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FOR THE TECHNOLOGY INSIDER
OCTOBER 2022

IEEE Spectrum

Do High-Tech Prosthetics Serve Their Users?

IEEE

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Contents

ON THE COVER:
Photo by Gabriela Hasbun

TOP: PHILIP CHEUNG/THE NEW YORK TIMES/REDUX; BOTTOM: PETER LI

BY HARRY GOLDSTEIN

"Nothing About Us Without Us"

Put the user at the center of assistive technology design

Participants at the annual Disability Pride Parade in New York City letting their voices be heard.

Before we redesigned our website a couple of years ago, we took pains to have some users show us how they navigate our content or complete specific tasks like leaving a comment or listening to a podcast. We queried them about what they liked or didn't like about how our content is presented. And we took onboard their experiences and designed a site based on that feedback.

So when I read this month's cover story by Britt Young about using a variety of high- and low-tech prosthetic hands, I was surprised to learn that much of bionic-hand development is conducted without taking the lived experience of people who use artificial hands into account.

I shouldn't have been. While user-centered design is a long-standing practice in Web development, it doesn't seem to have expanded deep into other domains. A quick search on the IEEE Xplore Digital Library tallied less than 2,000 papers (out of 5.7 million) on "user-centered design." Five papers bubbled up when searching "user-centered design" and "prosthesis."

Young, who is working on a book about the prosthetics industry, was in the first cohort of toddlers fitted with myoelectric prosthetic hands, which users control by tensing and relaxing their muscles against sensors inside the device's socket. Designed by people Young characterizes as "well-intentioned engineers," these technologically dazzling hands try to recreate in all its complex glory what Aristotle called "the instrument of instruments."

While high-tech solutions appeal to engineers, Young makes the case that low-tech solutions like the split hook are often more effective for users. "Bionic hands seek to make disabled people 'whole,' to have us participate in a world that is culturally two-handed. But it's more important that we get to live the lives we want, with access to the tools we need, than it is to make us look like everyone else."

"It's more important that we get to live the lives we want, with access to the tools we need, than it is to make us look like everyone else."

As Senior Editor Stephen Cass pointed out to me, one of the rallying cries of the disabled community is "nothing about us without us." It is a response to a long and often cruel history of able-bodied people making decisions for people with disabilities. Even the best intentions don't make up for doing things for disabled people instead of with them, as we see in Young's article.

Assistive and other technologies can indeed have huge positive impacts on the lives of people with disabilities. *IEEE Spectrum* has covered many of these developments over the decades, but generally speaking it has involved able-bodied journalists writing about assistive technology, often with the perspective of disabled people relegated to a quote or two, if it was included at all.

We are fortunate now to have the chance to break that pattern, thanks to a grant from the IEEE Foundation and the Jon C. Taenzer Memorial Fund. With the grant, *Spectrum* is launching a multiyear fellowship program for disabled writers. The goal is to develop writers with disabilities as technology journalists and provide practical support for their reporting. These writers will investigate not just assistive technologies, but also look at other technologies with ambitions for mass adoption through a disability lens. Will these technologies be built with inclusion in mind, or will disabled people be a literal afterthought? Our first step will be to involve people with disabilities in the design of the program, and we hope to begin publishing articles by fellows early next year. ■

PORTRAIT BY SERGIO ALBIAC; ERIK MCGREGOR/LIGHTROCKET/GETTY IMAGES

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MARK HARRIS

Harris, a contributing editor, is an investigative science and technology reporter based in Seattle. In this issue he writes about data collection from Tesla vehicles [see page 40]. "Cars have always been about freedom, out on the open highway," he says. "Now that has flipped," with these cars recording their surroundings and movements, as well as the driver's behavior. "It shows you how much society has changed."

DONG-WON KIM

Kim is a historian of science and technology and a former professor at Korea Advanced Institute of Science and Technology. As a cousin of Kim Choong-Ki, the "Godfather" of the South Korean semiconductor industry [see page 32], Kim has known his subject for a long time. "I however didn't know how important a figure he was...until the beginning of the 21st century," he says. His book about Kim Choong-Ki and his former students will be published by CRC Press in 2023.

QI "PETER" LI

Growing up near Beijing, Li got interested in electronics as a teenager: "I built a 9-inch black-and-white TV receiver by myself, from parts. And it worked!" Today, the company this IEEE Fellow founded in 2002, Li Creative Technologies, is marketing an AI-based technology called 3D Soundstage, which reproduces audio recordings with high levels of realism. He and coauthors Yin Ding and Jorel Olan describe the system in "How Audio Is Getting Its Groove Back," on page 46.

BRITT H. YOUNG

Young is a writer and human geographer based in Berkeley, Calif., who focuses on the impact of tech on marginalized communities and its intersections with disability. "There's a trend to create ever-more-sophisticated and expensive robotics for disabled people, when lower-tech, well-designed, simple activity-specific devices could do the job better," says Young. On page 24, she explores this theme through history, the latest research, and her own experience.

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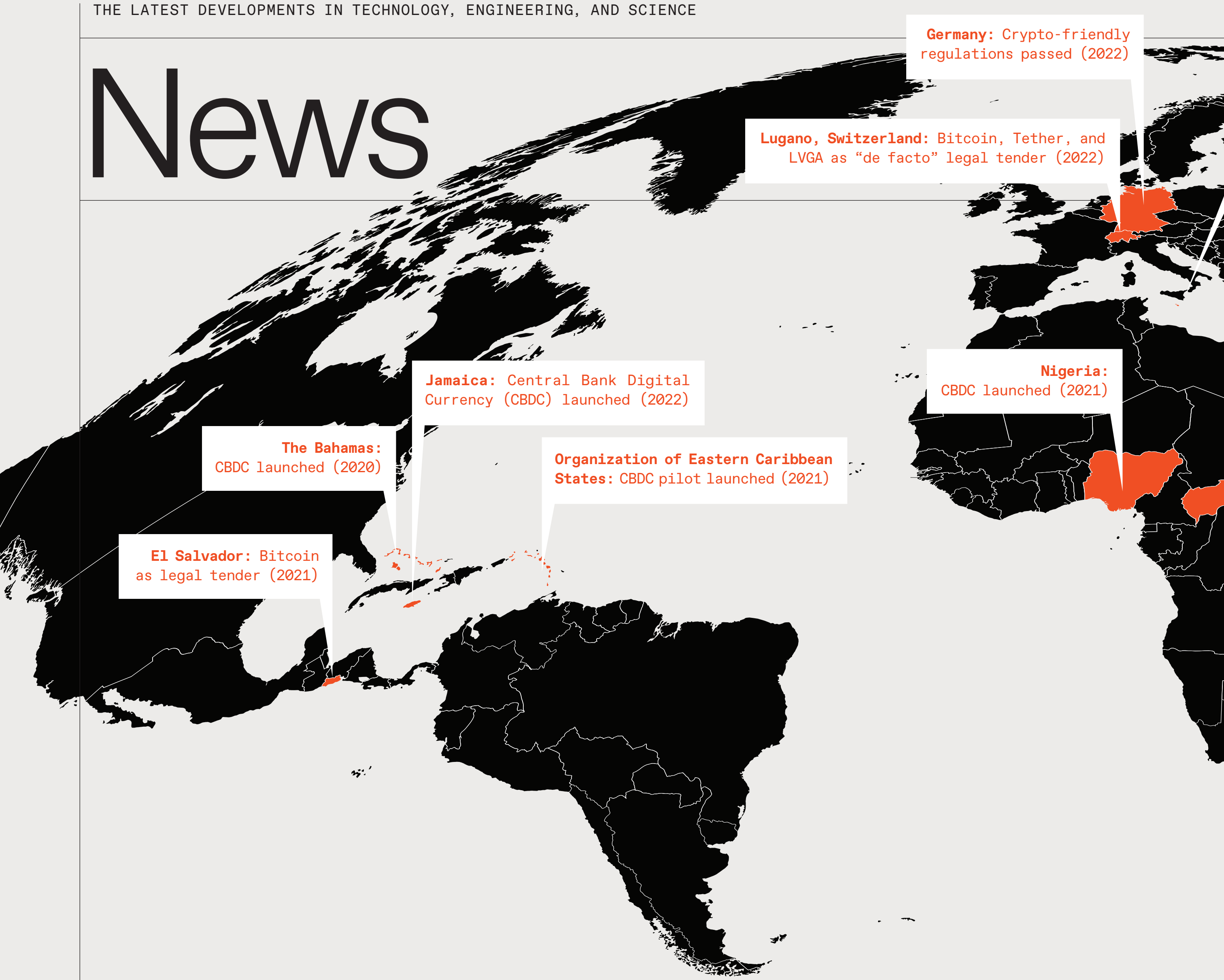
News



CRYPTOCURRENCY

Three Ways Governments Are Co-opting Crypto

> To supersede notes and coins, they're rushing in where Bitcoin never ventured

BY EDD GENT

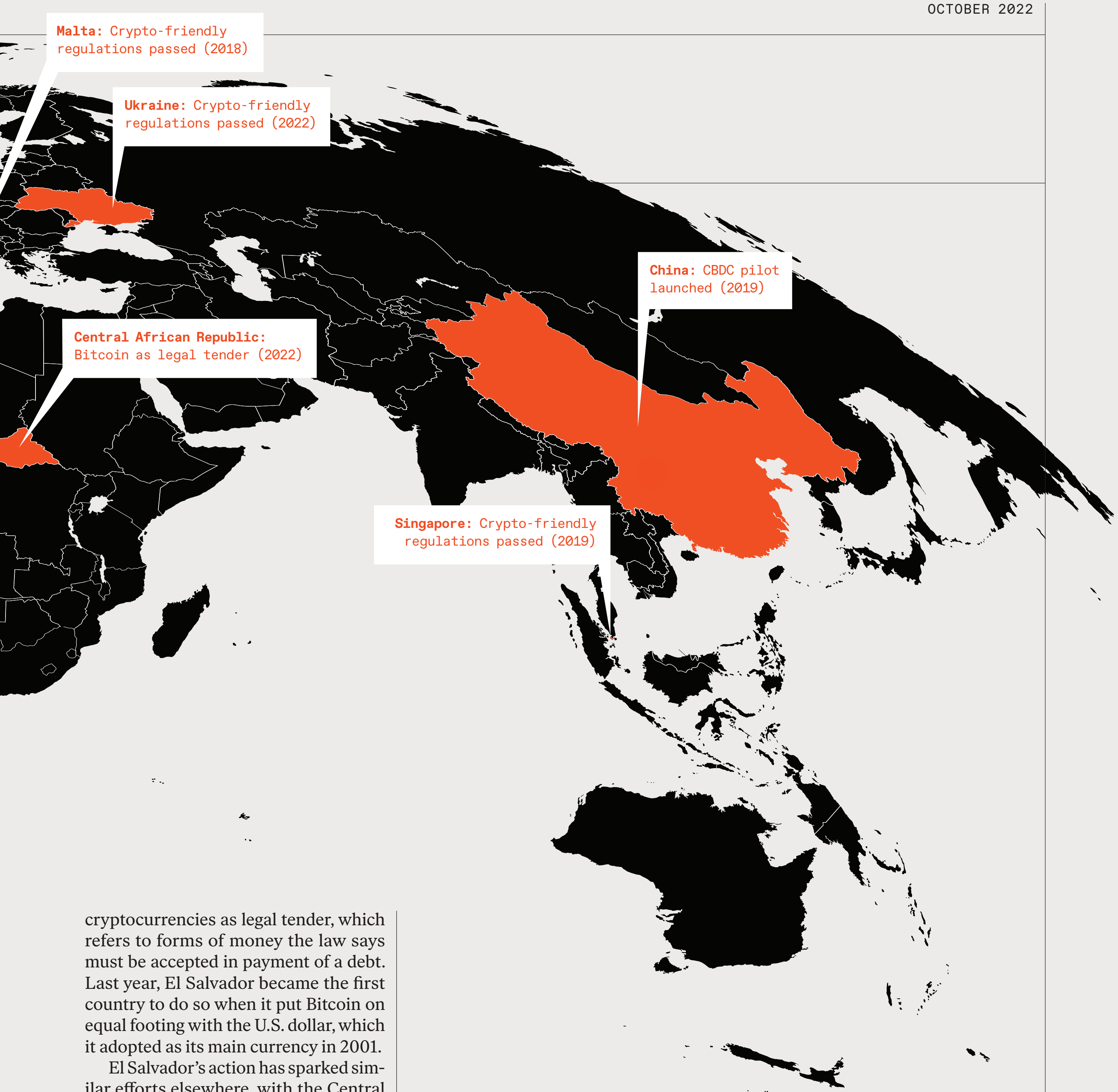
The rise of cryptocurrencies is rewriting long-standing ideas about how money should work. Eager not to get left behind, governments around the world are jumping on the bandwagon leading to an explosion of national experiments in crypto-friendly regulation and state-backed digital currencies.

In most developed economies, the production and distribution of money has predominantly been the remit of central banks for at least a century. That was turned on its head in 2009 with the launch of Bitcoin, which uses blockchain technology to delegate the minting and governance of the digital currency to a decentralized network of volunteers.

Since then, a host of new cryptocurrencies have emerged, promising a fast, cheap, and secure way to transfer money directly between users without relying on banks or payment providers. Volatile prices and regulatory uncertainty have limited their adoption as a medium of payment, but the underlying technology has led to a major rethink of what money should look like in the digital age.

"They proved that there can be a new way to organize money and make payments, and that this can be widely adopted," says Andreas Veneris, a professor of computer engineering at the University of Toronto, who has advised the Bank of Canada on digital currencies.

How governments have reacted to these developments varies significantly. Some have taken the leap and embraced

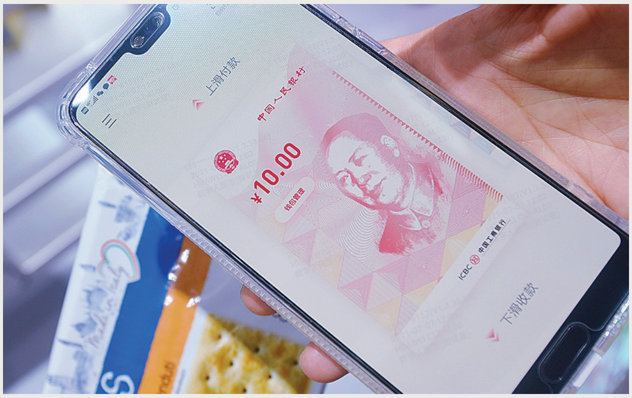


cryptocurrencies as legal tender, which refers to forms of money the law says must be accepted in payment of a debt. Last year, El Salvador became the first country to do so when it put Bitcoin on equal footing with the U.S. dollar, which it adopted as its main currency in 2001.

El Salvador's action has sparked similar efforts elsewhere, with the Central African Republic becoming the second country to make Bitcoin legal tender in April. The Swiss city of Lugano also announced plans to make Bitcoin, Tether (a stablecoin pegged to the value of the U.S. dollar), and LVGA (a Swiss Franc–based stablecoin launched by the city in 2020) "de facto" legal tender by allowing people to make all payments to the authorities in them.

Pietro Poretti, director of Lugano's Economic Promotion Division, says the city wants the local economy to get a boost by pulling in crypto enthusiasts, giving the city a crucial head start in what could be an important technology in the future. "It certainly doesn't do any harm being equipped for what is coming, to be ahead of the curve rather than catching up," he says.

For now, though, cryptocurrencies don't make good legal tender due to their wildly fluctuating values, says Thomas Dimpfl, a professor of economics at the University of Hohenheim, in Stuttgart, Germany. That's proven a significant problem for El Salvador's government, whose Bitcoin holdings have lost roughly 60 percent of their value due to the recent crypto crash. "A good legal tender is



In China, users can pay with e-CNY, the digital currency issued by China's central bank.

FEATURECHINA/AP

something that is reliable," he says. "The biggest risk is that [Bitcoin] is just so volatile."

Other countries have taken a less extreme approach, adopting crypto-friendly regulations that support innovation while still keeping these new forms of money at arm's length. Sergiu Hamza, CEO of crypto analyst firm Coincub, in Dublin, which provides a ranking of crypto-friendly countries, says the pace of experimentation has accelerated dramatically in the last year. "It changes so fast," he says. "In [May], we have compiled a list of 150 news articles on different regulation changes, with at least 10 countries radically changing their positions."

While die-hard crypto-anarchists might bristle at government oversight, Hamza says many in the industry welcome the clarity that regulation brings for both users and service providers. Perhaps unsurprisingly, major financial centers like Singapore and Switzerland and tax havens like Malta and the Bahamas have been ahead of the pack when it comes to passing more sophisticated crypto regulation. "Countries that are used to financial innovation and countries that are at the forefront of technology—obviously it's easier for them to understand crypto and deal with it," says Hamza.

Malta was one of the first countries to regulate cryptocurrencies when it passed a trio of laws in 2018 that defined Virtual Financial Assets and set out rules for how they could be issued, traded, and exchanged. Singapore has also been proactive, running a regulatory sandbox for financial technology, or fintech, companies since 2016 and introducing the Payment Services Act in 2019. The latter regulated how cryptocurrencies could be issued, and it established oversight mechanisms for exchanges and other crypto firms.

