on the same dielet.

This might seem like a long list of issues to solve, but researchers are already dealing with some of them through the Defense Advanced Research Projects Agency’s Common Heterogeneous Integration and IP Reuse Strategies (CHIPS) program as well as through industry consortia. And if we can solve these problems, it will go a long way toward continuing the smaller, faster, and cheaper legacy of Moore’s Law.
The New Science of
Bioball

SENSORS AND SOFTWARE PROTECT BASEBALL PITCHERS FROM INJURY

By WILL CARROLL & BEN HANSEN
When St. Louis Cardinals pitcher Jordan Hicks [below] takes to the mound, batters tremble. He has the same form as any other pitcher in Major League Baseball (MLB) as he throws the ball, but his results are extraordinary. In the windup, he steps back on one leg, lifting his other leg to raise his center of gravity. Then he strides forward, his hips swiveling, while his throwing arm extends back nearly parallel to the ground. As his arm comes forward, the muscles and ligaments in his elbow absorb over 100 newton meters of torque.

Hicks’s hand snaps forward, faster than the eye can see. If his arm were an engine, you’d see 1,200 rpm on the tachometer. Hicks’s fastballs have clocked in at 105 miles per hour (169 kilometers per hour), giving the batter less than a tenth of a second to recognize the pitch and react to it, trying to put bat on ball. But this repeatable miracle of biomechanics and talent does have a cost. In late June 2019, Hicks left a game with elbow pain—and it was soon revealed that he had torn a crucial ligament. He required what’s known as Tommy John surgery to repair the ligament and sat out the rest of the 2019 baseball season.

Baseball is at a crossroads. Pitchers are throwing at higher velocities than ever before, causing a surge of injuries to the ulnar collateral ligament (UCL) in the elbow, which connects the bones of the upper and lower arm. The number of Tommy John surgeries has skyrocketed over the past decade, and coaches, trainers, and players are desperately searching for technology to combat this epidemic. One ongoing MLB study uses motion capture to chart the pitching form of every new pitcher drafted into the league. It then combines that information with data from MRIs and other physical exams in an effort to identify players at risk of injury. While this campaign is laudable, a single assessment of pitching mechanics can’t predict injury over the years of athletic labor to come.

There is a better way. Technologies now exist that allow for constant and long-term recording of a pitcher’s arm movements, enabling players to track and understand the stresses on their bodies.

At our sports technology company, Motus Global, we use consumer-grade sensors—the kind that have been perfected for smartphones—to gather biometric data related to an athlete’s ultimate workload. Our analytics use software models of muscle fatigue to help pitchers improve performance while decreasing risk of injury. By using affordable technologies, we put data not just within the reach of the 30 MLB teams but also their 160 minor league affiliates, hundreds of college teams, and thousands of youth-level teams around the country.

In 2015, we introduced our first wearable for baseball: Motus Throw, a compression sleeve with a sensor that tracks the motion of a pitcher’s arm. A companion iOS app and Web-based dashboard present analytics to players and coaches. In 2015, MLB approved our technology for use on the field during ball games. By 2019, about a dozen MLB teams were using our technology for training and rehab programs.
In the 2000s, professional baseball was overhauled by an approach that’s often called moneyball, in which teams used obscure performance statistics to better understand players’ true value. You could call our approach bioball—by bringing biological data into the mix, we think teams can take their performance to the next level.

To track a pitcher’s arm movement precisely, the Motus sensor uses a three-axis gyroscope and a three-axis accelerometer, taking measurements 1,000 times per second. While the system is always sampling, it records the information permanently only when it detects the movement signature of a pitch. Then it files away the stream of data beginning 4 seconds before the pitch and ending 1 second after. The unobtrusive sensor, which weighs 6.9 grams and measures 9 millimeters thick, causes no discernible changes in pitchers’ movement patterns.

Our tiny sensor is incredibly accurate: Its results are comparable to the gold standard of motion-capture video, which requires high-speed cameras and specialized labs that can cost well into six figures. For motion-capture video recording, the player wears a spandex suit that’s dotted with position markers, which the cameras track to create a model of how the player’s body moves.

Motus began as a small motion-capture studio with a lab at the famed sports training facility IMG Academy, in Bradenton, Fla. But the problem with the motion-capture approach quickly became apparent: Throwing a ball in a lab while wearing a spandex suit doesn’t accurately simulate game conditions. An athlete’s biomechanical form, and thus the forces at work in the body, can be very different in such an artificial situation.

We still have a motion-capture setup in our performance lab: We currently use 16 Motion Analysis Raptor cameras for product testing and some other tasks for clients. But we put full faith in our sensor to do the same job as these fancy cameras. Independent studies by the American Sports Medicine Institute (ASMI), Driveline Baseball, and the MLB’s sport science committee have shown that Motus sensors are up to 95 percent as accurate and reliable as camera-based techniques for measuring key parameters such as elbow torque. This presents a clear advantage for in-game use, because motion-capture video isn’t easily adaptable for precisely tracking players on the ballfield.

Our Motus Throw devices have collected data from more than 10 million throws, at all levels of competition. Beginning in 2016, Motus embarked on a three-year study in cooperation with the National Collegiate Athletic Association (NCAA), collecting data from dozens of teams about pitchers’ throwing workloads and their injuries. We’re now preparing to mine that data.

But the device is helpful for more than just broad epidemiological studies. Take what happened at a small state college in Texas, where a baseball
coach named Bryan Conger went all in with the Motus Throw in the 2017 baseball season, using the technology to manage his pitching staff. During workouts, Conger could check the analytics on his phone, watching how a pitcher’s workload metrics changed with every pitch. He used all the data to create individualized training programs for each pitcher and to determine which pitchers were ready on game day.

Conger says the Motus analytics enabled him to keep his top pitchers in the game for more innings than he would have otherwise, confident that their fatigue levels were within bounds. He also used his top pitchers more often, finding that some could pitch on successive days without going beyond their workload limits. Most important, his pitchers suffered no major arm injuries all season. Conger’s team, from Tarleton State University, made it to the NCAA playoffs that year. Shortly thereafter, Conger was hired away by an MLB team, the Texas Rangers, where he’s now working as a pitching instructor.

When teams first got their hands on the Motus Throw device in 2015, they were most excited about its ability to measure a force called elbow valgus torque. If you look at your elbow, you’ll see that it can be moved in three ways: You can curl your arm inward in the motion of a bicep curl, twist your arm as if turning a doorknob, and stretch your arm outward as if throwing a baseball. That last motion causes valgus torque, the force that stresses the UCL.

When coauthor Hansen worked as a biomechanical specialist for the MLB’s Milwaukee Brewers, the team was focused on one-time assessments of pitchers’ valgus torque and using that data to predict future injury. But we now know that such snapshot measurements aren’t enough for accurate predictions, and that valgus torque is only part of the equation.

After our latest software update, the Motus Sleeve system no longer shows a measure of valgus torque in its analytics dashboard. Instead, it uses that measure to calculate accumulated workload for the muscles of the forearm. We believe that the fatigue of these muscles is the most critical factor for a pitcher’s stamina and arm health.

Muscle fatigue, which we define as a decline in a muscle’s ability to generate force, is the single most significant predictor of pitcher injury. A study of youth pitchers by ASMI found that pitchers who threw while fatigued were 36 times as likely to require surgery. And while the concept of fatigue may seem simple, the physiology involved is quite complex.
We use two complementary measurements of fatigue to calculate workload. The first is acute fatigue, which is commonly seen in baseball games: A pitcher starts off fresh but is pulled from the game as performance declines. This acute fatigue comes about as muscles use up available energy. The other metric we track, which we call “chronic fitness,” increases as pitchers build resistance to acute fatigue through training—and simply by throwing more.

It may seem obvious that working out more increases a pitcher’s fitness. But in baseball today, there’s no objective way to capture this commonsense idea. Baseball’s standard ways of managing a pitcher’s workload are to keep count of how many innings they’ve pitched and how many pitches they’ve thrown. These catchall metrics aren’t based on a specific pitcher’s physiology and fitness, and they lead to subjective decisions about when to take pitchers out of a game and whether a pitcher has been “overused.”

To codify the relationship between intense physical stress and resilience built up over time, Motus partnered with Tim Gabbett, an Australian physiologist who initially worked with rugby players. Gabbett pioneered a measurement he calls acute chronic ratio (ACR), which we use in our Motus Throw system.

Measuring this ratio begins by determining a pitcher’s acute workload (the 9-day average of total valgus load) and a chronic workload (28-day average of valgus load). The ratio of these two averages provides a valuable measure of fatigue. Early in the season, when chronic loads are still low, a pitcher must sustain an ACR greater than 1.0 to build fitness. But it mustn’t go too high: In a recent study of high school pitchers conducted with the Motus Throw device, researcher Sameer Mehta found that throwing with an ACR over 1.3 multiplies an athlete’s risk of injury by 25.