It's not only finance hubs getting involved though—the country that shared Coincub's top rankings for crypto-friendliness (alongside the United States) was Germany. The country charges no tax on gains from crypto held for longer than a year and a recently passed law allows investment funds called *spezialfonds*, which are not available to retail investors and therefore more lightly regulated, to invest up to 20 percent of their holdings in cryptocurrency.

Most countries setting crypto-friendly rules are trying to boost their domestic crypto industry, but there can be other reasons too. Ukraine has made headlines for using cryptocurrencies to raise funds for its defense against the Russian invasion. Max Semenchuk, a blockchain entrepreneur, reports that he's acting as an advisor to Ukraine's Ministry of Digital Transformation. He says that the country has long had a progressive attitude to cryptocurrencies and has topped adoption rankings for years, currently standing at about 12 percent of the population.

Shortly after the start of the war, a law passed that recognized cryptocurrencies as legal assets and introduced financial-monitoring measures. Semenchuk says it had been in the pipeline for years. The aim is primarily to support the use of the technology by individuals. "Cryptos work best at the places where more traditional instruments are not working," he says. "There's not so much trust for the banks. We have got some history of banks folding, and [of] crisis and devaluation of currency."

Other countries are taking a different tack. Rather than easing the adoption of cryptocurrencies, they are developing digital currencies of their own. China launched pilots of its digital yuan, reportedly, in four cities in late 2019. By the end of last year, total transactions had crossed 87.6 billion digital yuan with 261 million electronic wallets opened, according to the People's Bank of China. The project has now expanded to 23 cities and use has accelerated in 2022 with a reported total transaction volume hitting at least 83 billion yuan.

It's not the only such project, though. In October 2020, the Bahamas' Sand Dollar became the first central bank digital currency (CBDC) to be rolled out nationwide, and since then, digital versions of the Eastern Caribbean Dollar, Nigeria's naira (the e-Naira), and the Jamaican dollar (the Jam-Dex) have all launched. An executive order from the Biden administration in March called for the U.S. Treasury Department to investigate the possibility of a digital dollar and according to the Atlantic Council, more than 50 countries are in advanced stages of exploring CBDCs.

One of the primary motivations is that, like cryptocurrencies, CBDCs could make it possible to instantly transfer money between people without relying on third parties, resulting in cheaper, faster payments. "Payment systems today are expensive; they are clumsy and slow," says the University of Toronto's Veneris, pointing out that much of the underlying technology is more than 40 years old.

Public-sector organizations don't have a great record when it comes to digital transformation, though, says Dante Disparte, chief strategy officer at Circle, the company behind the USD Coin, a cryptocurrency pegged to the U.S. dollar. Expecting them to make the right calls on the future of digital money seems unwise, he says, adding that government's role should be to set guardrails on private-sector innovation.

"The air gap between the central bank, the banking system, your wallet, and your money is a feature, not a bug," Disparte says. "[CBDCs] would be the equivalent of the aviation-safety authorities choosing to fly planes and build jet engines." ■

TELECOM

Billionaires Battle for Global Spectrum Domination › Their skirmish over the 12-GHz band could affect every Internet user

BY MICHAEL DUMIAK

DISH NETWORK

Dish Network Corp., owner of this 5G cellular tower, is in a high-stakes skirmish with Elon Musk's SpaceX over the use of the 12-gigahertz spectrum band.

Billionaires, satellite links, and political chicanery: A present-day, oligopolistic game of jockeying for prime placement in the 12-gigahertz spectrum has at least a few of the ingredients of a thriller. Or—given the outsize personalities involved (including Elon Musk and Michael Dell), and the epic, six-year duration of the dispute to date—maybe more like a space opera.

At issue is a set of frequencies at which Musk's SpaceX transmits its Starlink Internet service, the company's well-publicized play for broadband beaming down from low-Earth orbit to satellite dishes in remote areas. Charlie Ergen's Dish Network Corp., which transmits TV on these frequencies and is one of the two big satellite viewing providers in the United States, has launched a 5G wireless service and wants to increase its signal volume in this set of wavelengths. Musk's side says Dish's move would create debilitating static that would impede his satellite transmissions; Ergen's engineers say that's nonsense. As for Dell (think Dell computers), his private investment firm holds rights to some of the airwaves in play. At the moment, his group is siding with Dish.

The current field, more precisely 12.2 to 12.7 GHz in the Ku microwave band, is a lot of bandwidth lightly used. At present, it is the go-to frequency range for assorted satellite broadcasts, live feeds, and ISS tracking. But the companies fighting over it recently cranked up their clashing. The sides are lobbying a shorthanded U.S. Federal Communications Commission, taking swipes at each other such as when Musk blasted his foes as "super shady and unethical." He took return fire from Dish for "flimsy" and "far-fetched" objections to opening bandwidth.

But what does it mean for those outside the immediate fray? For civilians going about their daily business? For people—possible satellite service subscribers—all around the world?

Only a handful of people who understand the nature of possible interference and related issues seem to be paying attention now. "Rights to use frequencies have not been sharply defined, and the overlapping permits generate controversy," says Thomas Hazlett, a Clemson University economist who writes about bandwidth battles (and once served as FCC chief economist). But the rulings—and market activities that result—stand to have real social impact wherever signals from satellite broadcasts or satellite Internet connections may one day fall. Which means pretty much everywhere.

The contretemps is understandable, given the economic value placed on frequency rights. More than 100 bandwidth auctions over the past 30 years had netted about US $230 billion for the U.S. Treasury as of the spring of 2022. But as with television, radio, and the railway before that, citizens aren't likely to tune in until more tangible developments happen. Industry players, however, are paying close attention, and the pressures are intense. In the United States, the intensifying jockeying over the fate of the 12-GHz spectrum band "is purely market driven," says Shahed Mazumder, global director of telecom solutions at Aerospike, a database firm.

"There's political pressure, the business pressure, and monetary pressure; there are legitimately major things going on here," says Mike Dano, who's been following the dispute as editorial director at Light Reading, a news website covering the global telecom sector. "Billions of dollars of value, potentially, [will] be created or destroyed depending on how an FCC engineer finally decides on it," he adds. Meanwhile the politically appointed commissioners at the FCC are down one member, leaving the board split 2-2 along party lines. Regular deadlocks make controversial calls like this one more difficult.

More techie influences may also affect the spectrum spat. In 2018, the United States became the first to approve a spectrum-sharing setup in the Citizens Broadband Radio Service band (3.5 GHz). It's an advanced concept allowing different sets of users to share spectrum—making more room. Dano says the FCC is under pressure to allocate 12 GHz in accordance with that bandwidth-sharing philosophy.

This notably did not happen with U.S. 5G network rollouts, which turned into a snarling issue earlier this year over fears of mutual interference in the C-band between high-speed cellular service towers and plane altimeters in low-visibility conditions on approach to airports.

Meanwhile Starlink wants to extend the reach of its satellite broadcasts to further-flung places; it has, for example, expressed a desire to open gateways in the United Kingdom. While its 12-GHz fight with Dish is centered in the United States, satellite spectrum allocation is...special. Space has international dimensions, points out Plum Consulting's Selçuk Kırtay, who has written about spectrum sharing and interference ever since he covered the topic in his 2001 doctoral thesis. Slicing up the Ku band has history—it even left its mark at a global astronautical confab in then-Czechoslovakia in Star Wars–era 1977.

Ofcom, the U.K. regulator, is monitoring developments with U.S. allocations in 12 GHz. This slice of the spectrum in the 12.2-to-12.7-GHz frequency range is sure to be a hot topic of conversation at the quadrennial ITU World Radiocommunication Conference to be held next year in the United Arab Emirates.

Stay tuned, say experts and satellite industry watchers. "How the conflicts are resolved in the U.S.A. will materially affect markets around the world," Clemson's Hazlett says. ■

TRANSPORTATION

Deutschland to England, on a Single Charge › Mercedes's solar-boosted EV shows off 1,200-km range

BY LAWRENCE ULRICH

The Mercedes-Benz Vision EQXX, and its showroom-bound tech, looks to banish EV range anxiety for good: In April, the sleek prototype sedan completed a 1,000-kilometer (621-mile) trek through the Alps from Mercedes's Sindelfingen facility to the Côte d'Azur in Cassis, France, with battery juice to spare. It built on that feat in late May, when the prototype traversed 1,202 km (747 miles) in a run from Germany to the Formula One circuit in Silverstone, England.

Despite modest power, a futuristic teardrop shape, and next-gen tech, the EQXX is, quintessentially, a small Mercedes luxury sedan. To underline the German automaker's real-world intent, Mercedes vows that the EQXX's power train will reach showrooms by 2024.

"The car is an R&D project, but we're feeding it into the development of our next compact-car platform," says Conrad Sagert, an engineer at Mercedes who is developing electric drive systems.

The engineering effort included specialists with the Mercedes-EQ Formula E team; it thus draws from their well of electric racing experience. Developed in just 18 months, the rear-drive Vision EQXX is powered by a single radial-flux electric motor—developed entirely in-house—fed by a battery pack with just under 100 kilowatt-hours of usable energy. One thing that won't reach production by 2024 is the EQXX's high-silicon battery anode, which Sagert says is closer to four years from showrooms. Such silicon-rich anodes, which can squeeze more range from batteries, are widely expected to be popularized over the next decade.

The car's 241-horsepower output delivers a reasonable 7-second acceleration from 0 to 100 kilometers per hour (0 to 60 miles per hour). But with a feathery (for an electric vehicle) 1,770-kilogram curb weight and wind-cheating aerodynamics, the carbon-fiber-bodied EQXX is designed for pure efficiency, not winning stoplight races. According to Sagert, the Benz sipped electrons at 14 kilometers per kilowatt-hour on its Riviera run, nearly double the roughly 7.2 km/kWh achieved by the Lucid Air (the current record holder for EV range). On the trip to the United Kingdom, he says, its efficiency squeaked just past 12 km/kWh. If that electric math still seems esoteric, the England-bound Benz delivered the equivalent of 111.3 kilometers per liter of fossil fuel (262 miles per gallon), nearly double the 58-km-per-liter energy efficiency of the industry-leading Tesla Model 3 Standard Range.

A roof panel with 117 solar cells lessens the burden by powering a conventional 12-volt system to run accessories, including lighting, an audio system, and dashboard display screens worthy of *Minority Report*. The Mercedes EV team found that on the cloudy April trip to southern France, with plenty of tunnel passages, the panels extended the EQXX's expected range by 13 km. On the sunnier May drive to the U.K., the solar boost provided an extra 43 km of range.

Aerodynamics naturally play an essential role, including a tiny frontal area and a dramatic Kamm tail whose active rear diffuser extends nearly 20 centimeters at speeds above 37 kilometers per hour. The sidewalls of the specially designed Bridgestone tires sit flush with

MERCEDES-BENZ

the body and 51-centimeter magnesium wheels, aiding a claimed drag coefficient of 0.17. This figure exceeds that of any current production car. Surprisingly for such a tech-forward design, the EQXX features traditional exterior mirrors. Mercedes says the camera-based "mirrors" used on many concept cars drew too much electricity to generate a tangible benefit.

Defying today's EV norms, the battery and motor are entirely air cooled. Replacing liquid-cooling circuits, pumps, and fluids with a smoothly shaped underbody that acts as a heat sink set off a spiral of savings in weight and packaging. Unlike solving the engineering challenge endemic to internal combustion engines and most EVs, which involves getting heat out of the system to keep the battery and motor from exceeding optimal operating temperatures, Mercedes solved the opposite problem: Active front shutters can close to limit the flow of cooling air as necessary.

"We had to insulate the electric motor. It's still about heat management, but the other way around," Sagert says.

Add it up, and the EQXX transfers a claimed 95 percent of electric energy into forward motion, up from 90 percent for Mercedes's current models such as the EQS. If that doesn't sound like much gain to nonengineers, Sagert puts it another way: The EQXX reduces typical EV energy losses by 50 percent.

"We're always hoping for this magical thing, but it's really the sum of the details," Sagert says.

That obsession with tiny details paid off. Based on computer and dynamometer simulations, engineers saw a 1,000-km trip on a single charge as a challenging but achievable target. With that goal in mind, they plotted the Mediterranean road trip to Cassis, France. Instead, the car blew away those conservative projections. Pulling into Cassis, the EQXX had 140 km of range remaining.

"We thought about waving and just driving on, but we weren't allowed," Sagert says, not least because Mercedes board member and chief technology officer Markus Schäfer was waiting to greet them. Mercedes then set its sights higher, choosing Silverstone and its Formula One track for a subsequent team meetup.

The sleek sedan capped off the record-breaking trek with an energy-guzzling flourish: Despite some misgivings, the team handed their precious prototype to a Formula E team driver, Nyck de Vries. The type-A racer forgot all about efficiency and pushed the car to its limits on the Silverstone F1 circuit, watched by nervous engineers. Where long-distance drivers had relied almost exclusively on regenerative braking (with four adjustable levels) during their runs, de Vries got to test the car's novel aluminum rear-brake rotors. Those ultralight rotors are possible because the Benz so rarely needs to use its foot-operated mechanical brakes, as telemetry readings from the track showed.

For the average driver on public roadways, that difference will yield huge dividends—principally, how far you can go on a single charge.

"Range anxiety is not a problem anymore," Sagert says. "If your range isn't enough today, wait two years; the [next] step will be big." ■

Rafael Mariano Grossi, director general of the International Atomic Energy Agency [hand to hat], paid a visit to the Zaporizhzhia nuclear power plant on 1 September to see the state of the combat-scarred facility firsthand.

FREDRIK DAHL/IAEA

ENERGY

Is Embattled Ukraine at Risk of Another Nuclear Disaster?

> Russia's near-miss attacks just one part of the goings-on that could foreshadow catastrophe

BY PETER FAIRLEY

The March 2022 seizure of Ukraine's Zaporizhzhia power plant by Russian forces and more recent shelling of the plant have veered dangerously close to nuclear disaster. But a more opaque threat may also stalk Europe's largest nuclear power plant and Ukraine's three other nuclear power stations: a cloak-and-dagger struggle pitting activist nuclear professionals against alleged Russian agents at state nuclear energy firm Energoatom.

It's an unstable situation that increases the risk of accidents that could spread radiation across Europe and threatens Ukraine's ability to defend itself. Ukraine's 15 reactors generate over half of its electricity and, thanks to Ukraine's rapid postinvasion synchronization with Europe's power grid, electricity exports are helping the embattled nation finance its defense.

The murky internal battle for Ukraine's nuclear power popped into sight briefly in March, when a few Ukrainian news outlets and *IEEE Spectrum* reported that Ukrainian counterintelligence officers had detained and questioned Energoatom director of personnel Oleg Boyarintsev. That cast a shadow over officials across Energoatom whom Boyarintsev had appointed.

In June and July, the plot thickened, as moves by counterintelligence agents with the Security Service of Ukraine (SBU), deputies in Ukraine's parliament, and Energoatom officials heightened concerns about the security and safety of the firm's operations.

- SBU spy hunters said they had pierced an "extensive agent network" led by Boyarintsev's longtime political patron and business partner Andriy Derkach, whom the SBU and U.S. intelligence agencies say is a Russian agent;
- Ukraine's president, Volodymyr Zelenskyy, affirmed pervasive infiltration of Ukraine's state security service, which routinely places officials at Energoatom headquarters and its plants;
- Energoatom CEO Petro Kotin stunned a panel of deputies probing his firm's personnel issues by telling them Boyarintsev would not appear as requested because he had the day off; and
- Kotin gave contradictory explanations for dismissing the director of the Rivne Nuclear Power Plant, which sits less than 60 kilometers from Belarus. Kotin said Pavlo Pavlyshyn, the sacked former director, was both suspected of hiding safety violations and was needed for a critical mission: starting up a new facility to store spent fuel previously sent to Russia. Without ready access to a depository for storing spent fuel, Ukraine can't refuel its reactors.

Ukrainian news site Glavcom's take from the hearing was that Ukraine's nuclear plants were "in danger," and that a "hunt for collaborators" was on. The panel's deputy chairman concurred, posting, "Russian ears are sticking out now from all sides."

In August, Energoatom sent *Spectrum* a statement by Kotin insisting that allegations of Russian influence are "part of a broad information campaign of Russian propaganda." Kotin pointed to post-invasion moves to sever ties to Russia's nuclear industry, including "the complete rejection of Russian nuclear fuel, Russian services, components, and technologies."

But Kotin's critics are not backing down. Olga Kosharna, a former advisor to Ukraine's nuclear regulator, sued for defamation after Energoatom accused her of being under Russian influence. The suit will be heard in October according to her lawyer, who heads the energy-law committee for Ukraine's bar association.

Kosharna maintains her March 2022 claim that officials planted by Boyarintsev facilitated the Zaporizhzhia plant's capture, including a new plant director appointed eight days before the 24 February invasion. Kosharna says Boyarintsev is part of a larger group headed by Andriy Derkach, who the SBU says worked for Russian intelligence under the codename "Veteran."

Derkach is a long-serving Ukrainian deputy, a pro-Russia media commentator, and a former Energoatom CEO. His whereabouts since the invasion are unknown. He gained global notoriety delivering alleged kompromat—compromising material—on U.S. President Joe Biden in 2019. In spite of that, he is widely credited with driving Boyarintsev's inclusion in 2020 when Zelenskyy appointed Kotin and a new leadership team at Energoatom. Why else, ask people like Kosharna and other nuclear professionals, would someone with Boyarintsev's connections win a job so crucial to Ukraine's security?

Between the appointment of Kotin's team and Russia's February 2022 invasion, journalists, activists, and government watchdogs documented a series of suspicious activities including the dumping of electricity on the market, the illegal dismissal of Energoatom's independent anticorruption official, and embezzlement of funds for the long-delayed spent-fuel repository.

They also decried a slide back toward Russian influence at Ukraine's Russian-designed and mostly Russian-fueled nuclear plants. Ukrainian security analyst Pavel Kost had previously praised Energoatom as one of the "quiet heroes" of post-Yanukovich Ukraine. Last year he called out the growing influence of "pro-Russian circles" and "silent sabotage" of crucial projects such as the spent-fuel repository.

Over half of Ukraine's parliamentarians called last year for new leadership to improve Energoatom's operations and assure nuclear safety.

Jeff Merrifield, a former U.S. Nuclear Regulatory Commission member and international nuclear consultant, likened the situation facing Ukraine's nuclear plants to a "multilayer set of chess." While he declined to address the specific accusations against Energoatom leaders, Merrifield said they "were not entirely surprising" based on some of the "unsavory" activity he's observed in 20 years of work in both Ukraine and Russia.

Kosharna, meanwhile, is not the only Ukrainian professional challenging Energoatom's actions under Kotin. The loudest critical voice among engineers and scientists (at least in writing) is Georgiy Balakan, a former top Energoatom engineer who led collaborations with U.S. national labs, Westinghouse Electric, and European agencies to upgrade safety at Ukraine's plants. Since April, he has posted a series of risk assessments, warnings, and questions regarding management of Energoatom.

Balakan was among the nuclear safety experts who successfully pushed for Zaporizhzhia to stop generating electricity last month. Cooling its reactors—a move endorsed in August by the U.S. National Security Council—was expected to reduce the likelihood and severity of a potential accident. ■

JOURNAL WATCH

Robot Bests Surgeon in Precision Task

High-precision autonomous surgical robots—which would be available 24 hours a day, never get tired, and never lose focus—are on the drawing board. In a paper published 10 May in *IEEE Transactions on Automation Science and Engineering*, a multinational team of researchers reported the results of a study where a robot was able to complete a common training task for robot-assisted surgery with the same accuracy as that achieved by an experienced surgeon, only faster.

Minho Hwang, an assistant professor at the Daegu Gyeongbuk Institute of Science and Technology, in South Korea, was involved in the study. He notes that many robotic surgery systems currently rely on automated control of cables, which are subject to friction, cable coupling, and stretch—all of which can make precision positioning of these robotic arms difficult.

"When humans control the robots, they can compensate through human visual feedback," explains Hwang. "But automation of robot-assisted surgery is very difficult due to [these] position errors."

In their study, Hwang and collaborators strategically placed 3D-printed markers on the robotic arm of a standard da Vinci robotic-surgery system. This allowed the team to track the arm's movements using a color and depth sensor. They then analyzed the movements using a machine-learning algorithm. Results suggest that the trained model can reduce the mean tracking error by 78 percent.

Next, the researchers put their system to the test against a human doctor who had performed more than 900 surgeries. The surgeon and the robot had to complete a peg-transfer task, a standardized test for trainees in robot-assisted surgery that involves moving six triangular blocks from one side of a pegboard to the other and then back again.

In the most difficult variation of the peg-transfer exercise, the robot achieved the same level of placement accuracy as the surgeon, but it completed the task 31.7 percent faster on average.

In future work, the team plans to extend its approach to surgical subtasks such as tissue suturing.

— Michelle Hampson

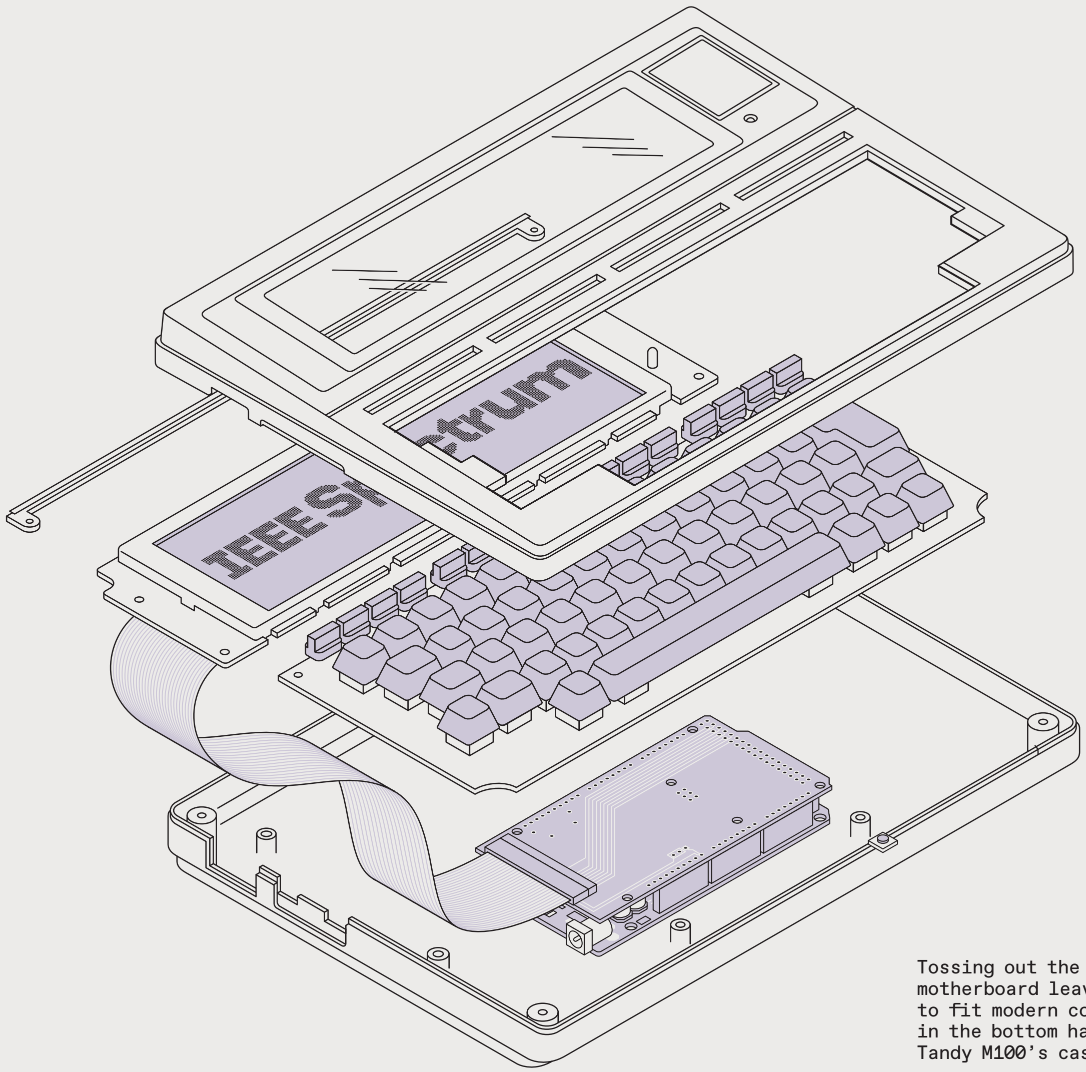
RoboCup Class Picture

By Willie D. Jones

Have you ever been awed by the pageantry of the parade of nations in the opening ceremony of the Olympic Games? Then this photo, featuring more than 100 Nao programmable educational robots, two Pepper humanoid assistive robots, and their human handlers, should leave you similarly amazed. It was taken at the end of RoboCup 2022 in Bangkok. After two years during which the RoboCup was scuttled by the global pandemic, the organizers were able to bring together 13 robot teams from around the world (with three teams joining in remotely) to participate in the automaton games. The spirit of the gathering was captured in this image, which, according to RoboCup organizers, shows robots with a combined market value of roughly US $1 million.

PHOTOGRAPH BY PATRICK GÖTTSCH AND THOMAS REINHARDT

Hands On



Tossing out the original motherboard leaves room to fit modern components in the bottom half of the Tandy M100's case.

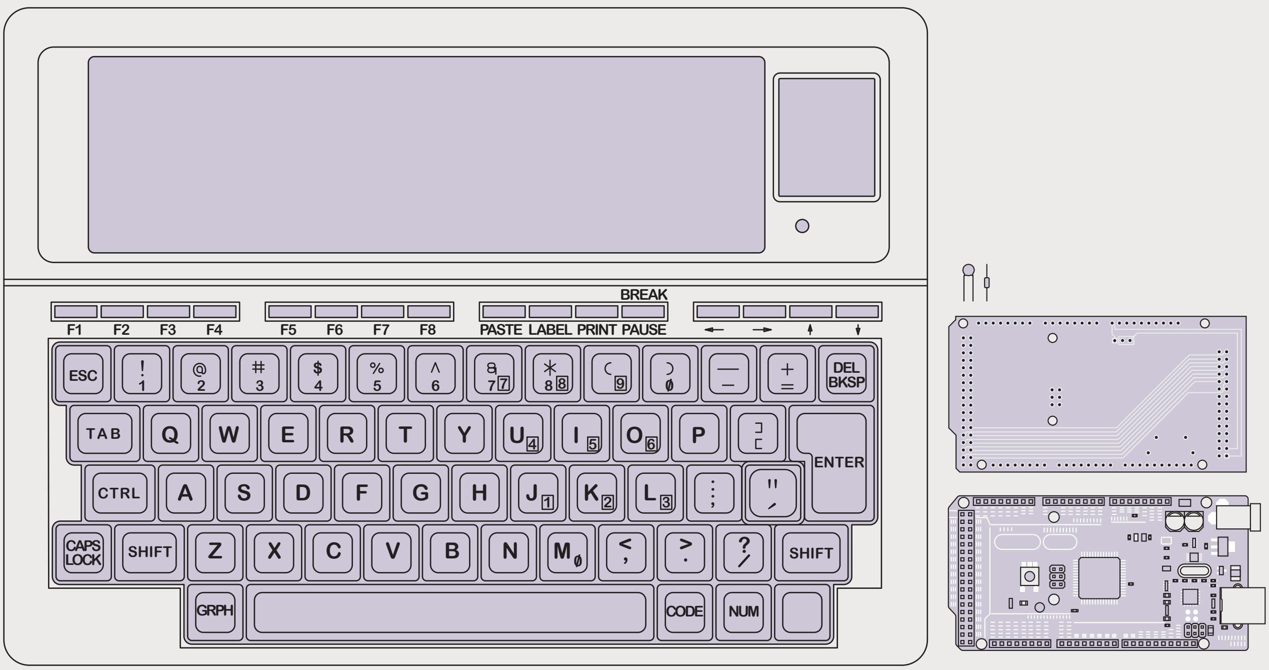
Upcycling a Tandy Model 100 › The tricky part is its weird display

BY STEPHEN CASS

Last year I picked up a Tandy Model 100 at the Vintage Computer Festival East for about US $90. Originally released in 1983, it was the forerunner of today's notebook computers, featuring a good-quality keyboard and an LCD display. It could run for 20 hours on four AA batteries and a month on standby.

Thanks to the work of the Club 100 user group, I was able to tap into a universe of software written for the Model

Illustrations by James Provost



Vintage Tandy M100 computers [left] can be bought for parts for less than US $100. An interface shield along with a resistor and capacitor [right, top] can plug into an Arduino Mega microcontroller and allow you to repurpose the screen and keyboard.

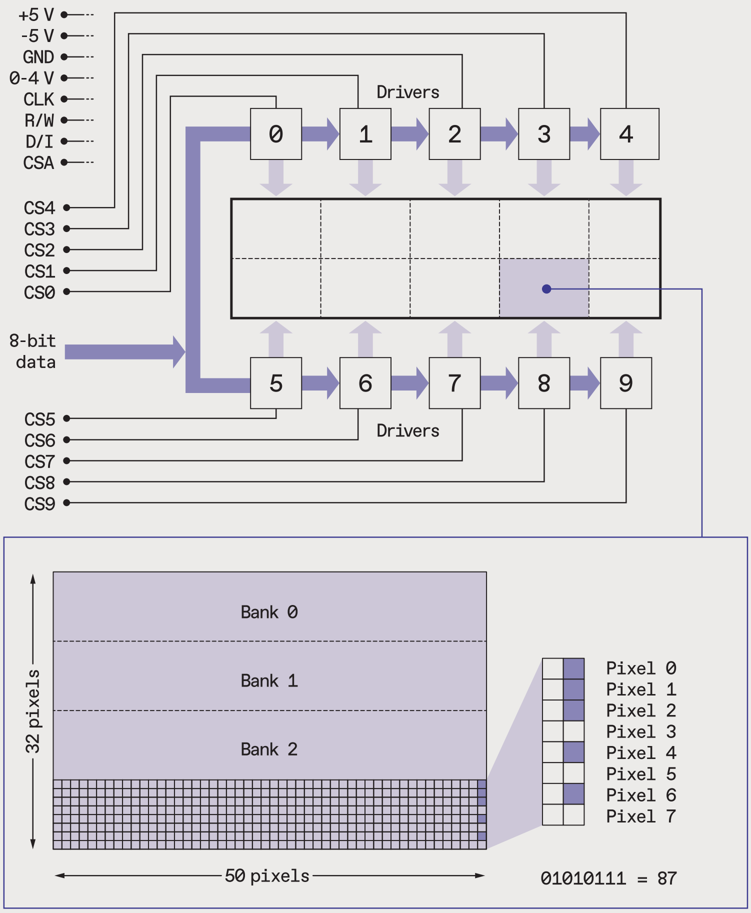
100 (also known as the M100). Unfortunately, my machine stopped working. I was able to identify the faulty component, and rather than attempt to find a new replacement, I bought a cheap, broken M100 that was being sold for parts on eBay. I extracted the component I needed from its motherboard and repaired my original M100. Then I looked at the now-even-*more*-broken second M100, still with its lovely keyboard and screen, and thought, “Surely there’s something I can do with this.” How hard could it be to swap out a 40-year-old 8-bit 8085 CPU and motherboard for something more modern?

I’m not the first person to have thought of this, of course. A number of folks have upcycled the M100, but they typically replace the 240-by-64-pixel monochrome display with something that has color and much higher resolution, or they keep the original LCD but use it as a text-only display. I wanted to keep the original display, because I like its big, chunky pixels and low power needs, but I also wanted the ability to support graphics and different fonts, as with the original M100. If I could do that, I could use any number of replacement CPUs, thanks to software like CircuitPython’s displayio libraries. But I soon discovered the challenge was in the M100’s deeply weird—by today’s standards—display.

The M100’s LCD is really *10* separate displays, each controlled by its own HD44102 driver chip. The driver chips are each responsible for a 50-by-32-pixel region of the screen, except for two chips at the right-hand side that control only 40 by 32 pixels. This provides a total screen resolution of 240 by 64 pixels. Within each region the pixels are divided into four rows, or banks, each eight pixels high. Each vertical column of eight pixels corresponds to one byte in a driver’s local memory.

To set an arbitrary pixel, you determine the screen region it’s in, enable the corresponding driver chip, tell the chip you are sending a command, send the command to select a bank and column, tell the chip you’re now sending pixel data, and then write a data byte that sets eight pixels at once, including the one you want and seven others that come along for the ride.

The reason for this arrangement is that it speeds things up considerably when displaying text. With a seven-pixel-tall font, plus one pixel of white space at the bottom, you can copy the font’s bitmap straight from memory byte by byte. Sequential bytes can often be sent without additional commands because the chip automatically advances the column index



Ten driver chips each control a region of the screen, and must be selected as required by one of 10 chip select lines. Then a bank and column within that row is selected to receive a byte of bitmapped data, setting eight pixels at once.

after receiving a data byte. The order of the banks as displayed can also be altered for fast scrolling.

This bank/column addressing scheme is still used, for example, in some modern OLED displays, but their banks span the entire display—that is, one chip per screen. I would have to manage each region and driver myself.

Some things made it easier. First, the M100 was designed to be serviced. The screen drivers sit on a board that interfaces with the motherboard via a 15-by-2-pin connector that can be simply pulled free. The keyboard uses a straightforward 10-by-10 matrix, and also connects via easily detachable connectors. There is a fantastic service manual that gives the details of every single circuit. With the service manual, the HD44102's datasheet, and some helpful online tips from other folks who'd played with the LCD, I was able to build an interface between the display and an Arduino Mega 2560. And the fact that older machines are often more tolerant of abuse also helped—none of this "give me even a half a volt over 3.3 volts and I'll let all the magic smoke out" business. Cross a wire by accident? No problem, just fix it and try again. Feed in a raw pulse-width-modulated (PWM) signal instead of a constant analog one? Fine, I'll just sit here and flicker a bit.

The interface provides the -5 V the LCD needs in addition to +5 V. The interface also hosts a RC low-pass filter to smooth the PWM signal that simulates the 0-to-4 V output of a potentiometer used to adjust the viewing angle. The other pins are passed through to the Mega's digital input/output or power lines.