“When I consult with organizations on concepts of acute and chronic workloads, I’m most often met with a reaction similar to what our fathers and grandfathers knew all along, “ says Gabbett. “If you work hard at something, you get better at it. If you train appropriately, you prepare for demands of the sport.” Now we can quantify this age-old wisdom with solid data.

Since its initial launch in 2015, Motus has uncovered meaningful workload measures that are predictive indicators for elbow and shoulder injuries. The next step has been to turn these findings into software tools to help pitchers train in the sweet spot, building endurance without causing excess muscle fatigue.

For example, when a minor league pitcher who had been using the Motus Throw tore his UCL, we were able to look at the data to see what had gone wrong with his training regimen. We saw clear

---

**Arm Anatomy 101**

When a pitcher throws the ball, the motion puts about 100 newton meters of torque on the elbow, which is a hinge joint. That force is absorbed by both the muscles of the forearm and the ligaments, the connective tissue between bones. When the arm muscles are fatigued and can’t contract sufficiently, more stress is placed on the ulnar collateral ligament (UCL). In Major League Baseball today, there’s an epidemic of UCL tears that require season-ending surgery.

**Three Kinds of Elbow Torque**

- **PRONATION TORQUE**: Experienced when the wrist twists around
- **FLEXION TORQUE**: Experienced when the arm curls inward
- **VALGUS TORQUE**: Experienced when the arm stretches outward, which places extreme stress on the hinge joint

---

**ILLUSTRATION BY McKibilo**
AXIAL-FLUX DESIGN, EXPLODED

This view shows the guts of the Magnax motor, which differs from the traditional layout by putting the one moving part—the rotor—inside the stator. Refinements of this design make it particularly powerful, efficient, and easy to make.
A BELGIAN STARTUP'S AXIAL-FLUX MOTOR FOR EVs IS SMALL, LIGHT, AND POWERFUL

By Daan Moreels & Peter Leijnen
THE WORLD IS ELECTRIFYING FAST. Manufacturing processes, cars, trucks, motorcycles, and now airplanes are making the move to electrons that Edison predicted more than a century ago. And they are all doing so for much the same reasons: quieter operation, reduced maintenance requirements, better performance and efficiency, and a more flexible use of energy sources.

At the heart of this great process of electrification stands the electric machine, filling either the role of a generator, for turning mechanical energy into electricity, or that of a motor, for doing the opposite.

For a long time, electric machines have hewed to a standard design, which has had the advantage of being very easy to manufacture. However, our startup, Magnax, based in Belgium, has taken another design that in theory can wring much more power and torque from a given mass and has made it commercially practical. We believe this new design can supplant the old one in many applications, notably in electric vehicles, in which it is now being tested.

One of our designs has a peak power density of around 15 kilowatts per kilogram. Compare that with today’s motors, such as the one in the all-electric BMW i3, which delivers a peak power density of 3 kW/kg—or just one-fifth as much. And the Magnax machine is also more efficient.

We believe that we can scale the design to whatever size carmakers (and other customers) may demand. If so, then there is every reason to believe that this design will push aside the traditional one. If it does, it will help to improve performance, save on energy and overall operating costs, and reduce carbon emissions for a better world.

THE CONCEPT OF AN ELECTRIC MACHINE IS SIMPLE. You start with a housing, which is called a stator because it remains stationary. Then you add a rotor, which spins, usually inside the stator but sometimes outside, an idea we’ll discuss later. When the machine is functioning as a motor, the magnetic fields of the stator and the rotor interact: Strategically placed magnets around the circumference of the rotor and stator repel or attract each other in a sequence to sustain the rotor’s spin and create torque. In this way, the machine converts electrical energy to mechanical energy. When the machine functions as a generator, the process operates in reverse.

Such a rotating machine today generally uses permanent magnets rather than electromagnets in the rotor and is thus called a permanent-magnet synchronous machine (PMSM). When operating as a motor, it passes alternating current to structures in the stator known as teeth. The result is a rotating magnetic field in the stator that acts on the permanent magnets of the rotor, spinning it.

The big advantage here is that permanent magnets don’t need energy to create a magnetic field. That makes this design more efficient and more powerful for a given weight and volume than a machine that uses electromagnets in the rotor.

There are many compelling reasons why PMSMs began to dominate in the 1980s, but the most important one was the development of a much more powerful breed of permanent magnet, based on neodymium. Nevertheless, because there was no change in the overall layout of the machine, the new magnet could provide only an incremental improvement.

To further reduce the weight, size, and cost of the machine, the electromagnetic interaction had to be fundamentally rethought. That’s what we’ve done. We call our product a yokeless axial-flux permanent-magnet machine. It’s a mouthful, and we’ll explain it in a moment. First, though, it’s important to understand that people already knew that the axial-flux topology had intrinsic advantages. It’s just that there seemed to be no way to exploit those advantages commercially, mainly because a design based on them would be hard to mass-produce using automated procedures.

BEFORE WE COULD BEGIN DESIGNING our motor, we had to overcome a fundamental problem: There was no commercially available software that could accurately and simultaneously model the electromagnetic and thermodynamic properties of an axial-flux motor. However, Peter Sergeant and Hendrik Vansompel of Ghent University, in Belgium, have been working on this problem since 2008. Their efforts, combined with several years of R&D and prototyping by Magnax, led to our design and our manufacturing methods.

A traditional, radial-flux machine puts the rotor inside the stator. Here the stator consists of a supporting part, called the yoke, which is fitted with teeth that contain electromagnetic coils. The teeth thus function as magnetic poles. As the rotor turns, its own poles transmit flux every time they sweep past a stator tooth, and the stator carries the flux elsewhere—closing what’s called the flux loop. The flux is routed from the rotor’s permanent magnet through the air gap and the stator teeth, taking a 180-degree bend through the yoke and back to another magnet. Meanwhile, of course, the interaction between the permanent magnets and the rotating electromagnetic field in the stator teeth keeps the rotor spinning.
For highest efficiency, the design should minimize the distance—the air gap—between the rotor and the stator teeth, because air transports magnetic flux poorly.

Our axial-flux machine turns that traditional arrangement inside out. It uses not one but two rotors, on either side of the stator, bracketing it. In this arrangement, the stator merely functions as the bearer of the electromagnetic teeth, not as the support—or yoke—for the rotor. In other words, it creates the possibility of a stator that is yokeless—hence the inclusion of this word in the name.

Eliminating the yoke—basically a steel cylinder that composes about two-thirds of the stator iron—saves an enormous amount of weight. As a result, yokelessness more than doubles the machine’s power density, compared with that of the older, yoked axial motors, and quadruples it compared with that of a traditional motor (like the one in the BMW i3). It also improves efficiency by reducing a bane of electric machines: iron loss.

Iron loss is mainly the result of two phenomena. First, there is the energy consumed when alternating current repeatedly magnetizes and demagnetizes cores in the stator—a process called hysteresis loss. Second are the losses to eddy currents,
which are created by the varying magnetic flux through the cores.

There are other reasons why the design is so power dense. In this design, the magnetic flux goes from the permanent magnets on the first rotor disk, through the stator core to the permanent magnets on the second rotor disk—a relatively short and straight path.

Thanks to that unidirectionality, Magnax can further decrease the flux losses in the iron by 85 percent by using a material that’s perfect for conducting flux in one direction only—grain-oriented steel. Such steel couldn’t go into a traditional, radial-flux motor or generator because such machines route the flux from the rotor through the stator and back to the rotor—a multidirectional route. Magnax closely collaborated with Thyssenkrupp Electrical Steel on the design of the laminated grain-oriented cores.

Other advantages: In our yokeless axial-flux design the stator needs only about 60 percent as much copper and the rotor needs about 80 percent as much magnetic material than would a radial-flux motor of comparable power and torque.

In theory, all of these advantages make possible a relatively inexpensive and lightweight machine that delivers a lot of torque. But actually building such a machine meant facing down several serious engineering challenges.

The most obvious involve finding ways to replace the traditional functions of a yoke. In a conventional motor, the yoke holds the stator teeth in place and provides a thermal path for transporting the heat from the coils to the motor casing. It also serves as a path that closes the loop along which the magnetic flux flows when returning to its original source.

**FIRST, MAGNAX HAD TO SOLVE** the mechanical challenges. Because there is no yoke to connect the individual stator teeth, another solution had to be found to create a stator with sufficient strength and stiffness to hold the teeth firmly in place even as they are wrenched by powerful electromagnetic forces.

**NEXT CAME THE THERMAL CHALLENGES.** Because the windings are buried deep inside the stator and between the two rotor discs, the heat they generate can be hard to disperse. Better cooling lets you increase a machine’s nominal power—that is, the actual mechanical power it puts out. Older axial-flux concepts—those that use a yoke—cool the coils by integrating a cooling channel in the yoke. However, that arrangement makes the heat flow through the yoke, and iron is not particularly good at transporting heat. Because the Magnax design has no yoke, we needed to find another way to directly cool the coils.