I wrote some code to store a 240-by-64-pixel framebuffer and to handle the mapping of its pixels to their corresponding screen regions. The software selects the appropriate chip, bank, and column, sends the data, and manages the various clock and other control signals. The Mega appears to the outside world as the driver of a modern monochrome display, accepting bitmap data as rows (or columns) of pixels that span the screen—exactly the kind of thing that the displayio library can handle.

The LCD can now be hooked up to the microcontroller of my choice via a parallel or serial connection to the Mega, which copies incoming data to the framebuffer; I intend to use a Teensy 4.1, which will allow me to talk to the matrix keyboard directly, have enough compute power for some basic text-editing firmware, and provide a VT100 terminal serial interface—which could be to a Raspberry Pi 4 compute module also mounted inside the M100. That would provide Wi-Fi, a 64-bit OS, and up to 8 gigabytes of RAM—a big step up from the 8 to 24 kilobytes that the case originally housed! ■

Cross a wire by accident? No problem, just fix it and try again.

Careers

Melanie Olsen, ReefWorks' project director, tests a remotely operated vehicle.

MARIE ROMAN/AUSTRALIAN INSTITUTE OF MARINE SCIENCE

Profile: Melanie Olsen >

She leads autonomous marine tech testing at ReefWorks

BY DANIEL P. DERN

The hot, humid environment of tropical marine areas such as Australia's Great Barrier Reef can wreak havoc on marine autonomous systems. Underwater and surface MAS are used for marine monitoring, locating objects such as mines on the seafloor, and rescuing swimmers.

"Tropical conditions can cause systems to overheat or prevent high-density lithium batteries from recharging," says Melanie Olsen, project director of the Australian Institute of Marine Science's (AIMS) ReefWorks, a technology testing and evaluation facility in northern Australia. "And the microbial and small creatures that thrive in these tropical environments grow rapidly on underwater surfaces and degrade the sensor performance and the hydrodynamics of the robotics and autonomous systems." Developing technology that can stand up to these conditions is part of Olsen's job, as is supporting ReefWorks' broader mission of helping others move their autonomous systems out of the lab.

It's essential to test these systems and collect compliance evidence to demonstrate that they meet regulatory requirements and can be certified for operations, says Olsen, an IEEE senior member. But there are very few places to test marine robotics, autonomous systems, and artificial-intelligence (RAS-AI) technologies in the tropics, which hampers the growth of this industry, she says.

"It's difficult for RAS-AI vendors to progress from a prototype to a commercial product because the pathway to a certified system is complex," she adds.

That's why AIMS established ReefWorks. The facility is used to test crewed and uncrewed tropical and marine vessels as well as robots, sensors, and other innovations. "We are Australia's—and possibly the world's—first such testing facility in the tropics," Olsen says.

AIMS has been testing equipment for over a decade, but ReefWorks opened to the public only in December 2021. ReefWorks supports the entire development cycle, from digital-model validation and developmental testing to product and operational-level testing, Olsen says. Physical tests can be done at AIMS's three marine field ranges, which offer different testing conditions.

"Our overall objective is to establish a sustainable marine autonomous systems sector in Australia," she says.

One of the ways ReefWorks helps its users make the most of their time on test ranges is to offer "digital twins" and virtual worlds. A digital twin is a virtual model of a real-world object, machine, or system that can be used to assess how the real-world counterpart is performing.

"Each of our test ranges is developing a digital twin," Olsen says. "Developers will be able to conduct a test mission on the virtual range so when they get here, they can replay missions with real-time collected data, and validate their MAS digital-model performance." She leads a team of five people, and expects the staff to triple in size in a few years as ReefWorks becomes more established in the region.

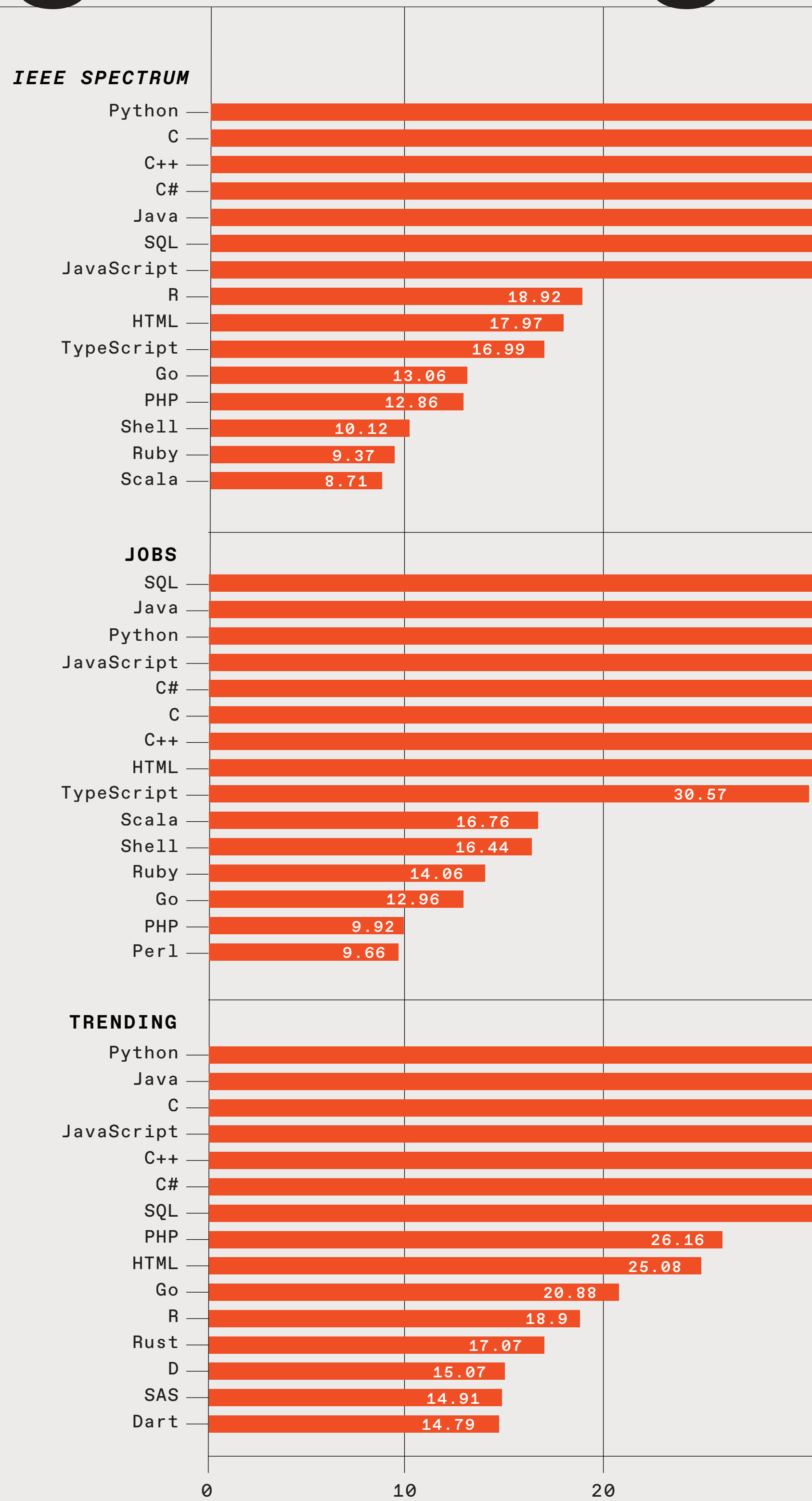
In 2016, Olsen took a job at AIMS as an engineering team leader in technology development. She is currently working on integrating embedded AI and Internet of Things edge computing into AIMS infrastructure.

"We're only just starting to get a feel for what marine autonomous systems can do—not just for our tropical marine waters but in general," she explains. "There are grand challenges like dealing with ocean pollution and the impacts of climate change."

Her career advice for engineering students is to take courses that include group projects. "Group projects help you grow your ability to solve problems outside your knowledge or expertise," she says. "They teach you how to work as an interdisciplinary team, who to ask for help, and where to find it." ■

Top Programming

SQL Should Be Your *Second* Language



Welcome to *IEEE Spectrum*'s annual ranking of the Top Programming Languages. This year we've revamped and streamlined our interactive ranking tool online and made other changes under the hood. But the goal remains the same—to combine metrics from different sources to estimate the relative popularity of different languages. Here we show the results for the highest-ranked languages, but you can find the full list of 57 languages online.

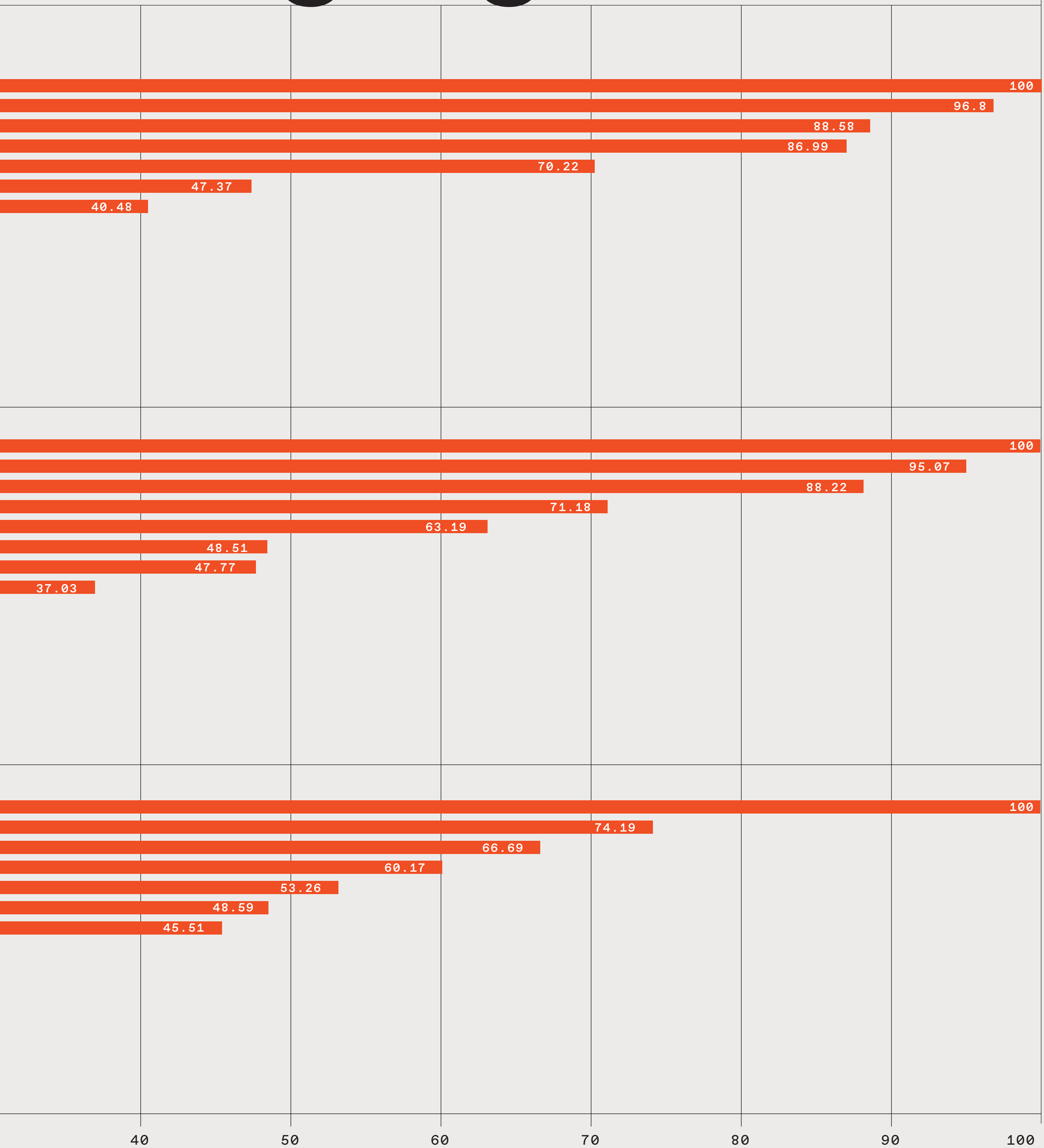
Sources include GitHub, Google, Stack Overflow, Twitter, and IEEE Xplore. The raw data is normalized and weighted according to the different rankings offered. For example, the *Spectrum* ranking is heavily weighted toward metrics that reflect the interests of IEEE members, while Trending puts more weight on forums and social-media metrics.

Not surprisingly, Python and C come out on top, followed by C, C++, C#, and Java. But among these stalwarts there is the rising popularity of SQL, which has become the de facto way to speak with databases. The strength of the SQL signal is not because there are a lot of employers looking for *just* SQL coders, in the way that they advertise for Java experts or C++ developers. They want a given language *plus* SQL.

This is likely because so many applications today involve a front-end or middleware layer talking to a back-end database. So it may not be the most glamorous language, or what you're going to use to implement the next Great Algorithm, but some experience with SQL is a valuable arrow to have in your quiver. ■

BY STEPHEN CASS

Languages



Numbers Don't Lie

Decarbonization Is Our Costliest Challenge

It has no clear beginning or end, and it affects every aspect of life

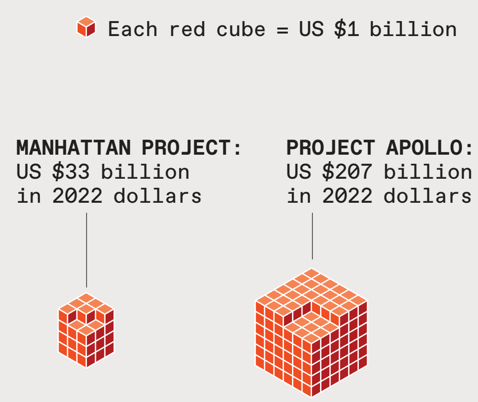
In his 1949 book ***The Concept of Mind,*** Gilbert Ryle, an English philosopher, introduced the term "category mistake." He gave the example of a visitor to the University of Oxford who sees colleges and a splendid library and then asks, "But where is the university?" The category mistake is obvious: A university is an institution, not a collection of buildings.

Today, no category mistake is perhaps more consequential than the all-too-common view of the global energy transition. The error is to think of the transition as the discrete, well-bounded task of replacing carbon fuels by noncarbon alternatives. The apparent urgency of the transition leads to calls for confronting the challenge just as the United States dealt with two earlier ones: winning the nuclear-arms race against Nazi Germany and the space race against the Soviet Union. The Manhattan Project produced an atomic bomb in three years, and Project Apollo put two U.S. citizens on the moon in July 1969, eight years after President Kennedy had announced the goal.

But as difficult and costly as those two endeavors were, they affected only small parts of the economy, their costs were relatively modest, and the lives of average citizens were hardly affected. It is just the opposite for the decarbonization of the energy supply.

Ours is an overwhelmingly fossil-fueled civilization, and the size and complexity of our extensive supersystem of fuel extraction, processing, distribution, storage, and conversion means that a complete displacement of it will directly affect every person and every industry, not least the growing of food and the long-distance transport of goods and people. The costs will be stupendous.

Affluent nations would have to devote on the order of 15 to 20 percent of their annual economic product to the task of decarbonizing the economy.

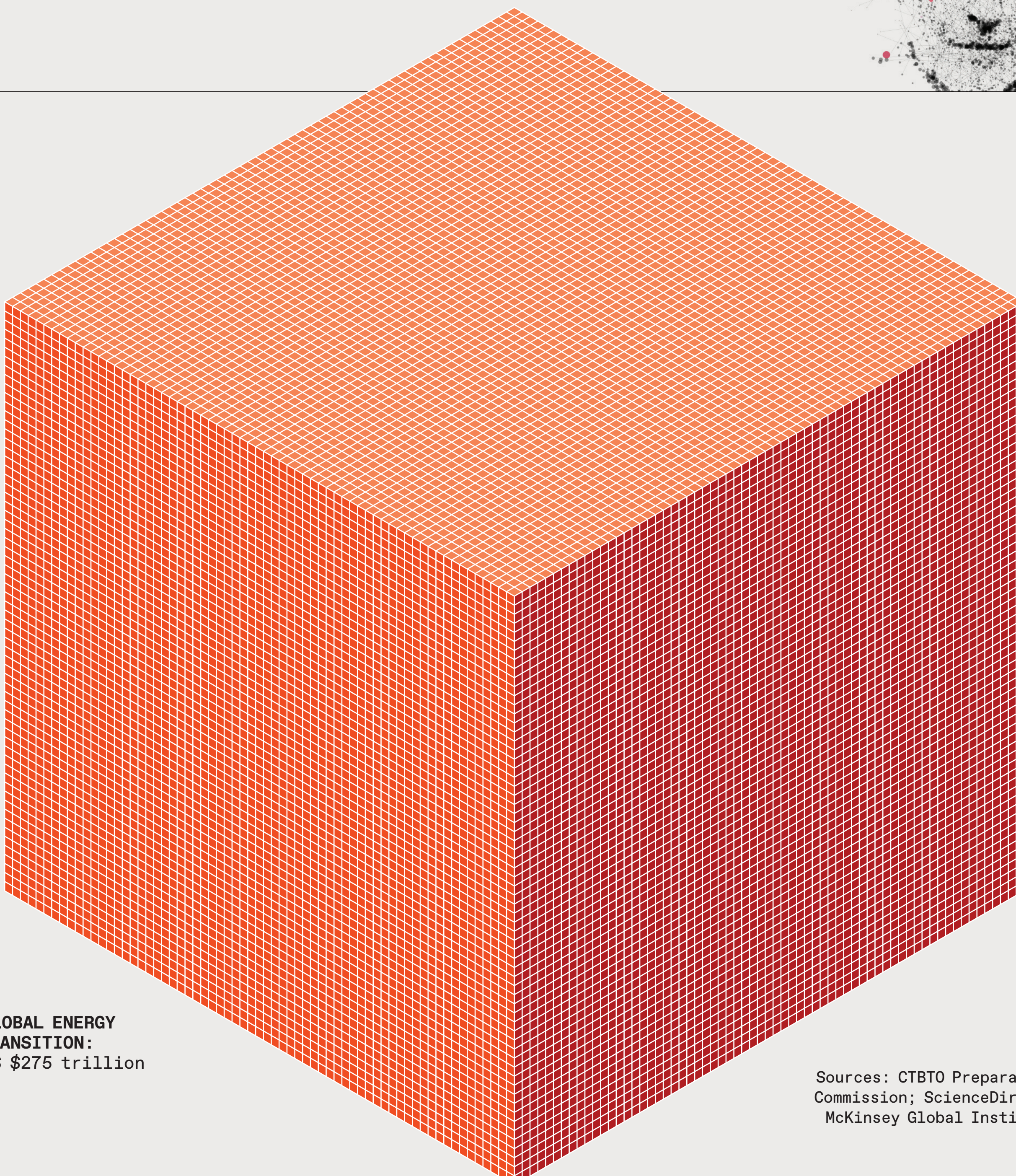


By the time the Manhattan Project ended in 1946, it had cost the country nearly US $2 billion, about $33 billion in today's money, the total equal to only about 0.3 percent of the 1943–45 gross domestic product. When Project Apollo ended in 1972, it had cost about $26 billion, or $207 billion in today's money; over 12 years it worked out annually to about 0.2 percent of the country's 1961–72 GDP.