Manufacturing was yet another challenge. Existing axial-flux machines have always been hard to manufacture because the stator and the windings are complex. That’s why until now such machines generally didn’t lend themselves to automated production. These challenges translate to higher cost and very poor scaling, which can be seen in most of the axial-flux designs that are now commercially available.

Yokeless concepts, however, have a simpler winding scheme, which saves on labor. So cooling emerged as one of the biggest challenges. YASA, in England, another developer of yokeless axial-flux motors, has a manufacturable motor concept; the company uses oil cooling and is building its own factory for volume production in the United Kingdom. Magnax’s design uses a different, and more flexible, cooling scheme.

Machines route the flux from the rotor through the stator and back to the rotor—a multidirectional route. Magnax closely collaborated with Thyssenkrupp Electrical Steel on the design of the laminated grain-oriented cores.

Other advantages: In our yokeless axial-flux design the stator needs only about 60 percent as much copper and the rotor needs about 80 percent as much magnetic material than would a radial-flux motor of comparable power and torque.

In theory, all of these advantages make possible a relatively inexpensive and lightweight machine that delivers a lot of torque. But actually building such a machine meant facing down several serious engineering challenges.

The most obvious involve finding ways to replace the traditional functions of a yoke. In a conventional motor, the yoke holds the stator teeth in place and provides a thermal path for transporting the heat from the coils to the motor casing. It also serves as a path that closes the loop along which the magnetic flux flows when returning to its original source.

**FIRST, MAGNAX HAD TO SOLVE** the mechanical challenges. Because there is no yoke to connect the individual stator teeth, another solution had to be found to create a stator with sufficient strength and stiffness to hold the teeth firmly in place even as they are wrenched by powerful electromagnetic forces.

Next came the thermal challenges. Because the windings are buried deep inside the stator and between the two rotor discs, the heat they generate can be hard to disperse. Better cooling lets you increase a machine’s nominal power—that is, the actual mechanical power it puts out. Older axial-flux concepts—those that use a yoke—cool the coils by integrating a cooling channel in the yoke. However, that arrangement makes the heat flow through the yoke, and iron is not particularly good at transporting heat. Because the Magnax design has no yoke, we needed to find another way to directly cool the coils.

Manufacturing was yet another challenge. Existing axial-flux machines have always been hard to manufacture because the stator and the windings are complex. That’s why until now such machines generally didn’t lend themselves to automated production. These challenges translate to higher cost and very poor scaling, which can be seen in most of the axial-flux designs that are now commercially available.

Yokeless concepts, however, have a simpler winding scheme, which saves on labor. So cooling emerged as one of the biggest challenges. YASA, in England, another developer of yokeless axial-flux motors, has a manufacturable motor concept; the company uses oil cooling and is building its own factory for volume production in the United Kingdom. Magnax’s design uses a different, and more flexible, cooling scheme.

Magnax has one that can use a number of coolants, notably air, water-glycol, and oil. Air cooling is preferred for use in drones and in two- and three-wheel electric vehicles (popular in India, for instance). It’s also good in big machines, such as wind-turbine generators. Liquid cooling is better for maximum power densities, in combination with gearboxes. Thus, it is often used in automotive applications.

We start by laminating aluminum or copper heat sinks in close thermal contact with the windings. The heat sinks transport the heat to the outer perimeter, where it can be carried away by cooling fins or a water-cooling jacket. This not only gives the machine a much higher capacity to evacuate heat, making it possible to produce greater nominal torque and power, it also allows for
a very stiff and completely solid stator construction. That means that the machine can handle a lot of torque and still last for a long time.

At the moment, our focus is on custom motor designs for automotive original-equipment manufacturers and their suppliers. Because axial-flux motors have a short axial length, they can help keep the power train short. That proves useful to automakers that integrate the motor, the transmission, and the electronics into an electric vehicle’s axle, an assembly called an eAxle. These motors are also very useful in a hybrid design, where the combination of an engine and an electric drive system usually leaves little room for the motor.

Our design is also suited for in-wheel applications, where the motor goes right inside the wheel assembly. That configuration has many advantages—for instance, you can help to steer the car by varying the torque at each wheel, a trick known as torque vectoring. However, putting the motor in the wheel increases the unsprung mass—the part of a car that’s between the suspension and the road—and that can make the ride bumpier. Every gram of weight saved on an in-wheel motor is therefore golden.

A European carmaker is now track-testing an in-wheel car concept that uses four Magnax motors, all made in the “outrunner” configuration. That’s where the spinning part of the motor is on the outside (rather than on the inside, on a shaft), making the machine ideal for integration inside the very tight spaces within a wheel assembly. Here, too, the result is a power density that’s twice as high as a conventional motor’s, with higher efficiency to boot.

Although most car designs don’t put motors right inside the wheels, many do use more than one motor in the vehicle. In fact, any car that uses multiple motors will benefit particularly from our product. The more motors you carry, the more important it is that they be light and compact. We have calculated that the absence of a yoke and its associated iron losses can increase the range an EV could travel by 7 percent in a car with a single motor and up to 20 percent in a car with two motors. Imagine the further effects on the battery, which is the most expensive part of an EV.

The main challenge now is to bring the concept into series production; Magnax will organize this together with production partners. We have invested a lot of time in the design for manufacturing our machines. As a result, we can prove that our machines can be produced. This capability, together with the savings we can realize on materials, makes our concept competitive on price—a key point for graduating from the niche markets to the original-equipment manufacturers.

The assembly line we are building will be capable of producing motors of several diameters. We plan to begin producing 25,000 motors per year by 2022 and to scale to hundreds of thousands later on.

Over the past two years we’ve had inquiries from hundreds of companies that are interested in motors of widely varying diameters for use in electric motorcycles, trucks, and other EV applications. In addition, we still receive requests from makers of wind turbines and industrial equipment. These particular markets are not our highest priority, but the widespread demand shows that our technology has what many companies need: compactness, power, and efficiency.

Our design can cut costs substantially in a high-volume business—for instance, the production in China of millions of motors of between 1 and 10 kW. When producing in large quantities, what counts is limiting the cost of the raw materials, which as we’ve shown is significantly lower than for traditional motors.

Tens, even hundreds of millions of electric motors were sold in 2017, for a total of some US $97 billion. Their average efficiency remains below 90 percent.

In tests at the University of Ghent on the first prototype, our yokeless axial-flux motor reached efficiencies from 91 to 96 percent. And that was just the prototype.

Motors and motor systems account for approximately 53 percent of global electricity consumption. We estimate that improving the efficiency of all the world’s motors by just 1 percent would reduce the motors’ power consumption by 94.5 terawatt-hours and shrink their carbon dioxide footprint by the equivalent of 60 million metric tons.

If yokeless axial-flux machines replaced only a fraction of the older machines, we would save our customers some money and make the planet more livable while we’re at it. ■

POST YOUR COMMENTS at https://spectrum.ieee.org/electricmotor1019
It’s Not Too Soon to Be Wary of AI

We need to act now to protect humanity from future superintelligent machines

By Stuart Russell

Editor’s Note: This article is based on a chapter of the author’s newly released book, Human Compatible: Artificial Intelligence and the Problem of Control, published by Viking, an imprint of Penguin Publishing Group, a division of Penguin Random House.
AI research is making great strides toward its long-term goal of human-level or superhuman intelligent machines. If it succeeds in its current form, however, that could well be catastrophic for the human race. The reason is that the “standard model” of AI requires machines to pursue a fixed objective specified by humans. We are unable to specify the objective completely and correctly, nor can we anticipate or prevent the harms that machines pursuing an incorrect objective will create when operating on a global scale with superhuman capabilities. Already, we see examples such as social-media algorithms that learn to optimize click-through by manipulating human preferences, with disastrous consequences for democratic systems.


Surely, with so much at stake, the great minds of today are already doing this hard thinking—engaging in serious debate, weighing up the risks and benefits, seeking solutions, ferreting out loopholes in solutions, and so on. Not yet, as far as I am aware. Instead, a great deal of effort has gone into various forms of denial.

Some well-known AI researchers have resorted to arguments that hardly merit refutation. Here are just a few of the dozens that I have read in articles or heard at conferences:

**Electronic calculators are superhuman at arithmetic.** Calculators didn’t take over the world; therefore, there is no reason to worry about superhuman AI.