Of course, nobody can provide a reliable account of the eventual cost of global energy transition because we do not know the ultimate composition of the new primary energy supply. Nor do we know what shares will come from converting natural renewable flows, whether we will use them to produce hydrogen or synthetic fuels, and the extent to which

Illustration by Chris Philpot

BY VACLAV SMIL



GLOBAL ENERGY TRANSITION:
US $275 trillion

Sources: CTBTO Preparatory Commission; ScienceDirect; McKinsey Global Institute

we will rely on nuclear fission (and, as some hope, on fusion) or on other, still unknown options.

But a recent attempt to estimate such costs confirms the magnitude of the category mistake. The McKinsey Global Institute, in a highly conservative estimate, puts the cost at $275 trillion between 2021 and 2050. That is roughly $9.2 trillion a year, compared with the 2021 global economic product of $94 trillion. Such numbers imply an annual expenditure of about 10 percent of today's world economic product. And because the world's low-income countries could not carry such burdens, affluent nations would have to devote on the order of 15 to 20 percent of their annual economic product to the task. Such shares are comparable only to the spending that was required to win World War II. ■

PORTRAIT: SERGIO ALBIAC

THE BIONIC-HAND Arms Race

By **BRITT H. YOUNG**

HIGH-TECH HANDS ARE COMPLICATED, COSTLY, AND OFTEN IMPRACTICAL

Photos by **GABRIELA HASBUN**

The author [right] found that using her Ottobock Bebionic hand made some routine tasks more cumbersome than if she'd used her stump alone.

IN JULES VERNE'S 1865 NOVEL *From the Earth to the Moon*, members of the fictitious Baltimore Gun Club, all disabled Civil War veterans, restlessly search for a new enemy to conquer. They had spent the war innovating new, deadlier weaponry. By the war's end, with "not quite one arm between four persons, and exactly two legs between six," these self-taught amputee-weaponsmiths decide to repurpose their skills toward a new projectile: a rocket ship.

The story of the Baltimore Gun Club propelling themselves to the moon is about the extraordinary masculine power of the veteran, who doesn't simply "overcome" his disability; he derives power and ambition from it. Their "crutches, wooden legs, artificial arms, steel hooks, caoutchouc [rubber] jaws, silver craniums [and] platinum noses" don't play leading roles in their personalities—they are merely tools on their bodies. These piecemeal men are unlikely crusaders of invention with an even more unlikely mission. And yet who better to design the next great leap in technology than men remade by technology themselves?

As Verne understood, the U.S. Civil War (during which 60,000 amputations were performed) inaugurated the modern prosthetics era in the United States, thanks to federal funding and a wave of design patents filed by entrepreneurial prosthetists. The two World Wars solidified the for-profit prosthetics industry in both the United States and Western Europe, and the ongoing War on Terror helped catapult it into a US $6 billion industry across the globe. This recent investment is not, however, a result of a disproportionately large number of amputations in military conflict: Around 1,500 U.S. soldiers and 300 British soldiers lost limbs in Iraq and Afghanistan. Limb loss in the general population dwarfs those figures. In the United States alone, more than 2 million people live with limb loss, with 185,000 people receiving amputations every year. A much smaller subset—between 1,500 and 4,500 children each year—are born with limb differences or absences, myself included.

Today, the people who design prostheses tend to be well-intentioned engineers rather than amputees themselves. The fleshy stumps of the world act as repositories for these designers' dreams of a high-tech, superhuman future. I know this because throughout my life I have been fitted with some of the most cutting-edge prosthetic devices on the market. After being born missing my left forearm, I was one of the first cohorts of infants in the United States to be fitted with a myoelectric prosthetic hand, an electronic device controlled by the wearer's muscles tensing against sensors inside the prosthetic socket. Since then, I have donned a variety of prosthetic hands, each of them striving toward perfect fidelity of the human hand—sometimes at a cost of aesthetics, sometimes a cost of functionality, but always designed to mimic and replace what was missing.

In my lifetime, myoelectric hands have evolved from clawlike constructs to multigrip, programmable, anatomically accurate facsimiles of the human hand, most costing tens of thousands of dollars. Reporters can't get enough of these sophisticated, multigrasping "bionic" hands with lifelike silicone skins and organic movements, the unspoken promise being that disability will soon vanish and any lost limb or organ will be replaced with an equally capable replica. Prosthetic-hand innovation is treated like a high-stakes competition to see what is technologically possible. Tyler Hayes, CEO of the prosthetics startup Atom Limbs, put it this way in a WeFunder video that helped raise $7.2 million from investors: "Every moonshot in history has started with a fair amount of crazy in it, from electricity to space travel, and Atom Limbs is no different."

We are caught in a bionic-hand arms race. But are we making real progress? It's time to ask whom prostheses are really for, and what we hope they will actually accomplish. Each new multigrasping bionic hand tends to be more sophisticated but also more expensive than the last and less likely to be covered (even in part) by insurance. And as recent research concludes, much simpler and far less expensive prosthetic devices can perform many tasks equally well, and the fancy bionic hands, despite all of their electronic options, are rarely used for grasping.

PREVIOUS PAGE AND THIS PAGE: MAKEUP: MARIA NGUYEN FOR MAC COSMETICS; HAIR: JOAN LAQUI FOR LIVING PROOF

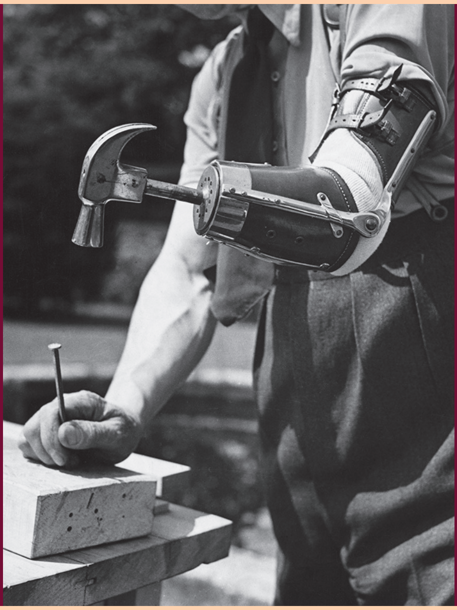
Activity arms, such as this one manufactured by prosthetics firm Arm Dynamics, are less expensive and more durable than bionic prostheses. The attachment from prosthetic-device company Texas Assistive Devices is rated for very heavy weights, allowing the author to perform exercises that would be risky or impossible with her much more expensive Bebionic hand.

FUNCTION OR FORM

In recent decades, the overwhelming focus of research into and development of new artificial hands has been on perfecting different types of grasps. Many of the most expensive hands on the market differentiate themselves by the number and variety of selectable prehensile grips. My own media darling of a hand, the Bebionic from Ottobock, which I received in 2018, has a fist-shaped power grip, pinching grips, and one very specific mode with thumb on top of index finger for politely handing over a credit card. My 21st-century myoelectric hand seemed remarkable—until I tried using it for some routine tasks, where it proved to be *more* cumbersome and time consuming than if I had simply left it on the couch. I couldn't use it to pull a door shut, for example, a task I can do with my stump. And without the extremely expensive addition of a powered wrist, I couldn't pour oatmeal from a pot into a bowl. Performing tasks the cool bionic way, even though it mimicked having two hands, wasn't obviously better than doing things my way, sometimes with the help of my legs and feet.

When I first spoke with Ad Spiers, lecturer in robotics and machine learning at Imperial College London, it was late at night in his office, but he was still animated about robotic hands—the current focus of his research. Spiers says the anthropomorphic robotic hand is inescapable, from the reality of today's prosthetics to the fantasy of sci-fi and anime. "In one of my first lectures here, I showed clips of movies and cartoons and how cool filmmakers make robot hands look," Spiers says. "In the anime *Gundam*, there are so many close-ups of gigantic robot hands grabbing things like massive guns. But why does it need to be a human hand? Why doesn't the robot just have a gun for a hand?"

Spiers believes that prosthetic developers are too caught up in form over function. But he has talked to enough of them to know they don't share his point of view: "I get the feeling that people love the idea of humans being great, and that hands are what make humans quite unique." Nearly every university robotics department Spiers visits has an anthropomorphic robot hand in development. "This is what the future looks like," he says, and he sounds a little exasperated. "But there are often better ways."



The Hosmer Hook [left], originally designed in 1920, is the terminal device on a body-powered design that is still used today. A hammer attachment [right] may be more effective than a gripping attachment when hammering nails into wood.

The vast majority of people who use a prosthetic limb are unilateral amputees—people with amputations that affect only one side of the body—and they virtually always use their dominant "fleshy" hand for delicate tasks such as picking up a cup. Both unilateral and bilateral amputees also get help from their torsos, their feet, and other objects in their environment; rarely are tasks performed by a prosthesis alone. And yet, the common clinical evaluations to determine the success of a prosthetic are based on using only the prosthetic, without the help of other body parts. Such evaluations seem designed to demonstrate what the prosthetic hand can do rather than to determine how useful it actually is in the daily life of its user. Disabled people are still not the arbiters of prosthetic standards; we are still not at the heart of design.

PROSTHETICS IN THE REAL WORLD

To find out how prosthetic users live with their devices, Spiers led a study that used cameras worn on participants' heads to record the daily actions of eight people with unilateral amputations or congenital limb differences. The study, published last year in *IEEE Transactions on Medical Robotics and Bionics*, included several varieties of myoelectric hands as well as body-powered systems, which use movements of the shoulder, chest, and upper arm transferred through a cable to mechanically operate a gripper at the end of a prosthesis. The research was conducted while Spiers was a research scientist at Yale University's GRAB Lab, headed by Aaron Dollar. In addition to Dollar, he worked closely with grad student Jillian Cochran, who coauthored the study.

Watching raw footage from the study, I felt both sadness and camaraderie with the anonymous prosthesis users. The clips show the clumsiness, miscalculations, and accidental drops that are familiar to even very experienced prosthetic-hand users. Often, the prosthesis simply helps brace an object against the body to be handled by the other hand. Also apparent was how much time people spent preparing their myoelectric prostheses to carry out a task—it frequently took several extra seconds to manually or electronically rotate the wrists of their devices, line up the object to grab it just right, and work out the grip approach. The participant who simply hung a bottle of disinfectant spray on their "hook" hand while wiping down a kitchen counter seemed to be the one who had it all figured out.

In the study, prosthetic devices were used on average for only 19 percent of all recorded manipulations. In general, prostheses were employed in mostly nonprehensile actions, with the other, "intact" hand doing most of the grasping. The study highlighted big differences in usage between those with nonelectric,

LEFT: JOHN PRIETO/THE DENVER POST/GETTY IMAGES; RIGHT: HULTON-DEUTSCH COLLECTION/CORBIS/GETTY IMAGES body-powered prosthetics and those with myoelectric prosthetics. For body-powered prosthetic users whose amputation was below the elbow, nearly 80 percent of prosthesis usage was nongrasping movement—pushing, pressing, pulling, hanging, and stabilizing. For myoelectric users, the device was used for grasping just 40 percent of the time.

More tellingly, body-powered users with nonelectric grippers or split hooks spent significantly less time performing tasks than did users with more complex prosthetic devices. Spiers and his team noted the fluidity and speed with which the former went about doing tasks in their homes. They were able to use their artificial hands almost instantaneously and even experience direct haptic feedback through the cable that drives such systems. The research also revealed little difference in use between myoelectric single-grasp devices and fancier myoelectric multiarticulated, multigrasp hands—except that users tended to avoid hanging objects from their multigrasp hands, seemingly out of fear of breaking them.

"We got the feeling that people with multigrasp myoelectric hands were quite tentative about their use," says Spiers. It's no wonder, since most myoelectric hands are priced over $20,000, are rarely approved by insurance, require frequent professional support to change grip patterns and other settings, and have costly and protracted repair processes. As prosthetic technologies become more complex and proprietary, the long-term serviceability is an increasing concern. Ideally, the device should be easily fixable by the user. And yet some prosthetic startups are pitching a subscription model, in which users continue to pay for access to repairs and support.

Despite the conclusions of his study, Spiers says the vast majority of prosthetics R&D remains focused on refining the grasping modes of expensive, high-tech bionic hands. Even beyond prosthetics, he says, manipulation studies in nonhuman primate research and robotics are overwhelmingly concerned with grasping: "Anything that isn't grasping is just thrown away."

IT'S TIME TO ASK WHOM PROSTHESES ARE REALLY FOR, AND WHAT WE HOPE THEY WILL ACTUALLY ACCOMPLISH.

GRASPING AT HISTORY

If we've decided that what makes us human is our hands, and what makes the hand unique is its ability to grasp, then the only prosthetic blueprint we have is the one attached to most people's wrists. Yet the pursuit of the ultimate five-digit grasp isn't necessarily the logical next step. In fact, history suggests that people haven't always been fixated on perfectly re-creating the human hand.

As recounted in the 2001 essay collection *Writing on Hands: Memory and Knowledge in Early Modern Europe*, ideas about the hand evolved over the centuries. "The soul is like the hand; for the hand is the instrument of instruments," Aristotle wrote in *De Anima*. He reasoned that humanity was deliberately endowed with the agile and prehensile hand because only our uniquely intelligent brains could make use of it—not as a mere utensil but a tool for *apprehensio*, or "grasping," the world, literally and figuratively.

More than 1,000 years later, Aristotle's ideas resonated with artists and thinkers of the Renaissance. For Leonardo da Vinci, the hand was the brain's mediator with the world, and he went to exceptional lengths in his dissections and illustrations of the human hand to understand its principal components. His meticulous studies of the tendons and muscles of the forearm and hand led him to conclude that "although human ingenuity makes various inventions…it will never discover inventions more beautiful, more fitting or more direct than nature, because in her inventions nothing is lacking and nothing is superfluous."

Da Vinci's illustrations precipitated a wave of interest in human anatomy. Yet for all of the studious rendering of the human hand by European masters, the hand was regarded more as an inspiration than as an object to be replicated by mere mortals. In fact, it was widely accepted that the intricacies of the human hand evidenced divine design. No machine, declared the Christian philosopher William Paley, is "more artificial, or more evidently so" than the flexors of the hand, suggesting deliberate design by God.

By the mid-1700s, with the Industrial Revolution in the global north, a more mechanistic view of the world began to emerge, and the line between living things and machines began to blur. In her 2003 article "Eighteenth-Century Wetware," Jessica Riskin, professor of history at Stanford University, writes, "The period between the 1730s and the 1790s was one of simulation, in which mechanicians tried earnestly to collapse the gap between animate and artificial machinery." This period saw significant changes in the design of prosthetic limbs. While mechanical prostheses of the 16th century were weighed down with iron and springs, a 1732 body-powered prosthesis used a pulley system to flex a hand made of lightweight copper. By the late 18th century, metal was being replaced with leather, parchment, and cork—softer materials that mimicked the stuff of life.

The techno-optimism of the early 20th century brought about another change in prosthetic design, says Wolf Schweitzer, a forensic pathologist at the Zurich Institute of Forensic Medicine and an amputee. He owns a wide variety of contemporary prosthetic arms and has

TRS makes a wide variety of body-powered prosthetic attachments for different hobbies and sports. Each attachment is specialized for a particular task, and they can be easily swapped.

the necessary experience to test them. He notes that anatomically correct prosthetic hands have been carved and forged for the better part of 2,000 years. And yet, he says, the 20th century's body-powered split hook is "more modern," its design more willing to break the mold of the human hand.