**Historically, there are zero examples of machines killing millions of humans, so, by induction, it cannot happen in the future.**

**No physical quantity in the universe can be infinite, and that includes intelligence, so concerns about superintelligence are overblown.**

Perhaps the most common response among AI researchers is to say that “we can always just switch it off.” Alan Turing himself raised this possibility, although he did not put much faith in it:

*If a machine can think, it might think more intelligently than we do, and then where should we be? Even if we could keep the machines in a subservient position, for instance by turning off the power at strategic moments, we should, as a species, feel greatly humbled... This new danger... is certainly something which can give us anxiety.*

Switching the machine off won’t work for the simple reason that a superintelligent entity will already have thought of that possibility and taken steps to prevent it. And it will do that *not* because it “wants to stay alive” but because it is pursuing whatever objective we gave it and knows that it will fail if it is switched off. We can no more “just switch it off” than we can beat AlphaGo (the world-champion Go-playing program) just by putting stones on the right squares.

Other forms of denial appeal to more sophisticated ideas, such as the notion that intelligence is multifaceted. For example, one person might have more spatial intelligence than another but less social intelligence, so we cannot line up all humans in strict order of intelligence. This is even more true of machines: Comparing the “intelligence” of AlphaGo with that of the Google search engine is quite meaningless.
Kevin Kelly, founding editor of *Wired* magazine and a remarkably perceptive technology commentator, takes this argument one step further. In “The Myth of a Superhuman AI,” he writes, “Intelligence is not a single dimension, so ‘smarter than humans’ is a meaningless concept.” In a single stroke, all concerns about superintelligence are wiped away.

Now, one obvious response is that a machine could exceed human capabilities in *all* relevant dimensions of intelligence. In that case, even by Kelly’s strict standards, the machine would be smarter than a human. But this rather strong assumption is not necessary to refute Kelly’s argument.

Consider the chimpanzee. Chimpanzees probably have better short-term memory than humans, even on human-oriented tasks such as recalling sequences of digits. Short-term memory is an important dimension of intelligence. By Kelly’s argument, then, humans are not smarter than chimpanzees; indeed, he would claim that “smarter than a chimpanzee” is a meaningless concept.

This is cold comfort to the chimpanzees and other species that survive only because we deign to allow it, and to all those species that we have already wiped out. It’s also cold comfort to humans who might be worried about being wiped out by machines.

The risks of superintelligence can also be dismissed by arguing that superintelligence cannot be achieved. These claims are not new, but it is surprising now to see AI researchers themselves claiming that such AI is impossible. For example, a major report from the AI100 organization, “Artificial Intelligence and Life in 2030,” includes the following claim: “Unlike in the movies, there is no race of superhuman robots on the horizon or probably even possible.”

To my knowledge, this is the first time that serious AI researchers have publicly espoused the view that human-level or superhuman AI is impossible—and this in the middle of a period of extremely rapid progress in AI research, when barrier after barrier is being breached. It’s as if a group of leading cancer biologists announced that they had been fooling us all along: They’ve always known that there will never be a cure for cancer.

What could have motivated such a volte-face? The report provides no arguments or evidence whatever. (Indeed, what evidence could there be that no physically possible arrangement of atoms outperforms the human brain?) I suspect that the main reason is tribalism—the instinct to circle the wagons against what are perceived to be “attacks” on AI. It seems odd, however, to perceive the claim that superintelligent AI is possible as an attack on AI, and even odder to defend AI by saying that AI will never succeed in its goals. We cannot insure against future catastrophe simply by betting against human ingenuity.

If superhuman AI is not strictly impossible, perhaps it’s too far off to worry about? This is the gist of Andrew Ng’s assertion that it’s like worrying about “overpopulation on the planet Mars.” Unfortunately, a long-term risk can still be cause for immediate concern. The right time to worry about a potentially serious problem for humanity depends not just on when the problem will occur but also on how long it will take to prepare and implement a solution.

For example, if we were to detect a large asteroid on course to collide with Earth in 2069, would we wait until 2068 to start working on a solution? Far from it! There would be a worldwide emergency project to develop the means to counter the threat, because we can’t say in advance how much time is needed.

Ng’s argument also appeals to one’s intuition that it’s extremely unlikely we’d even try to move billions of humans to Mars in the first place. The analogy is a false one, however. We are already devoting huge scientific and technical resources to creating ever more capable AI systems, with very little thought devoted to what happens if we succeed. A more apt analogy, then, would be a plan to move the human race to Mars with no consideration for what we might breathe, drink, or eat once we arrive. Some might call this plan unwise.

Another way to avoid the underlying issue is to assert that concerns about risk arise from ignorance. For example, here’s Oren Etzioni, CEO of the Allen Institute for AI, accusing Elon Musk and Stephen Hawking of Luddism because of their calls to recognize the threat AI could pose:

---

**Switching the machine off won’t work for the simple reason that a superintelligent entity will already have thought of that possibility and taken steps to prevent it.**

---

*Illustration by Justin Metz*
At the rise of every technology innovation, people have been scared. From the weavers throwing their shoes in the mechanical looms at the beginning of the industrial era to today’s fear of killer robots, our response has been driven by not knowing what impact the new technology will have on our sense of self and our livelihoods. And when we don’t know, our fearful minds fill in the details.

Even if we take this classic ad hominem argument at face value, it doesn’t hold water. Hawking was no stranger to scientific reasoning, and Musk has supervised and invested in many AI research projects. And it would be even less plausible to argue that Bill Gates, I.J. Good, Marvin Minsky, Alan Turing, and Norbert Wiener, all of whom raised concerns, are unqualified to discuss AI.

The accusation of Luddism is also completely misdirected. It is as if one were to accuse nuclear engineers of Luddism when they point out the need for control of the fission reaction. Another version of the accusation is to claim that mentioning risks means denying the potential benefits of AI. For example, here again is Oren Etzioni:

Doom-and-gloom predictions often fail to consider the potential benefits of AI in preventing medical errors, reducing car accidents, and more.

And here is Mark Zuckerberg, CEO of Facebook, in a recent media-fueled exchange with Elon Musk:

If you’re arguing against AI, then you’re arguing against safer cars that aren’t going to have accidents. And you’re arguing against being able to better diagnose people when they’re sick.

The notion that anyone mentioning risks is “against AI” seems bizarre. (Are nuclear safety engineers “against electricity”?) But more importantly, the entire argument is precisely backwards, for two reasons. First, if there were no potential benefits, there would be no impetus for AI research and no danger of ever achieving human-level AI. We simply wouldn’t be having this discussion at all. Second, if the risks are not successfully mitigated, there will be no benefits.

The potential benefits of nuclear power have been greatly reduced because of the catastrophic events at Three Mile Island in 1979, Chernobyl in 1986, and Fukushima in 2011. Those disasters severely curtailed the growth of the nuclear industry. Italy abandoned nuclear power in 1990, and Belgium, Germany, Spain, and Switzerland have announced plans to do so. The net new capacity per year added from 1991 to 2010 was about a tenth of what it was in the years immediately before Chernobyl.

Strangely, in light of these events, the renowned cognitive scientist Steven Pinker has argued that it is inappropriate to call attention to the risks of AI because the “culture of safety in advanced societies” will ensure that all serious risks from AI will be eliminated. Even if we disregard the fact that our advanced culture of safety has produced Chernobyl, Fukushima, and runaway global warming, Pinker’s argument entirely misses the point. The culture of safety—when it works—consists precisely of people pointing to possible failure modes and finding ways to prevent them. And with AI, the standard model is the failure mode.

Pinker also argues that problematic AI behaviors arise from putting in specific kinds of objectives; if these are left out, everything will be fine:

AI dystopias project a parochial alpha-male psychology onto the concept of intelligence. They assume that superhumanly intelligent robots would develop goals like deposing their masters or taking over the world.

Yann LeCun, a pioneer of deep learning and director of AI research at Facebook, often cites the same idea when downplaying the risk from AI:

There is no reason for AIs to have self-preservation instincts, jealousy, etc.... AIs will not have these destructive “emotions” unless we build these emotions into them.

Unfortunately, it doesn’t matter whether we build in “emotions” or “desires” such as self-preservation, resource acquisition, knowledge discovery, or, in the extreme case,
taking over the world. The machine is going to have those emotions anyway, as subgoals of any objective we do build in—and regardless of its gender. As we saw with the “just switch it off” argument, for a machine, death isn’t bad per se. Death is to be avoided, nonetheless, because it’s hard to achieve objectives if you’re dead.

A common variant on the “avoid putting in objectives” idea is the notion that a sufficiently intelligent system will necessarily, as a consequence of its intelligence, develop the “right” goals on its own. The 18th-century philosopher David Hume refuted this idea in *A Treatise of Human Nature*. Nick Bostrom, in *Superintelligence*, presents Hume’s position as an orthogonality thesis:

**Intelligence and final goals are orthogonal: more or less any level of intelligence could in principle be combined with more or less any final goal.**

For example, a self-driving car can be given any particular address as its destination; making the car a better driver doesn’t mean that it will spontaneously start refusing to go to addresses that are divisible by 17.

By the same token, it is easy to imagine that a general-purpose intelligent system could be given more or less any objective to pursue—including maximizing the number of paper clips or the number of known digits of pi. This is just how reinforcement learning systems and other kinds of reward optimizers work: The algorithms are completely general and accept any reward signal. For engineers and computer scientists operating within the standard model, the orthogonality thesis is just a given.

The most explicit critique of Bostrom’s orthogonality thesis comes from the noted roboticist Rodney Brooks, who asserts that it’s impossible for a program to be “smart enough that it would be able to invent ways to subvert human society to achieve goals set for it by humans, without understanding the ways in which it was causing problems for those same humans.”

Unfortunately, it’s not only possible for a program to behave like this; it is, in fact, inevitable, given the way Brooks defines the issue.

Brooks posits that the optimal plan for a machine to “achieve goals set for it by humans” is causing problems for humans. It follows that those problems reflect things of value to humans that were omitted from the goals set for it by humans. The optimal plan being carried out by the machine may well cause problems for humans, and the machine may well be aware of this. But, by definition, the machine will not recognize those problems as problematic. They are none of its concern.

In summary, the “skeptics”—those who argue that the risk from AI is negligible—have failed to explain why superintelligent AI systems will necessarily remain under human control; and they have not even tried to explain why superintelligent AI systems will never be developed.

Rather than continue the descent into tribal name-calling and repeated exhumation of discredited arguments, the AI community must own the risks and work to mitigate them. The risks, to the extent that we understand them, are neither minimal nor insuperable. The first step is to realize that the standard model—the AI system optimizing a fixed objective—must be replaced. It is simply bad engineering. We need to do a substantial amount of work to reshape and rebuild the foundations of AI.
indicators of excess fatigue (his chart showed ACRs of greater than 1.3 and often greater than 2.0) due to both intense single-day workouts and the pitcher’s abrupt transition from throwing every other day to throwing six days per week. Through software simulation, we’ve shown that a different training regimen would have kept the ACRs lower and would likely have prevented the injury. We want Motus users to take heed of the red flags in the dashboard’s reports to keep their workloads manageable and healthy.

Christopher Camp, a physician at the Mayo Clinic of Sports Medicine, says baseball teams need to “embrace workload and fatigue measures” during both rehabilitation and preseason throwing. He uses the Motus Throw with patients and says he appreciates that the app now prescribes workload plans to pitchers that set an effort limit for each day. The app helps pitchers safely build chronic workload over months, he says, by making sure the ACR is moderately—not dangerously—elevated.

In pitching, avoiding injury and enhancing performance go hand in hand: When muscle fatigue sets in, injury risk increases and control and performance begin to decline. Zach Dechant, director of strength and condition-

For decades, baseball coaches have relied on pitch counts and the subjective concept of overuse to manage their pitchers. Today, as we gain more insights into the relationship among workload, fatigue, and arm health, it’s clear that data-driven systems can do better to protect players from injury.

Sports physiologists have come to recognize that the forearm muscles protect the UCL from rupture. But to do so, they must have sufficient energy stores to contract effectively, thus keeping the UCL from taking too much strain. To drive each contraction, cells in the muscles convert glycogen, one of the body’s primary stores of energy, into the chemical adenosine triphosphate (ATP). Each successive pitch depletes the muscles’ glycogen stores, causing an energy debt. As a pitcher reaches the end of an inning, the muscles reach peak levels of fatigue. In between innings, the pitcher rests, and glycogen stores slowly recover over a period of minutes. This cycle con-

The New Science of Bioball CONTINUED FROM PAGE 39
But how should this gradual decline be measured? Mike Sonne, a biomechanics expert who works with Canadian baseball teams, came up with the concept of “fatigue units” based on his study of this accumulative energy debt, which he modeled on the scale of milliseconds. Sonne developed his models using publicly available data from Pitchf/x and MLB’s Statcast system, both of which provide information about pitch velocity, release point, spin, and more. Now, using the Motus Throw to gather far more granular and precise data, Sonne anticipates further progress in understanding the biochemistry of pitching.

In the summer of 2019, Motus released an app update to provide information about fatigue units. With this data, pitchers can identify incidents of excess overload within a matter of hours—feedback that they can use to learn safe limits for their bodies and to determine when extra rest and recovery are needed.

The current MLB rules allow players to wear the Motus Throw during games so that the device can collect data. But pitchers and coaches are not permitted to download that data or access it during a game; only afterward can they look at the analytics. We believe those rules will soon be revised—and we hope to lead the charge for in-game analytics. If a coach could track a player’s fatigue units during a game, maybe he could visit the mound at a moment when the pitcher really needs a few minutes to recover his strength. A coach would also have an objective measure of when a pitcher has reached his limit and should be taken out.

If coaches switch to a “bioball” management strategy based on biochemistry and physiology, the change might do away with endless postgame arguments over whether a player was left in for too long, causing an injury or the loss of a game. Such an evolution might be bad for talk radio. But if it’s good for players’ performance and bodies, we think baseball will consider it a win.

The world’s most daunting challenges require innovations in engineering, and IEEE is committed to finding the solutions. The IEEE Foundation is leading a special campaign to raise awareness, create partnerships, and generate financial resources needed to combat these global challenges. Our goal is to raise $30 million by 2020.
The Electrical and Computer Engineering department invites applications for tenure-track faculty positions in (i) robotics with particular emphasis on human-robot interaction, robot learning, and formal methods for robot autonomy, and (ii) digital communications focused on future wireless networks including 5G and beyond, Internet-of-Things, and artificial intelligence for future communication networks such as massive unmanned vehicle networks. While the search is mainly focused on an Assistant Professor position, more senior candidates with exceptional records will still be considered.

The Department of Electrical and Computer Engineering has over 32 faculty members, including 13 Fellows of the IEEE, AAAS or other professional societies, and many of our junior faculty members have been awarded Young Investigator/CAREER awards. The ECE department trains over 200 graduate students and receives annually over $8.0 million in research funding. Research areas in the department include computer engineering, controls and robotics, intelligent systems including computer vision, machine learning and transportation, smart grids and energy, nano materials and devices, and signal processing and communications. Multiple ECE faculty collaborate with other faculty in the campus research centers, including the Center for Nanoscale Science & Engineering (CNSE), the Winston Chung Global Energy Center (WCGE), the Center for Research in Intelligent Systems, and the College of Engineering's Center for Environmental Research and Technology (CE-CERT).

Successful candidates will have a proven record of, or exceptional promise for, developing a vibrant externally-funded research program, as well as a portfolio of high quality teaching at the undergraduate and graduate levels; and will be expected to maintain an active research agenda and record of publications; teach a regular course load at both the undergraduate and graduate levels; and to participate in service activities at department, college campus, and professional levels. They should also demonstrate clear potential for complementing and/or synergistically leveraging existing research activities within the department, college and campus. Applicants must be "all but dissertation" or have met the requirements for the PhD in Electrical and Computer Engineering or a closely related field by time of appointment, July 1, 2020.

Advancement through the faculty ranks at the University of California is through a series of structured, merit-based evaluations, occurring every 2-3 years, each of which includes substantial peer input. Applicants are expected to begin July 1, 2020. Salary will be commensurate with education and experience.

UCR is a world-class research university with an exceptionally diverse undergraduate student body. Its mission is explicitly linked to providing routes to educational success for underrepresented and first-generation college students. A commitment to this mission is a preferred qualification.

Review of applications will begin January 1, 2020 and will continue until the position is filled. To Apply: Interested individuals are required to submit a cover letter, a 2-page research plan, a CV plus copies of 3 most significant publications, and names of three referees to: sist@ucr.edu. For more information and instructions regarding the specific areas of interest and application procedures, please visit http://www.engr.ucr.edu. For inquiries and questions please refer to the contact email address under the specific recruitment on the AP Recruit website.

The University of California is an Equal Opportunity/Affirmative Action Employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, age, disability, protected veteran status, or any other characteristic protected by law.

**Positions Open**

**Toyota Technological Institute** has an opening for faculty positions. Applications are encouraged from all relevant areas.

**RESEARCH FIELD:** Laser science and technology, or its related field

**Position 1:** Associate professor or Lecturer (tenure- or tenure-track)

https://www.toyota-ti.ac.jp/english/employment/2019/07/000395.html#000395

**Position 2:** Assistant Professor (full-time, 5-year contract, non-tenured, non-renewable)

https://www.toyota-ti.ac.jp/english/employment/2019/07/000396.html#000396

**QUALIFICATIONS:**

1. A Ph.D. IN A RELEVANT FIELD. The successful candidate is expected to demonstrate potential to develop strong and outstanding programs in the above research field. It is also necessary for him/her to supervise students, and to teach basic and advanced courses both at the undergraduate and graduate levels.

2. A Ph.D. IN A RELEVANT FIELD. The successful candidate is expected to demonstrate potential to develop strong and outstanding programs in the above research field. It is also necessary for him/her to supervise students.