"The body powered arm—in terms of its symbolism—(still) expresses the man-machine symbolism of an industrial society of the 1920s," writes Schweitzer in his prosthetic arm blog, "when man was to function as clockwork cogwheel on production lines or in agriculture." In the original 1920s design of the Hosmer Hook, a loop inside the hook was placed just for tying shoes and another for holding cigarettes. Those designs, Ad Spiers told me, were "incredibly functional, function over form. All pieces served a specific purpose."

Schweitzer believes that as the need for manual labor decreased over the 20th century, prostheses that were high-functioning but not naturalistic were eclipsed by a new high-tech vision of the future: "bionic" hands. In 2006, the U.S. Defense Advanced Research Projects Agency launched Revolutionizing Prosthetics, a research initiative to develop the next generation of prosthetic arms with "near-natural" control. The $100 million program produced two multiarticulating prosthetic arms (one for research and another that costs over $50,000). Even more important, it influenced the creation of other similar prosthetics, establishing the bionic hand—as the military imagined it—as the holy grail of prosthetics. Today, the multigrasp bionic hand is hegemonic, a symbol of cyborg wholeness.

And yet some prosthetic developers are pursuing a different vision. TRS, based in Boulder, Colo., is one of the few manufacturers of activity-specific prosthetic attachments, which are often more durable and more financially accessible than robotic prosthetics. These plastic and silicone attachments, which include a squishy mushroom-shaped device for push-ups, a ratcheting clamp for lifting heavy weights, and a concave fin for swimming, have helped me experience the greatest functionality I have ever gotten out of a prosthetic arm.

Such low-tech activity prostheses and body-powered prostheses perform astonishingly well, for a tiny fraction of the cost of bionic hands. They don't look or act like human hands, and they function all the better for it. According to Schweitzer, body-powered prostheses are regularly dismissed by engineers as "arcane" or derisively called "Captain Hook." Future bionic shoulders and elbows may make a huge difference in the lives of people missing a limb up to their shoulder, assuming those devices can be made robust and affordable. But for Schweitzer and a large percentage of users dissatisfied with their myoelectric prosthesis, the prosthetic industry has yet to provide anything fundamentally better or cheaper than body-powered prostheses.

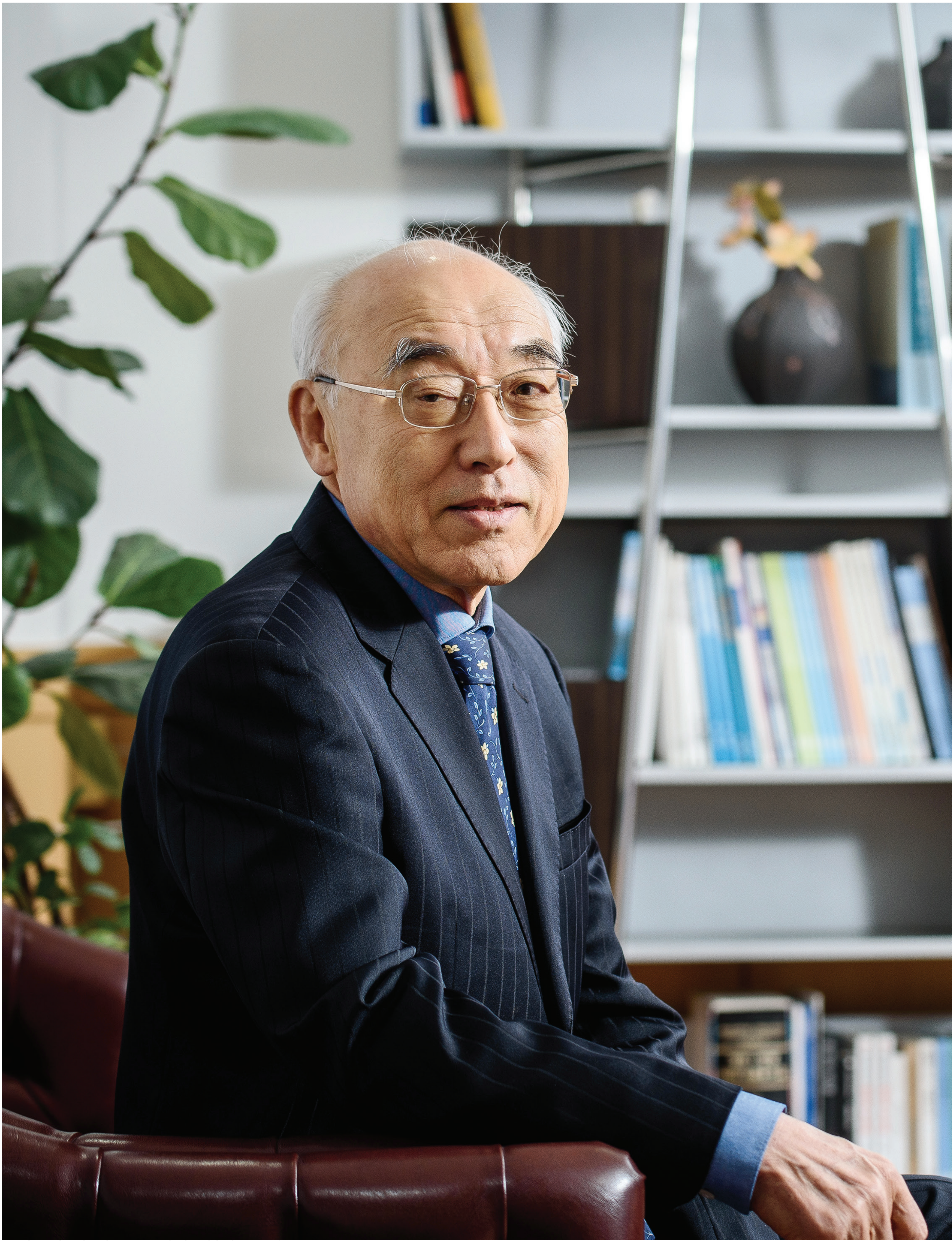
THE BREAKTHROUGHS WE WANT

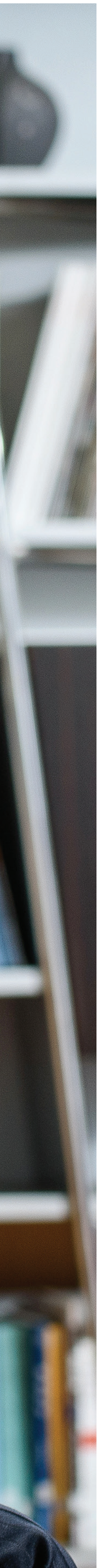
Bionic hands seek to make disabled people "whole," to have us participate in a world that is culturally two-handed. But it's more important that we get to live the lives we want, with access to the tools we need, than it is to make us look like everyone else. While many limb-different people have used bionic hands to interact with the world and express themselves, the centuries-long effort to perfect the bionic hand rarely centers on our lived experiences and what we want to do in our lives.

We've been promised a breakthrough in prosthetic technology for the better part of 100 years now. I'm reminded of the scientific excitement around lab-grown meat, which seems simultaneously like an explosive shift and a sign of intellectual capitulation, in which political and cultural change is passed over in favor of a technological fix. With the cast of characters in the world of prosthetics—doctors, insurance companies, engineers, prosthetists, and the military—playing the same roles they have for decades, it's nearly impossible to produce something truly revolutionary.

In the meantime, this metaphorical race to the moon is a mission that has forgotten its original concern: helping disabled people acquire and use the tools they want. There are inexpensive, accessible, low-tech prosthetics that are available right now and that need investments in innovation to further bring down costs and improve functionality. And in the United States at least, there is a broken insurance system that needs fixing. Releasing ourselves from the bionic-hand arms race can open up the possibilities of more functional designs that are more useful and affordable, and might help us bring our prosthetic aspirations back down to earth. ■

FILLAUER TRS





한국 반도체학계의 대부

THE GODFATHER OF SOUTH KOREA’S CHIP INDUSTRY

KIM CHOONG-KI’S “ENGINEER’S MIND” HELPED MAKE THE COUNTRY A SEMICONDUCTOR SUPERPOWER

BY DONG-WON KIM

They were called “Kim’s Mafia.” Kim Choong-Ki himself wouldn’t have put it that way. But it was true what semiconductor engineers in South Korea whispered about his former students: They were everywhere. • Starting in the mid-1980s, as chip manufacturing in the country accelerated, engineers who had studied under Kim at Korea Advanced Institute of Science and Technology (KAIST) assumed top posts in the industry as well as coveted positions teaching or researching semiconductors at universities and government institutes. By the beginning of the 21st century, South Korea had become a dominant power in the global semiconductor market, meeting more than 60 percent of international demand for memory chips alone. Around the world, many of Kim’s protégés were lauded for their brilliant success in transforming the economy of a nation that had just started assembling radio sets in 1959 and was fabricating outdated memory chips in the early ’80s. • That success can be traced in part to Kim, now an emeritus professor at KAIST. Of average height, with gray hair since his mid-30s, he was the first professor in South Korea to systematically teach semiconductor engineering. From 1975, when the nation had barely begun producing its first transistors, to 2008, when he retired from teaching, Kim trained more than 100 students, effectively creating the first two generations of South Korean semiconductor experts.

Left: Kim, shown on the Columbia campus, studied for his Ph.D. at the university under Edward S. Yang, a specialist in transistor theory. Bottom left: Kim's colleagues at Fairchild Semiconductor's research and development laboratories called him "Professor CCD." Below: Kim's mother and father, a renowned Korean textile engineer, visited him in Palo Alto, Calif., in 1972.

The Samsung Welfare Foundation recognized Kim's influence when it awarded him its prestigious Ho-Am Prize in 1993 for "building a solid foundation for Korea's semiconductor industry." Since then, he has been revered in the South Korean media as the industry's "godfather." Yet even today, Kim remains largely unknown outside of South Korea's chip community. Who, then, is this inconspicuous semiconductor "Mafia" boss?

Kim Choong-Ki was born in Seoul in 1942, when Korea was a colony of the Japanese Empire. His mother taught elementary school; his father, Kim Byung-Woon, was a textile engineer for Kyungbang, Korea's iconic manufacturer of yarns and fabrics. The elder Kim had helped build the company's first spinning factory, and his engineering savvy and consequent renown impressed his son. "He made a daily tour of the factory," the younger Kim recalls. "He told me that he could detect which machines were in trouble and why, just by listening to them." Such lessons planted the seed of an ethos that would drive Kim Choong-Ki's career—what he came to call the "engineer's mind."

Growing up, Kim Choong-Ki was a model South Korean student: bookish, obedient, and silent. Although his family pressed him to join his father in the textile industry, he instead chose to pursue electrical engineering. He studied at Seoul National University and then at Columbia University, in New York City, where he earned his doctorate under Edward S. Yang, a specialist in transistor theory. Shortly after, in the summer of 1970, Fairchild Camera and Instrument hired Kim to work in its research and development laboratory in Palo Alto, Calif.

Since World War II, Fairchild Camera had been the world's leading developer of imaging equipment, including radar cameras, radio compasses, and X-ray machines. In 1957, the company launched the Fairchild Semiconductor division to fabricate transistors and integrated circuits from silicon, then an innovative move, as most semiconductor devices at the time used germanium. The venture spawned dozens of products, including the first silicon integrated circuit, thus fueling the rise of Silicon Valley. As a newcomer to Fairchild's R&D lab, Kim was put to work on one of these new kinds of chips: the charge-coupled device.

PREVIOUS PAGES: KOREA ACADEMY OF SCIENCE AND TECHNOLOGY

Kim and his former students and their families celebrated his 60th birthday on the summit of South Korea's Mount Deokyu.

Just the year before, in 1969, George E. Smith and Willard Boyle at Bell Laboratories proposed the idea of the CCD, for which they would later win a Nobel Prize. But it was Kim and his colleagues at Fairchild who realized the first CCD devices that evolved into commercial products widely used in digital photography, radiography, and astronomy. Kim became so proficient in CCD technology that other engineers at the company regularly dropped by his office at the end of the day to pick his brain. "Soon they began to call me Professor CCD," he remembers.

Among other inventions, Kim helped develop a CCD area image sensor that greatly improved low-light detection and the first two-phase CCD linear image sensor—which, he reported, guaranteed "the ease of use and the high quality of image reproduction." "Fairchild's—or better call them Choong-Ki's—CCDs made possible the wide applications in high-resolution cameras," Columbia's Yang says. Without these functional devices, he adds, "there would be no Nobel Prize for the CCD."

Kim's time at Fairchild transformed him as much as it did camera technology. His schooling in South Korea and at Columbia had primarily emphasized book learning and theory. But his experience at Fairchild solidified his belief, first inspired by his father, that a true "engineer's mind" requires practical skill as much as theoretical knowledge. In addition to performing experiments, he made a habit of reading internal technical reports and memos that he found at the company library, some of which he later brought to KAIST and used as teaching material.

At Fairchild, Kim also learned how to communicate with and lead other engineers. When he started there, he was soft-spoken and introverted, but his mentors at Fairchild encouraged him to express himself confidently and clearly. Later, the converted Kim would become the "loudest-speaking" professor at KAIST, according to several fellow faculty members, and they say his absence made the whole campus seem quiet.

Kim rose quickly within Fairchild's hierarchy. But in 1975, just five years into his tenure, he returned to South Korea. His beloved father had died, and, as the eldest son, he felt a heavy responsibility to care for his widowed mother. Racial discrimination he experienced at Fairchild had also hurt his pride. Most important, however, he had found an ideal place to work back home.

Then called KAIS (the "T" was added in 1981), Kim's new employer was the first science and technology university in South Korea and remains one of the most prestigious. The South Korean government had established the institute in 1971 with financing from the United States Agency for International Development and had invited Frederick E. Terman, the legendary dean of Stanford University's school of engineering and a "father" of Silicon Valley, to draw up the blueprint for its direction. Terman stressed that KAIS should aim to "satisfy the needs of Korean industry and Korean industrial establishments for highly trained and innovative specialists, rather than to add to the world's store of basic knowledge." It was the perfect place for Kim to spread his newfound philosophy of the "engineer's mind."

"SCIENTISTS CONSIDER WHY FIRST, BUT WE ENGINEERS MUST THINK HOW FIRST."

Kim's laboratory at KAIS attracted scores of ambitious master's and doctoral candidates from almost the moment he arrived in the spring of 1975. The primary reason for the lab's popularity was obvious: South Korean students were hungry to learn about semiconductors. The government touted the importance of these devices, as did electronics companies like GoldStar and Samsung, which needed them to manufacture their radios, televisions, microwaves, and watches. But the industry had yet to mass-produce its own chips beyond basic integrated circuits such as CMOS watch chips,

THESE PAGES: CHANG HAE-JA

in large part due to a lack of semiconductor specialists. For 20 years, until the mid-1990s, joining Kim's lab was essentially the only way for aspiring semiconductor engineers in South Korea to get hands-on training; KAIST was the only university in the country that had able teachers and proper facilities, including clean rooms for assembling high-quality chips.

But it wasn't KAIST's virtual monopoly on semiconductor training that made Kim a mentor without peer. He introduced a style of teaching and of mastering engineering that was new to South Korea. For instance, his conviction that an "engineer's mind" requires equal parts theory and application at first puzzled his students, who regarded engineering as chiefly a scholarly discipline. Although they were proficient in mathematics and well read, most of them had never carried out any serious work in design and construction.

Therefore, one of the first lessons Kim taught his students was how to use their hands. Before they embarked on their own projects, he put them to work cleaning the lab, repairing and upgrading equipment, and tracking down necessary parts. In this way, they learned how to solve problems for themselves and how to improvise in situations for which no textbook had prepared them. Their view of what it means to be an engineer changed profoundly and permanently. Many of them confess they still repeat Kim's dicta to this day. For example: "Don't choose the subjects that others have already thrown into the trash can." And: "Scientists consider why first, but we engineers must think how first." And: "Wrong decision is better than slow decision."

"WRONG DECISION IS BETTER THAN SLOW DECISION."

Kim's former students remember him as kind, humorous, nonauthoritarian, meticulous, and hardworking. But they also say he was strict and could be hot tempered and even terrifying, especially when he thought they were being lazy or sloppy. Legend has it that some of his students entered the lab via a ladder from the rooftop to bypass Kim's office. One of his biggest grievances was when students failed to properly balance theory and practice. "Make it yourself; then we will start a discussion," he scolded those who focused too much on intellectual study. On the other hand, he said, "Why don't you use something malleable within the hard nut on your neck?" as a reproach to those who spent too much time building things, implying that they should also use their brains.