**Start date:** As soon as possible after April 1, 2020

**Inquiry:** Search Committee Chair, Professor Yasutake Ohishi

E-mail: y-ohishi1@toyota-ti.ac.jp

Please refer to the link above for more details and instructions regarding how to apply. Applications will be accepted until October 31, 2019.

**Toyota Technological Institute is an Equal Opportunity/Affirmative Action Employer.**
Applications
Submit (in English, PDF version) a cover letter, a statement in research and teaching, a CV plus copies of 3 most significant publications, and contacts of three referees to : sme-hr@sme.sustech.edu.cn entitled with “Apply for Faculty Position”. Applicants are required to specify the rank of the position in their letter of application. The positions will be open until they are filled by appropriate candidates.

For more information, please visit http://ohr.sustc.edu.cn/sustczp/product/recruit/a.do?action=toZPGWList2&entityId=T_RECRUIT_PLAN&postType=2&selectedId=100901.

Salary and Fringe Benefits
Salary and startup funds are highly competitive, commensurate with experience and academic accomplishment. All regular faculty members will join the tenure-track system in accordance with international practice for progress evaluation and promotion. Applicants are encouraged to check out the details about the university at: http://www.sustech.edu.cn.

THE ELECTRICAL AND COMPUTER ENGINEERING
(EE) Division of the Electrical Engineering and Computer Science Department at the University of Michigan, Ann Arbor invites applications for junior or senior faculty positions, especially from women and under-represented minorities.

Successful candidates will have a relevant doctorate or equivalent experience and an outstanding record of research in academia, industry and/or at national laboratories. They should have a strong record or commitment to teaching at undergraduate and graduate levels, to providing service to the university and profession, and to broadening the intellectual diversity of the ECE Division.

We invite candidates across all research areas to apply, with particular interest in machine learning, data science, computer engineering, and embedded systems.

The highly ranked ECE Division (www.ece.umich.edu) prides itself on the mentoring of junior faculty toward successful careers.

Ann Arbor is highly rated as a family friendly best-place-to-live.

Please see application instructions at: https://ece.engin.umich.edu/people/faculty-positions/

The review of applications will begin November 18, 2019 with full consideration given to candidates submitting by then.

The University of Michigan is an Affirmative Action, Equal Opportunity Employer with an Active Dual-Career Assistance Program. The College of Engineering is especially interested in candidates who contribute, through their research, teaching, and/or service, to the diversity and excellence of the academic community.
The department has openings for exceptional tenure-track faculty members, two in ECE plus another one in the areas of robotics for a multi-disciplinary cluster. All emergent and traditional areas of ECE are considered. Of special interests are candidates in the following areas:

1) Learning and real-time decision making; 2) Secure hardware or secure cyber-physical systems; 3) High-performance computing and cloud computing; 4) AI and big data applications in ECE fields.

The multi-disciplinary cluster of Disability, Aging and Technology (DAT) has several open faculty positions at the entry level. The areas of interest include cooperative robotics and dynamics and control. The DAT cluster seeks transdisciplinary engagement in research and education to link health and wellness interventions with technology applications so that effective and feasible health, behavioral, and assistive technologies can be used with diverse populations. More details can be found at our cluster website https://www.ucf.edu/faculty/cluster/disability-aging-technology/.

UCF offers a competitive salary and start-up package as well as generous benefits. New faculty members have graduate student support and significantly reduced teaching loads during their first two years of tenure-track employment.

All applicants must have a Ph.D. in an area appropriate to the ECE disciplines by the start of the appointment and a strong commitment to academic activities, including teaching, scholarly publications and sponsored research. Successful candidates will have an exceptional record of scholarly research and, at the senior levels, be highly recognized for their technical contributions and leadership in their areas of expertise.

ECE has strong educational programs, with over 400 graduate students and 1,200 undergraduates, and state-of-the-art facility, the Harris Engineering Center and Interdisciplinary Research Building. The department has competitive research programs funded by ARO, DARPA, Department of Defense, Department of Energy, Harris-LST, Intel, Lockheed Martin, National Science Foundation, NASA, Siemens, and Texas Instruments as well as local high-tech start-ups.

UCF, located in Orlando, has over 68,000 students. ECE and UCF are at the center of Florida High Tech Corridor with an excellent industrial base in telecommunications, energy, computer systems, semiconductors, defense, space, lasers, simulation, software and the world-renowned entertainment/theme park industry. Exceptional weather, easy access to the seashore, one of the largest convention centers in the nation and an international airport that is among the world’s best are just a few features that make the UCF/ Orlando area ideal.

UCF is an equal opportunity/affirmative action employer. All qualified applicants are encouraged to apply, including minorities, women, veterans and individuals with disabilities. As a Florida public university, UCF makes all application materials and selection procedures available to the public upon request.

Please send inquiries for ECE positions to facultysearch@ece.ucf.edu and facultycluster@ucf.edu for the DAT cluster positions.

To apply, please follow the instructions for the ECE positions and utilize the link for the DAT Cluster position.

ECE positions: Go to https://jobs.ucf.edu, search for position number 498157 to apply.


Diversity candidates are strongly encouraged to apply. Interested persons should submit an online application at https://www.eee.upenn.edu/faculty-staff/ and include curriculum vitae, research, teaching, and diversity statements, as well as at least three references. Review of applications will begin on December 1, 2019.

The University of Pennsylvania is an Equal Opportunity Employer. Minorities/Women/Individuals with Disabilities/Veterans are encouraged to apply.
The University of Michigan-Shanghai Jiao Tong University (UM-SJTU) Joint Institute invites applications for tenure-track or tenured positions at all levels (Assistant, Associate, and Full) in Electrical and Computer Engineering. Candidates should hold a Ph.D. in electrical and computer engineering, computer science, or a closely related field. The Joint Institute particularly seek candidates in the areas of micro-electronics, communication theory and networking, signal and image processing, robotics, computer architecture, data science, artificial intelligence, and database. The candidates are expected to establish vigorous research programs and contribute to undergraduate and graduate education. Salaries are highly competitive and commensurate with qualifications and experience.

The UM-SJTU Joint Institute receives strong support from both partner universities and the Chinese government. It offers B.S., M.S., and Ph.D. degrees in Electrical and Computer Engineering and related fields. Its ECE program is the first ABET accredited ECE program in the mainland of China, and its students are among China’s best. The Joint Institute models itself after the world class U.S. research universities, in terms of its tenure review and promotion system, academic environment, research program, and undergraduate curriculum. Its official language is English.

For full consideration, please send a CV, statement of research interests and teaching goals, copies of three key publications, and the names and contact information of five references, as a single PDF file, to the Search Committee of the Joint Institute at ji-ece-facultysearch@sjtu.edu.cn. More information is available at http://ji.sjtu.edu.cn/.

Department Heads - Kate Gleason College of Engineering

Reporting to the dean of engineering, the department heads provide visionary leadership to advance the mission of their respective departments. Responsibilities include recruiting and mentoring excellent faculty, expanding scholarship and sponsored research, developing innovative and relevant curricula, managing department resources, promoting successes to internal and external audiences, and demonstrating a commitment to diversity and inclusion. Appointments at the rank of full professor will be considered with an anticipated start of August 15, 2020.

Two positions available:

• Department Head Electrical and Microelectronic Engineering: The Department of Electrical and Microelectronic Engineering offers preeminent bachelor’s and master’s level programs in electrical engineering and microelectronic engineering to approximately 600 undergraduate and 175 graduate students. Faculty and staff include 23 tenured/tenure-track faculty members, six lecturers, four support staff, and three academic advisors. In addition to teaching within the department, faculty conduct research and advise doctoral students in Engineering, Microsystems, Imaging Science, Computer and Information Sciences, and Sustainability. Faculty research expertise includes digital and computer systems, robotics, biomedical devices, communications, controls, integrated devices/circuits, MEMs, electromagnetic fields, semiconductor electronics, photonics/optoelectronics and signal/image/video processing. Researchers have access to exceptional laboratory resources for design and simulation of electronic/photonics circuits and systems, and a state of the art microfabrication clean room facility that supports materials and processes for micro/nano devices. Research expenditures average approximately $1M annually. Candidates may apply online at https://aptrkr.com/1590141. Search: 4775BR

• Department Head Computer Engineering: Known for its comprehensive system-oriented curricula, career-focused education, collaborative research, and state-of-the-art laboratories and computing facilities, the department offers B.S, M.S, and dual B.S/MS degrees in Computer Engineering, and participates in cross-disciplinary Ph.D. programs in Engineering, Computing and Information Sciences, Microsystems Engineering, and Imaging Science. With approximately 375 undergraduates and 50 graduate students, the department includes 11 tenured and tenure-track faculty members, three lecturers, four support staff, and two academic advisors. Faculty members are actively engaged in advancing technology in computing and information processing systems through dedicated teaching and groundbreaking transformative research in areas that include neuromorphic computing, computer architecture, quantum computing, computer communications and networking, artificial intelligence and machine learning, computer vision, and computer security. Research expenditures average approximately $1M annually. Candidates may apply online at https://aptrkr.com/1590141. Search: 4774BR

• Required Minimum Qualifications: Applicants must have an earned doctorate or equivalent terminal degree and a record of distinguished scholarship and teaching requisite for an appointment as a tenured full professor in the college. The interested candidates should refer to the individual job links for the preferred qualifications.