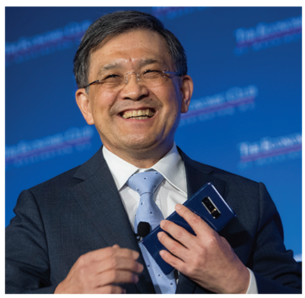
Kim influenced not only his own students but also countless others through his openness, and his collegiality extended beyond academia to industry and government. In the early 1980s, during a sabbatical, he led semiconductor research and development at the government-funded Korea Institute of Electronics Technology, which developed both 32-kilobit and 64-kilobit ROM under his directorship. His popular semiconductor workshops at KAIST inspired GoldStar (LG since 1995), Hyundai Electronics (Hynix since 2001), and Samsung to sponsor their own training programs at KAIST in the 1990s. Kim's close partnership with these companies also helped launch other pioneering mostly-industry-funded initiatives at KAIST, including the Center for High-Performance Integrated Systems and the Integrated-Circuit Design Education Center, both directed by Kim's former student Kyung Chong-Min. And the semiconductor industry, in turn, benefited from the ever more highly trained workforce emerging from Kim's orbit.

Kim's lab at KAIST evolved in parallel with the growth of the semiconductor sector in South Korea, which can be divided into three periods. During the first period, beginning in the mid-1960s, the government led the charge by enacting laws and drawing up plans for industry development, establishing research institutes, and pressing companies and universities to pay more attention to semiconductor technology. Samsung and other electronics companies wouldn't get serious about manufacturing semiconductor devices until the early 1980s. So when Kim started his lab, almost a decade prior, he was training engineers to meet the industry's future needs.

His first group of students worked primarily on the design and fabrication of semiconductors using PMOS, NMOS, and

Kim [front row, orange tie] also served as director of Korea's Center for Electro-Optics, a government-sponsored research institute formed to develop technologies for thermal imaging, fiber optics, and lasers.

CHANG HAE-JA



Top: KAIST engineering professors Kim [center, gray robe] and Kwon Young-Se [right, blue hood] posed with master's graduates in 1982. Above left: Chung Jin-Yong [right], a former student of Kim [left], graduated from KAIST in 1976 and later developed DRAM for Hynix. Above right: Kim's former master's student, Kwon Oh-Hyun, rose to become vice chairman and CEO of Samsung Electronics.

CMOS technologies that, while not cutting edge by global standards, were quite advanced for the South Korea of the time. Because there were few industry jobs, many alumni of Kim's lab took positions at government research institutes, where they developed state-of-the-art experimental chips. An exception was Lim Hyung-Kyu, one of Kim's first master's candidates, whom Samsung sent to study at KAIST in 1976. Lim would go on to lead the development of various memory devices at Samsung, most importantly NAND flash memory in the 1990s.

The second period started in 1983, when Samsung declared that it would pursue semiconductors aggressively, starting with DRAM. The move drove rival conglomerates such as Hyundai and GoldStar to do likewise. As a result, the South Korean chip industry rapidly expanded. KAIST and other universities provided the necessary manpower, and the government reduced its role. In Kim's lab, students began to explore emerging technologies—including polysilicon thin-film transistors (for LCD panels), infrared sensors (for military use), and rapid thermal processing (which increased efficiency and reduced costs of semiconductor production)—and published their results in prestigious international journals.

KAIST graduates flocked to Samsung, GoldStar/LG, and Hyundai/Hynix. At the same time, more and more of Kim's former students accepted university professorships. After leaving Kim's lab in 1991, for instance, Cho Byung-Jin spent four years developing DRAM and flash memory at Hyundai before becoming a star professor at the National University

CLOCKWISE FROM BOTTOM RIGHT: SAUL LOEB/AFP/GETTY IMAGES; CHANG HAE-JA (2)

Meet Kim's Mafia

Many of Kim Choong-Ki's former students helped lead the rise of semiconductor engineering in South Korea through prominent roles in industry, government, and academia. Here are some of the standouts.

KYUNG CHONG-MIN: As Kim's first doctoral candidate at KAIST, Kyung became a professor at his alma mater at the age of 30. He is best known for designing microprocessor chips in the early 1990s that were fully compatible with Intel 80386 and 80486 chips. He also established and operated two centers for chip design.

KWON OH-HYUN: Kwon received a master's degree under Kim and his doctoral degree from Stanford University. At Samsung Electronics, he developed 64-megabit DRAM in the early 1990s and contributed to the development of the company's System LSI division in the 2000s. He served as CEO and vice-chairman of the company during most of the 2010s.

LIM HYUNG-KYU: Lim studied PMOS devices under Kim and later became Samsung's first overseas scholarship student (at the University of Florida). He was best known for developing NAND flash memory in the early 1990s and was often called "Mr. NAND Flash." After retiring from Samsung, he served as vice-chairman of the SK conglomerate.

SUH KANG-DEOG: Suh received both master's and doctoral degrees under Kim. At Samsung Electronics, he participated in various memory projects including NAND flash. In 2006 he was elected a Samsung Fellow, the company's highest honor, for his contributions and in expectation of his future work.

CHO BYUNG-JIN: Cho has authored more than 300 technical papers on various subjects. He briefly worked at Hyundai Electronics (now Hynix) and then became a star engineering professor at the National University of Singapore for 10 years. He returned to KAIST in 2007 and pioneered research in graphene and thermoelectric devices.

HA YONG-MIN: Ha is the master of TFT-LCD and OLED technologies at LG Display, having worked on the subject from his graduate years under Kim to the present. Thanks to his efforts, LG Display became a major supplier of TFT-LCD and OLED panels for medium and small electronic devices, including those marketed by Apple, HP, Dell, and Lenovo.

PARK SUNG-KYE: Park, sometimes called the "treasure of Hynix," has developed almost all types of memory chips, including highly efficient and speedier DRAMs and the smallest NAND flash-memory cell. He was also in charge of the development of the 96-layer 3D NAND flash memory in the late 2010s.

CHUNG HAN: Chung is perhaps the most successful engineer-turned-startup-entrepreneur among Kim's former students. His i3system develops sophisticated infrared image sensors for both defense and commercial markets. Thanks to his more than 30 years of effort, South Korea became the seventh nation in the world to mass-produce infrared image sensors.

김충기 KIM CHOONG-KI

DATE OF BIRTH: 1 October 1942
BIRTHPLACE: Seoul
HEIGHT: 170 centimeters
FAMILY: Wife, Chang Hae-Ja; sons, Ho-Sun and Ho-Jung
EDUCATION: B.E., Seoul National University, 1965; M.E., Columbia University, 1967; Ph.D., Columbia University 1970
FIRST EMPLOYER: Fairchild Camera and Instrument Corp.
CURRENT JOB: Distinguished Professor and Professor Emeritus at KAIST
STUDENTS: 117 (78 master's, 39 doctoral)
PATENTS: 15 (3 in the United States, 12 in South Korea)
BIGGEST SURPRISE IN CAREER: Appointment to vice president of KAIST in 1995
HERO: His father, Kim Byung-Woon
FAVORITE PERIODICAL: *Time* magazine
FAVORITE KIND OF MUSIC: Classical
FAVORITE MOVIE: *Ode to My Father*, 2014 (South Korean film).
LEISURE: Walking
LANGUAGES SPOKEN: English and Korean
CAR: Hyundai Genesis
ORGANIZATIONAL MEMBERSHIPS: IEEE, Korean Institute of Electrical Engineers, The Korean Academy of Science and Technology (KAST)
MAJOR AWARDS: Ho-Am Prize by the Samsung Welfare Foundation (1993), Moran Medal (1997) and election as Person of Distinguished Service to Science and Technology (2019) by the South Korean government, IEEE Fellow

of Singapore and later at KAIST. Kyung Chong-Min, Kim's first doctoral candidate, joined KAIST's faculty in 1983; by the time he retired in 2018, Kyung had trained more semiconductor specialists than Kim himself.

During the third period, from 2000 on, industry seized the helm of semiconductor development. Academia churned out more specialists as well as significant research, with minimal contribution from government. Alumni of Kim's lab continued to lead semiconductor engineering, some of them rising to become high-ranking executives. For example, Kwon Oh-Hyun, who received his master's degree from KAIST in 1977, served as CEO at Samsung Electronics for most of the 2010s, when the company dominated the world market in not only memory but also mobile phones, TVs, and home appliances.

Other alums played key roles in semiconductor research and development. Ha Yong-Min at LG Display mastered TFT-LCD and OLED screens for tablets, notebook computers, and cellphones; Park Sung-Kye, sometimes called the "treasure of Hynix," developed most of the company's memory products. In academia, meanwhile, Kim had become a model to emulate. Many of his trainees adopted his methods and principles in teaching and mentoring their own students to become leaders in the field, ensuring a steady supply of highly skilled semiconductor engineers for generations to come.

In the spring of 2007, less than a year before Kim turned 65—the compulsory retirement age in South Korean academia—KAIST elected him as one of its first distinguished professors, thus extending his tenure for life. Besides the Ho-Am Prize, he has garnered numerous other awards over the years, including the Order of Civil Merit for "outstanding meritorious services...in the interest of improving citizens' welfare and promoting national development." And in 2019, he was named a Person of Distinguished Service to Science and Technology, one of the nation's highest honors.

For young semiconductor engineers in South Korea today, Kim Choong-Ki is a legend—the great unsung hero behind their nation's ascendancy in chip production. But its dominance in the world market is now under threat. Although South Korea has competed furiously with Taiwan in recent decades, its most formidable challenger in the future will likely be China, whose ambitious Made in China 2025 plan prioritizes semiconductor development. Since 2000, the country has been a major importer of South Korean chips. But China's recent heavy investment in semiconductors and the availability of highly educated Chinese engineers—including semiconductor specialists trained in the United States, Japan, and South Korea—means that Chinese semiconductor companies could soon become major global competitors.

Compounding the problem, the South Korean government has neglected its role in supporting chip development in the 21st century. Nearly 50 years after Kim began educating its first semiconductor engineers, the industry again faces a significant workforce shortage. Experts estimate that several thousand new engineering specialists are needed each year, but the country produces only a few hundred. Yet despite companies' pleas for more workers and universities' calls for policies that advance academic education and research, the government has done little.

Toward the end of his career, Kim had become concerned with the limitations of the kind of "engineer's mind" that had taken root in South Korea. "The economic development of Korea was dependent on reverse engineering and following advanced countries," he said in an interview in 1997. That fast-follower approach, he added, relied on an educational system that taught students "how to read maps"—to identify a known product goal and plot a course for achieving it. "And who made the maps? Advanced countries." He thus concluded, "We now have to change our educational policy and teach our students how to draw maps."

Kim himself may not have fully realized this ambitious vision of cultivating a country of creative-minded engineers, capable of pioneering truly groundbreaking technologies that might secure his country's leadership on the world stage. But hopefully his successors have taken his advice to heart. The future of South Korea depends on it. ■

KOREA ACADEMY OF SCIENCE AND TECHNOLOGY

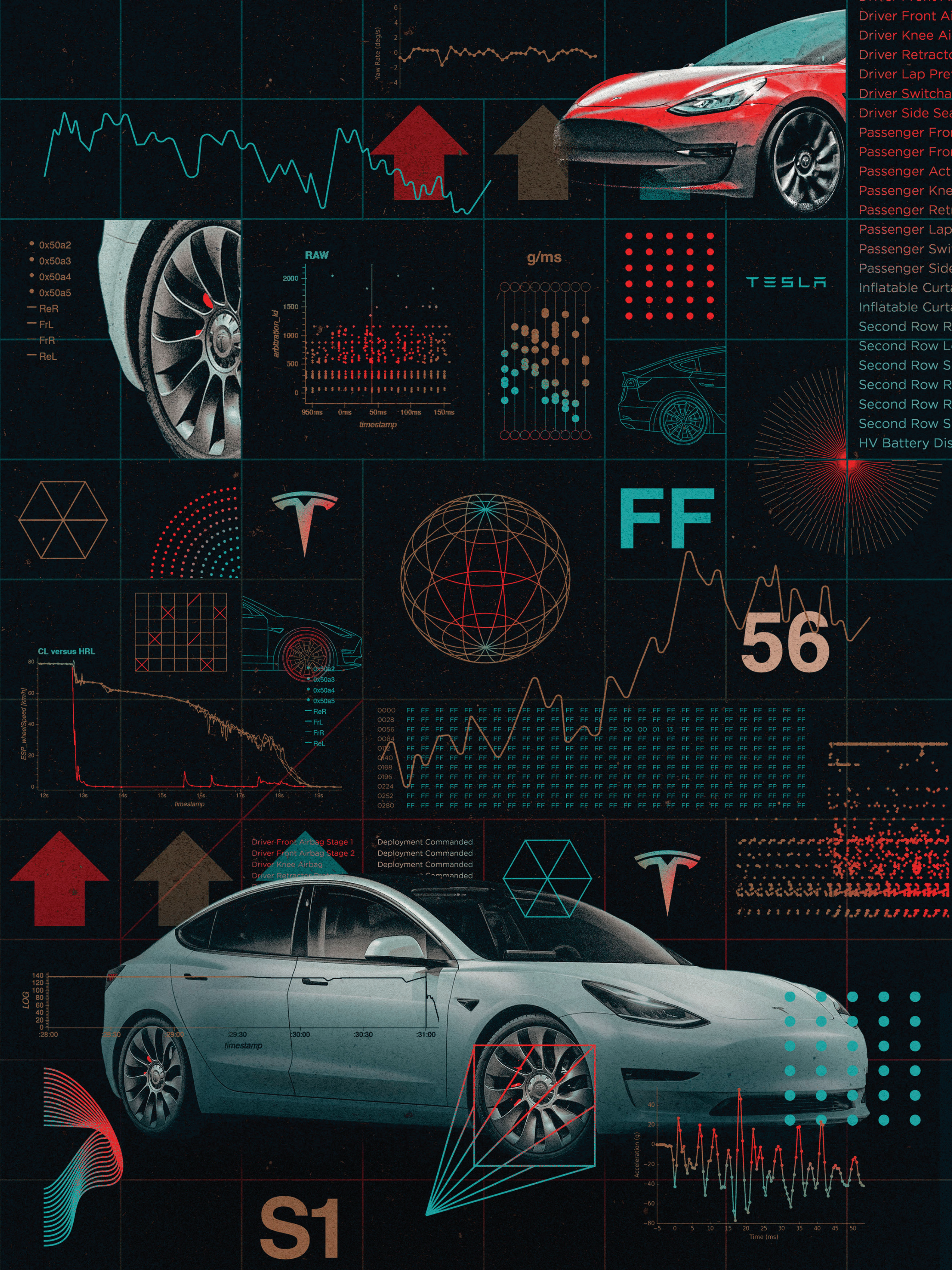
Every Tesla is providing reams of sensitive data about its driver's life

By MARK HARRIS

THE RADICAL SCOPE of TESLA'S DATA HOARD

YOU WOULDN'T HAVE SEEN A SINGLE TESLA in the Beidaihe District of Qinhuangdao, China, this summer. Officials banned Elon Musk's popular electric vehicles from this beachfront resort for two months while it hosted the Communist Party's annual retreat, presumably fearing what the cars' built-in cameras might capture and send back to the United States. • This might seem to be undue paranoia, but Tesla vehicles do collect an enormous amount of information. That's well illustrated by events in Florida, where Tesla faced a negligence lawsuit after two young men died in the fiery crash of a 2014 Model S. The father of the teen driver sued Tesla for producing a battery prone to ignite. As part of its defense, the company submitted a historical speed analysis showing that in the months before the crash the car had been routinely driven dangerously fast. This information was quietly captured by the car and uploaded to Tesla's servers.

Photo-illustration by Max-o-matic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Although there is no evidence that Tesla collects any data beyond what customers agree to in the company's terms of service, it's not been clear to outsiders exactly what data Tesla vehicles collect and how the company uses this information. So you really have to wonder whether owners or the company are in the driver's seat when it comes to accessing and exploiting those data.

These questions are relevant to you even if you don't own a Tesla. Every new production vehicle has a gaggle of sensors, often including cameras and radars that capture data about their drivers and their surroundings. There is now a worldwide connected car–data industry, trading in anonymized vehicle, driver, and location data aggregated from billions of journeys made in tens of millions of vehicles from all the major automotive equipment manufacturers. But none of those vehicles seem to store that information and send it back to the manufacturer as regularly, or in such volume, or have been doing so for as long, as those made by Tesla.

"As far as we know, Tesla vehicles collect the most amount of data," says Francis Hoogendijk, a researcher at the Netherlands Forensic Institute who began investigating Tesla's data systems after fatal crashes in the United States and the Netherlands in 2016.

While much still remains unclear, crash investigations by the U.S. National Transportation Safety Board (NTSB), reports from the U.S. National Highway Traffic Safety Administration (NHTSA), and Tesla's own documents help to reveal the data these vehicles collect and what the company does with them. Here's a short accounting of what's known.

To start, Teslas have event data recorders (EDRs), as is true for most new vehicles. To assist in crash investigations, these "black box" recorders save a scant 5 seconds of information collected before an accident, including speed, acceleration, brake use, steering input, and the operation of automatic-brake and stability controls.

Tesla vehicles keep a permanent record of these data—and many more—on a 4-gigabyte SD or 8-GB microSD card located in the "infotainment" computer, part of the car's media control unit (MCU). These time-stamped "gateway log" files also include information about seatbelt use and various parameters of the car's self-driving system, including whether drivers had their hands on the steering wheel.

Because the gateway logs use data from cars' standard Controller Area Network (CAN) buses, they can include the unique vehicle identification number. But there is no evidence to suggest that these logs include information from the car's GPS module or cameras.