• Required Application Documents: Cover Letter, Curriculum Vitae or Resume, List of References, Statement of Diversity Contribution

A review of applications will begin immediately. The positions will remain open until an acceptable candidate is found.

RIT does not discriminate. RIT is an equal opportunity employer that promotes and values diversity, pluralism, and inclusion. For more information or inquiries, please visit RIT/TitleIX or the U.S. Department of Education at ED.Gov
The Department of Electrical and Computer Engineering at Tufts University invites applications for a tenure-track faculty position in Electrical and Computer Engineering to begin in September 2020.

We are seeking candidates at the rank of Assistant Professor. Candidates are sought primarily in one of the following areas or closely related fields:

- **Computer Engineering** with focus on security, embedded systems, and computer architecture/systems for artificial intelligence.
- **Electronic materials** with focus on growth (using MBE etc.) and fabrication of novel devices for emerging artificial intelligence.
- **Computer Engineering** with focus on security, embedded systems, and computer architecture/systems for industrial electronics.

Job Duties:
- **Teaching**: Teaching undergraduate and graduate courses on topics in the area of specialization mentioned above and develop new undergraduate and graduate courses in these areas; (2) conducting research in at least one of the areas listed; (3) securing external funding for research programs; and (4) participating in service to the department and university through committee work, recruitment, and interaction with industry.

WSU Vancouver serves about 3,400 graduate and undergraduate students and is fifteen miles north of Portland, Oregon. The rapidly growing School of Engineering and Computer Science (ENCS) equally values both research and teaching. WSU is Washington's land grant university with faculty and programs on five campuses. For more information: http://ecs.vancouver.wsu.edu. WSU Vancouver is committed to building a culturally diverse educational environment.

Applications: Visit www.wsujobs.com and search postings by location. Applications must include: (1) cover letter with a clear description of experience relevant to each of the required and preferred qualifications; (2) vita including a list of at least three references; (3) a statement (two-page total) of how candidate’s research will expand/complement the current research in ENCS and a list of the existing ENCS courses the candidate can teach and any new courses the candidate proposes to develop; and (4) a statement on equity and diversity (guidelines found at https://admin.vancouver.wsu.edu/sites/admin.vancouver.wsu.edu/files/Diversity%20Statement%20Guidelines.pdf). Application deadline is December 1, 2019.

Washington State University is an equal opportunity/affirmative action educator and employer. Members of historically and currently underrepresented racial/ethnic groups, women, special disabled veterans, veterans of the Vietnam-era, recently separated veterans, persons of disability and/or persons age 40 and over are encouraged to apply. WSU employs only U.S. citizens and lawfully authorized non-U.S. citizens.

Tufts University

The Department of Electrical and Computer Engineering at Tufts University invites applications for a permanent full time tenure-track position at the Assistant Professor level beginning 8/16/2020. Preference will be given to candidates with expertise in the areas of power electronics including, but not limited to, power on a chip, power management ICs, power converters, energy harvesting and charging circuits, and packaging.

Job Requirements: Earned Ph.D. in Electrical Engineering or related field by employment start date and demonstrated ability to (1) develop a funded research program; (2) establish industrial collaborations; (3) teach undergraduate/graduate courses; (4) have published promising scholarly work in the field and (5) contribute to our campus diversity goals (e.g. incorporate issues of diversity into mentoring, curriculum, service or research).

Job Duties: (1) teaching undergraduate and graduate courses on topics in the area of specialization mentioned above and develop new undergraduate and graduate courses in these areas; (2) conducting research in at least one of the areas listed; (3) securing external funding for research programs; and (4) participating in service to the department and university through committee work, recruitment, and interaction with industry.

WSU Vancouver serves about 3,400 graduate and undergraduate students and is fifteen miles north of Portland, Oregon. The rapidly growing School of Engineering and Computer Science (ENCS) equally values both research and teaching. WSU is Washington’s land grant university with faculty and programs on five campuses. For more information: http://ecs.vancouver.wsu.edu. WSU Vancouver is committed to building a culturally diverse educational environment.

Applications: Visit www.wsujobs.com and search postings by location. Applications must include: (1) cover letter with a clear description of experience relevant to each of the required and preferred qualifications; (2) vita including a list of at least three references; (3) a statement (two-page total) of how candidate’s research will expand/complement the current research in ENCS and a list of the existing ENCS courses the candidate can teach and any new courses the candidate proposes to develop; and (4) a statement on equity and diversity (guidelines found at https://admin.vancouver.wsu.edu/sites/admin.vancouver.wsu.edu/files/Diversity%20Statement%20Guidelines.pdf). Application deadline is December 1, 2019.

Washington State University is an equal opportunity/affirmative action educator and employer. Members of historically and currently underrepresented racial/ethnic groups, women, special disabled veterans, veterans of the Vietnam-era, recently separated veterans, persons of disability and/or persons age 40 and over are encouraged to apply. WSU employs only U.S. citizens and lawfully authorized non-U.S. citizens.
Multiple Tenure-Track Faculty Positions in Electrical Engineering

The Electrical Engineering program at Western Washington University is expanding with the addition of three new tenure-track faculty positions with a start date of September 16, 2020. For two of the positions we prefer expertise in embedded systems, Internet of Things, cyber-physical systems, machine learning, or related areas; for the third position, we prefer an individual with interests in advanced vehicle systems such as automated vehicles, connected vehicles, or powertrain electrification who will be instrumental in facilitating research and development partnerships with PACCAR Inc. We expect to hire at the Assistant Professor level, but applications at all levels will be considered.

Responsibilities include developing and maintaining a program of scholarship, and developing and teaching lab-based electrical engineering courses with a commitment to cultivating equitable and inclusive learning environments.

Located in a coastal college town between Seattle and Vancouver, WWU is the highest-ranking public, master’s-granting university in the Pacific Northwest, according to the 2019 U.S. News & World Report rankings.

See the full job announcements at: https://cse.wwu.edu/engineering-design/employment

Job reference #s: 497138 and 497140

Review of applications will begin December 2, 2019 and will continue until the positions are filled. ADEE

Tenure Track Faculty in Electrical Engineering

The Department of Electrical Engineering (EE) in the School of Electrical Engineering and Computer Science at the Pennsylvania State University invites applications for multiple tenure-track faculty positions at all levels. Those considered at the Associate and Full Professor levels must demonstrate an established record in research. Successful candidates will be expected to establish and sustain an outstanding research program and to be effective, inspiring teachers at both the undergraduate and graduate levels. Candidates must have a doctorate in electrical engineering, or a related discipline completed before the start date of the position. The EE Department has 38 tenured/tenure-track faculty members, with annual research expenditures of over $15 million. The undergraduate (juniors and seniors) and graduate programs currently enroll over 550 and 220 students, respectively. The Department is committed to embracing diversity and fostering an inclusive and supportive environment for its students, faculty, and staff. Exceptional candidates for multiple positions covering a broad range of areas in electrical engineering will be considered, including but not limited to applied electromagnetics (RF, millimeter wave, and terahertz systems), communications systems, control systems, electronic devices and circuits, environmental remote sensing, signal processing, and machine learning and all of its applications. Information about the Department can be found at: http://www.eecs.psu.edu. Nominations and applications will be considered until the positions are filled. Applicants should submit the following: curriculum vita, statement of research, statement of teaching, and the names and addresses of four references. Please submit these documents electronically at https://psu.jobs/jobs. If you have any questions regarding the application process, please contact Christina Reese at mailto:cms97@psu.edu or (814) 863-2788.

Apply online at https://apprkr.com/1593278

CAMPUS SECURITY CRIME STATISTICS: For more about safety at Penn State, and to review the Annual Security Report which contains information about crime statistics and other safety and security matters, please go to http://www.police.psu.edu/clery/, which will also provide you with detail on how to request a hard copy of the Annual Security Report.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.

Tenure Track Faculty in Electrical Engineering

The Department of Electrical Engineering (EE) in the School of Electrical Engineering and Computer Science at the Pennsylvania State University invites applications for multiple tenure-track faculty positions at all levels. Those considered at the Associate and Full Professor levels must demonstrate an established record in research. Successful candidates will be expected to establish and sustain an outstanding research program and to be effective, inspiring teachers at both the undergraduate and graduate levels. Candidates must have a doctorate in electrical engineering, or a related discipline completed before the start date of the position. The EE Department has 38 tenured/tenure-track faculty members, with annual research expenditures of over $15 million. The undergraduate (juniors and seniors) and graduate programs currently enroll over 550 and 220 students, respectively. The Department is committed to embracing diversity and fostering an inclusive and supportive environment for its students, faculty, and staff. Exceptional candidates for multiple positions covering a broad range of areas in electrical engineering will be considered, including but not limited to applied electromagnetics (RF, millimeter wave, and terahertz systems), communications systems, control systems, electronic devices and circuits, environmental remote sensing, signal processing, and machine learning and all of its applications. Information about the Department can be found at: http://www.eecs.psu.edu. Nominations and applications will be considered until the positions are filled. Applicants should submit the following: curriculum vita, statement of research, statement of teaching, and the names and addresses of four references. Please submit these documents electronically at https://psu.jobs/jobs. If you have any questions regarding the application process, please contact Christina Reese at mailto:cms97@psu.edu or (814) 863-2788.

Apply online at https://apprkr.com/1593278

CAMPUS SECURITY CRIME STATISTICS: For more about safety at Penn State, and to review the Annual Security Report which contains information about crime statistics and other safety and security matters, please go to http://www.police.psu.edu/clery/, which will also provide you with detail on how to request a hard copy of the Annual Security Report.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.

Multiple Tenure-Track Faculty Positions in Electrical Engineering

The Electrical Engineering program at Western Washington University is expanding with the addition of three new tenure-track faculty positions with a start date of September 16, 2020. For two of the positions we prefer expertise in embedded systems, Internet of Things, cyber-physical systems, machine learning, or related areas; for the third position, we prefer an individual with interests in advanced vehicle systems such as automated vehicles, connected vehicles, or powertrain electrification who will be instrumental in facilitating research and development partnerships with PACCAR Inc. We expect to hire at the Assistant Professor level, but applications at all levels will be considered.

Responsibilities include developing and maintaining a program of scholarship, and developing and teaching lab-based electrical engineering courses with a commitment to cultivating equitable and inclusive learning environments.

Located in a coastal college town between Seattle and Vancouver, WWU is the highest-ranking public, master’s-granting university in the Pacific Northwest, according to the 2019 U.S. News & World Report rankings.

See the full job announcements at: https://cse.wwu.edu/engineering-design/employment

Job reference #s: 497138 and 497140

Review of applications will begin December 2, 2019 and will continue until the positions are filled. ADEE

Tenure Track Faculty in Electrical Engineering

The Department of Electrical Engineering (EE) in the School of Electrical Engineering and Computer Science at the Pennsylvania State University invites applications for multiple tenure-track faculty positions at all levels. Those considered at the Associate and Full Professor levels must demonstrate an established record in research. Successful candidates will be expected to establish and sustain an outstanding research program and to be effective, inspiring teachers at both the undergraduate and graduate levels. Candidates must have a doctorate in electrical engineering, or a related discipline completed before the start date of the position. The EE Department has 38 tenured/tenure-track faculty members, with annual research expenditures of over $15 million. The undergraduate (juniors and seniors) and graduate programs currently enroll over 550 and 220 students, respectively. The Department is committed to embracing diversity and fostering an inclusive and supportive environment for its students, faculty, and staff. Exceptional candidates for multiple positions covering a broad range of areas in electrical engineering will be considered, including but not limited to applied electromagnetics (RF, millimeter wave, and terahertz systems), communications systems, control systems, electronic devices and circuits, environmental remote sensing, signal processing, and machine learning and all of its applications. Information about the Department can be found at: http://www.eecs.psu.edu. Nominations and applications will be considered until the positions are filled. Applicants should submit the following: curriculum vita, statement of research, statement of teaching, and the names and addresses of four references. Please submit these documents electronically at https://psu.jobs/jobs. If you have any questions regarding the application process, please contact Christina Reese at mailto:cms97@psu.edu or (814) 863-2788.

Apply online at https://apprkr.com/1593278

CAMPUS SECURITY CRIME STATISTICS: For more about safety at Penn State, and to review the Annual Security Report which contains information about crime statistics and other safety and security matters, please go to http://www.police.psu.edu/clery/, which will also provide you with detail on how to request a hard copy of the Annual Security Report.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.

The Department of Electrical Engineering seeks applications in all areas of Electrical Engineering for a tenure-track assistant professor faculty position. Candidates should have a commitment to teaching and a demonstrated ability to pursue a high impact research program. A start date of September 1, 2020 is preferred.

The department is committed to fostering an academic environment that acknowledges and encourages diversity and differences. The successful candidate will pursue academic excellence in diverse, multicultural, and inclusive settings.

Applicant review will begin in November. For full consideration, please submit applications no later than December 31, 2019, using the following site: https://www.princeton.edu/acad-positions/position/13461. Applications require: a cover letter, complete curriculum vitae, descriptions of research and teaching interests, and the contact information for four references.

Princeton University is an equal opportunity employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability status, protected veteran status, or any other characteristic protected by law. The selected candidate will be required to successfully complete a background check.

The Department of Electrical Engineering (EE) in the School of Electrical Engineering and Computer Science at the Pennsylvania State University invites applications for multiple tenure-track faculty positions at all levels. Those considered at the Associate and Full Professor levels must demonstrate an established record in research. Successful candidates will be expected to establish and sustain an outstanding research program and to be effective, inspiring teachers at both the undergraduate and graduate levels. Candidates must have a doctorate in electrical engineering, or a related discipline completed before the start date of the position. The EE Department has 38 tenured/tenure-track faculty members, with annual research expenditures of over $15 million. The undergraduate (juniors and seniors) and graduate programs currently enroll over 550 and 220 students, respectively. The Department is committed to embracing diversity and fostering an inclusive and supportive environment for its students, faculty, and staff. Exceptional candidates for multiple positions covering a broad range of areas in electrical engineering will be considered, including but not limited to applied electromagnetics (RF, millimeter wave, and terahertz systems), communications systems, control systems, electronic devices and circuits, environmental remote sensing, signal processing, and machine learning and all of its applications. Information about the Department can be found at: http://www.eecs.psu.edu. Nominations and applications will be considered until the positions are filled. Applicants should submit the following: curriculum vita, statement of research, statement of teaching, and the names and addresses of four references. Please submit these documents electronically at https://psu.jobs/jobs. If you have any questions regarding the application process, please contact Christina Reese at mailto:cms97@psu.edu or (814) 863-2788.

Apply online at https://apprkr.com/1593278

CAMPUS SECURITY CRIME STATISTICS: For more about safety at Penn State, and to review the Annual Security Report which contains information about crime statistics and other safety and security matters, please go to http://www.police.psu.edu/clery/, which will also provide you with detail on how to request a hard copy of the Annual Security Report.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.
In the 1920s in Weimar Germany, Friedrich Trautwein was a young electrical engineer and musician who wanted to make a splash in the burgeoning field of electronic music. And so he invented the Trautonium. The instrument’s playing interface consisted of a single wire stretched over a metal plate. When the musician pressed the wire against the plate, it closed the circuit and produced a tone. Moving your finger along the wire from left to right changed the resistance and therefore the pitch. It sounded like a violin. Sort of. Trautwein’s attempt to find a mass market for his instrument went nowhere. But decades later, electronic music pioneer Oskar Sala would use the Trautonium to terrifying effect, producing the screeches and caws for Alfred Hitchcock’s 1963 horror-thriller The Birds.

For more on the history of electronic musical instruments, see https://spectrum.ieee.org/pastforward1019
She should live her dream.

Even if you’re not there.

IEEE Member Group Term Life Insurance Plan.
You can’t predict the future, but you can prepare for it.

To learn more*, visit IEEEinsurance.com/Dream

*For information on plan features, costs, eligibility, renewability, limitations and exclusions.

The Group Term Life Insurance Plan is available only for residents of the U.S. (except territories), Puerto Rico and Canada (except Quebec). This plan is underwritten by New York Life Insurance Company, 51 Madison Ave., New York, NY 10010 on Policy Form GMR. This plan is administered by Mercer Health & Benefits Administration LLC. This coverage is available to residents of Canada (except Quebec). Mercer (Canada) Limited, represented by its employees Nicole Swift, Pauline Tremblay and Suzanne Dominico, acts as broker with respect to residents of Canada.

Program Administered by Mercer Health & Benefits Administration LLC
In CA d/b/a Mercer Health & Benefits Insurance Services LLC
AR Insurance License #100102691 | CA Insurance License #0G39709

85476 (10/19) Copyright 2019 Mercer LLC. All rights reserved.
MATLAB SPEAKS

DEEP LEARNING

With just a few lines of MATLAB® code, you can use CNNs and training datasets to create models, visualize layers, train on GPUs, and deploy to production systems.

mathworks.com/deeplearning