When an owner connects a Tesla to a Wi-Fi network—for instance, to download an over-the-air update that adds new features or fixes bugs—the gateway logs are periodically uploaded to Tesla. Judging from that Florida lawsuit, the company must have ways to link that data to the originating vehicle. (Tesla did not respond to requests for clarification on this or other issues.)

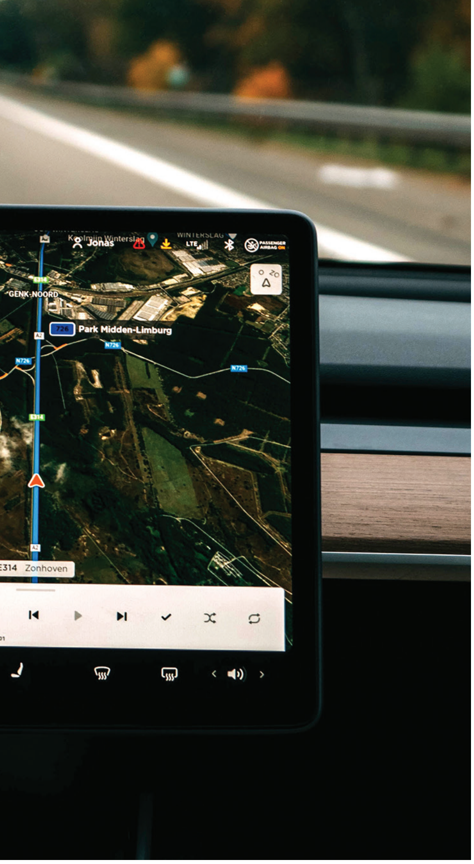
These gateway log files are just the tip of the data iceberg, though. Tesla's Autopilot computer takes inputs from vehicle cameras to handle driver-assistance functions, including cruise control, lane-keeping, and collision warnings. If owners plug their own USB thumb drives into the car, they can make live dashcam recordings and set up Sentry Mode to record the vehicle's surroundings when parked. These recordings do not appear to be uploaded to Tesla.

But there are occasions in which Tesla vehicles do store images and (in 2016 and later models) videos that are then shared with the company. These Autopilot "snapshots" can span several minutes and consist of up to several hundred megabytes of data, according to one engineer and Tesla owner who studied Tesla's data-collection process using salvaged vehicles and components. This engineer tweets about his findings using the pseudonym Green (@greentheonly). These snapshots also include high-resolution log data, similar to that captured in the gateway logs but at a much higher sampling rate—up to 50 times per second for wheel-speed information, notes Hoogendijk.

Such data snapshots are triggered when the vehicle crashes or when certain other conditions are met. These can include anything that Tesla engineers want to learn about, such as particular driving behaviors, or specific objects or situations being detected by the Autopilot system.

According to Green, GPS location data are always captured for crash events and sometimes included for other snapshots. Like gateway log data, snapshots are uploaded to Tesla when the car connects to Wi-Fi, although those triggered by crashes will also attempt to upload over the car's 4G cellular connection. Green indicates that once a snapshot has been successfully uploaded, it is deleted from the Autopilot computer's onboard 32-GB storage.

In addition to the snapshots, the Autopilot computer also records a complete trip log every



Tesla's controversial semi-autonomous driver-assistance system, called Autopilot, is trained using data collected from owners' vehicles. Autopilot has been involved in many crashes, some of which were fatal, and is currently under investigation by the U.S. National Highway Traffic Safety Administration.

BRECHT DENIL/UNSPLASH

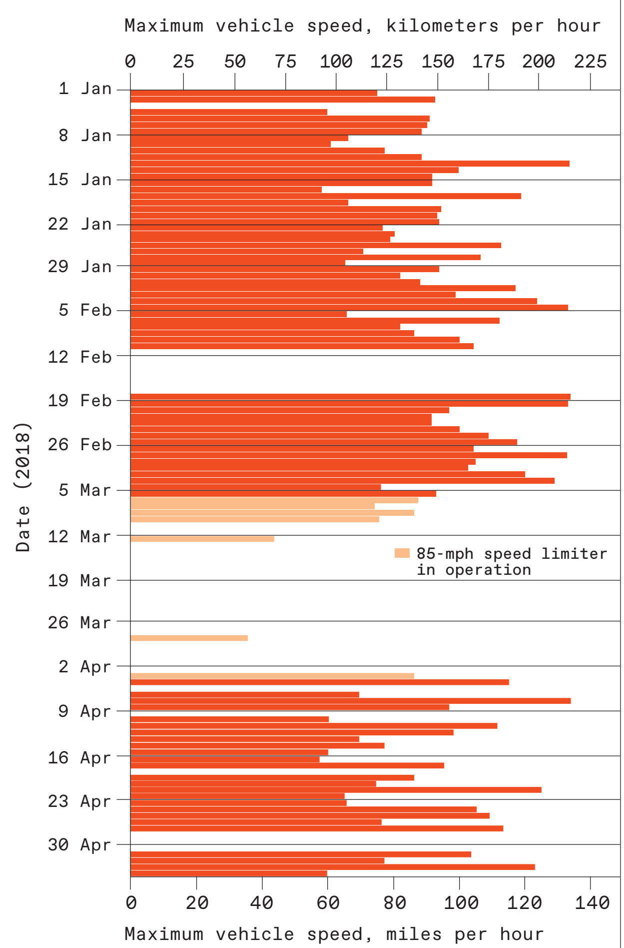
time a mid-2017 or later Tesla is shifted from Park to Drive, says Green. Trip logs include a series of GPS coordinates of the path followed, speeds, road types, and when or whether Autopilot was activated. Green says that trip logs are recorded whether or not Autopilot (or the car's full self-driving mode) is used. Like the snapshots, trip logs are deleted from the vehicle's computer after being uploaded to Tesla.

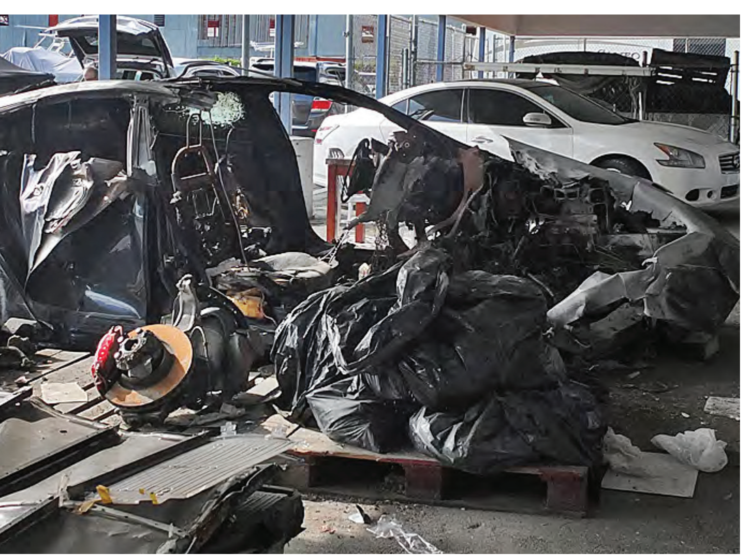
What happens to this treasure trove of data? Tesla has sold about 3 million vehicles worldwide, the majority of which are phoning home daily. They have provided the company with billions of kilometers of real-world driving data and GPS tracks, and many millions of photos and videos. What is the world's leading EV automaker doing with all that information? Tesla doesn't say exactly, but it's not hard to surmise.

IN 2019, ELON MUSK stood up at a Tesla Day event that was devoted to automated driving and said, "Essentially everyone's training the network all the time."

He was referring to Tesla's suite of assistive and semi-autonomous technologies, collectively known as Autopilot, which is the most widely deployed—and most controversial—driver-assistance system on the road today. While many drivers love it, the technology has been involved in hundreds of crashes, some of them fatal, and is currently the subject of a comprehensive investigation by the NHTSA.

Most companies working on automated driving rely on a small fleet of highly instrumented test vehicles that are outfitted with high-resolution cameras, radars, and laser-ranging devices. Some of these vehicles have been estimated to generate 750 megabytes of sensor data every second, providing a rich



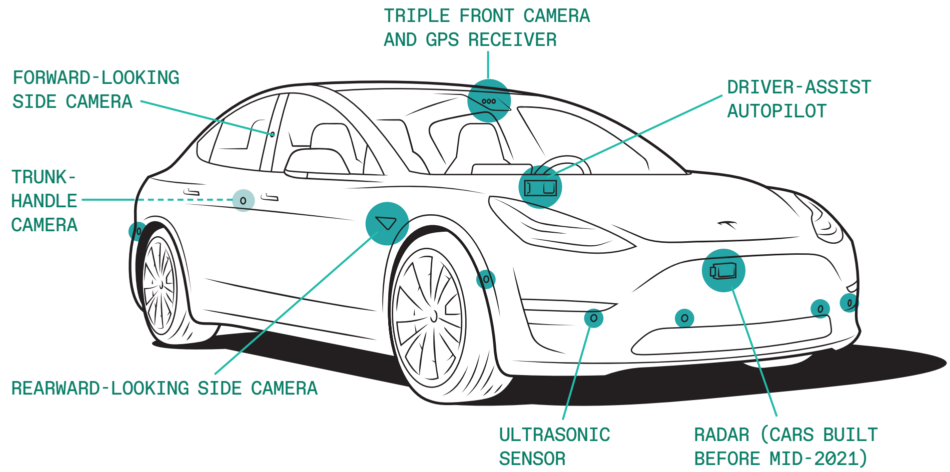


In 2018, two teens were killed in a fiery crash of a Tesla Model S [left], after which the father of the driver sued the company in a Florida court. To demonstrate a pattern of reckless driving, Tesla presented data about the top daily speeds of the car in the months prior to the fatal crash.

LEFT AND CHART: CAR ENGINEERING/TESLA/ SOUTHERN DISTRICT OF FLORIDA U.S. COURTS

TESLA'S MOUNTAIN OF DATA

The company's vehicles carry eight cameras: three front-facing, two on each side, and one on the rear-trunk handle. A GPS module and various sensors add to the data being generated and recorded.

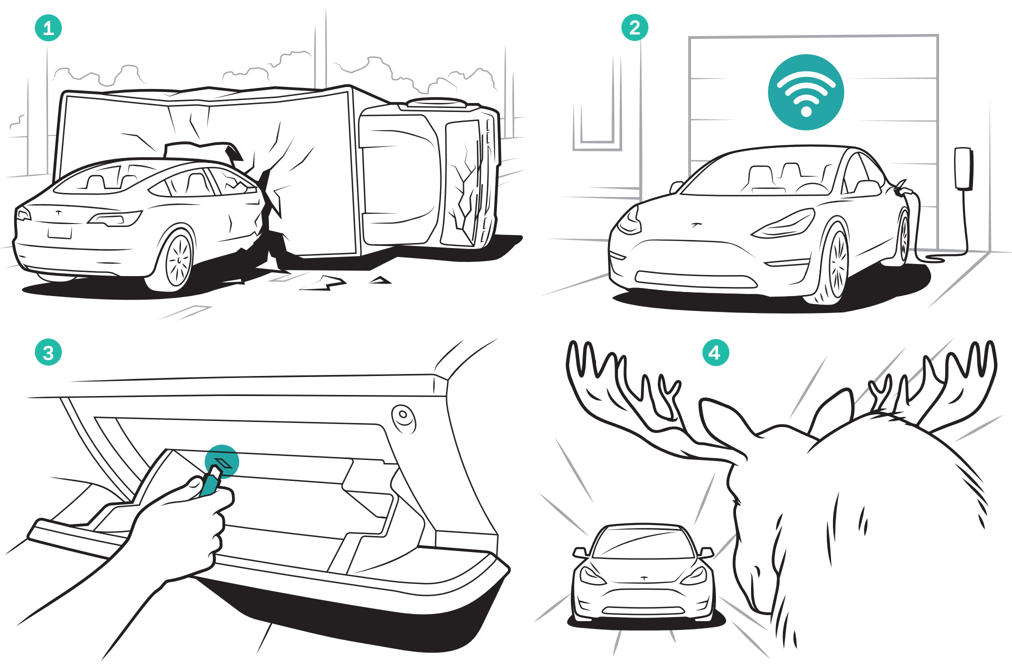


(1) The vehicle's event data recorder will save measurements taken in the seconds before an accident, creating gateway logs. The car will attempt to upload this information to the company using the cellular network.

(2) When connected to Wi-Fi, say, while charging at home, the vehicle may periodically upload gateway logs and Autopilot snapshots.

(3) Using their own USB storage devices, owners can capture dashcam video and images recorded in Sentry Mode while the car is parked.

(4) Tesla may program the car to save video and other sensor data when the car encounters rare events of interest to the company's engineers.



seam of training data for neural networks and other machine-learning systems to improve their driving skills.

Such systems have now effectively solved the task of everyday driving in a variety of weather conditions and road types, says Henry Liu, director of Mcity, a public-private mobility-research partnership at the University of Michigan.

"But right now, automated vehicles are one to two magnitudes below human drivers in terms of safety performance," says Liu. "And that's because current automated vehicles can't handle the curse of rarity: low-frequency, long-tail, safety-critical events that they just don't see enough to know how to handle."

Tesla's bold bet is that its own customers can provide the data needed to boost self-driving cars to superhuman levels of safety. Many are happy to do so—willing participants in the development of technology that they have been told will one day soon allow them to sit back and enjoy being driven by the car itself.

In presentations over the past few years, Musk and Tesla's former head of AI, Andrej Karpathy, detailed the company's approach, including its Shadow Mode. Here the car's Autopilot computer is not controlling the car, but it is simulating the driving process in parallel with the human driver. When its own predictions do not match the driver's behavior, the Autopilot computer might trigger the recording of a data snapshot for later uploading to Tesla.

Tesla engineers can then use these results to better train its neural networks for autonomous driving. Or they may notice through these snapshots that their system is failing, for instance, to properly identify road signs obscured by trees.

In that case, engineers can create special software known as a detector and download it to some Tesla vehicles. If that

Illustration by James Provost

detector thinks it spots such a road sign, it will capture images from the car's cameras for later uploading. Tesla engineers would then soon receive thousands of images, which they would use to improve the detector and eventually roll it out to all production vehicles. "I'm not exactly sure how you build out a data set like this without the fleet," said Karpathy.

LIU IS BULLISH on Tesla's approach to leveraging its ever-growing consumer base. "I don't think a small...fleet will ever be able to handle these [rare] situations," he says. "But even with these shadow drivers—and if you deploy millions of these fleet vehicles, that's a very, very large data collection—I don't know whether Tesla is fully utilizing them because there's no public information really available."

One obstacle is the sheer cost. Karpathy admitted that having a large team assess and label images and video was expensive. He said that Tesla was working on detectors that can train themselves on video clips captured in Autopilot snapshots. It seems the company must now have this capability, because in June Tesla laid off 195 people working on data annotation.

For all the promise of Tesla's fleet learning and the enthusiastic support of many of its customers, Autopilot has yet to prove that it can drive as safely as a person can, let alone be trusted to operate a vehicle without supervision. And there are other difficulties looming. Karpathy left Tesla in mid-July, and the company continues to face the possibility of NHTSA issuing a recall for Autopilot. This would be a terrible blow for the company but would likely not halt its harvesting of customer data nor prevent the continued deployment of Autopilot outside the United States.

"Individuals ought to think about their cars more like they think about their cellphones."

—JOHN VERDI, senior vice president of policy at the Future of Privacy Forum

Tesla's use of fleet-vehicle data to develop Autopilot echoes the user-fueled rise of Internet giants like Facebook, Google, and Twitter. The more its customers drive, so Musk's story goes, the better the system performs.

But just as other tech companies have faced scrutiny for mining customer data, Tesla, too, is beginning to see a backlash. People are beginning to wonder about all the information these cars collect and what happens when other entities, including the government, seek access to it.

FOR TESLAS BUILT since mid-2017, "every time you drive, it records the whole track of where you drive, the GPS coordinates and certain other metrics for every mile driven," says Green. These trip logs and the data snapshots captured by the Autopilot system are stripped of vehicle-identification numbers and given a temporary, random ID number when uploaded to Tesla, says Green. But he notes that temporary IDs can persist for days or weeks, connecting all the uploads made during that time.

Given that some trip logs will also likely record journeys between a driver's home, school, or place of work, expecting anonymity is unrealistic, says John Verdi, senior vice president of policy at the Future of Privacy Forum: "If an entity is collecting, retaining, [and] sharing historical location data on an individualized level, it's extraordinarily difficult to de-identify that, verging on impossible."

Tesla, like all other automakers, has a policy that spells out what it can and cannot do with the data it gets from customers' vehicles, including location information. This policy states that while the company does not sell customer and vehicle data, it can share that data with service providers, business partners, affiliates, some authorized third parties, and government entities according to the law.

Owners can buy a special kit for US $1,400 that allows them to access data on their own car's event data recorder, but this crash-related data represents just a tiny subset of the information the company collects. Owners living in California and Europe benefit from legislation that requires Tesla to provide access to more data generated by their vehicles, although not the Autopilot snapshots and trip logs, which are nominally anonymized.

Once governments realize that a company possesses such a trove of information, it may be only a matter of time before they seek access to it. "If the data exists...and in particular exists in the domain of somebody who's not the subject of those data, it's much more likely that a government will eventually get access to them in some way," says Bryant Walker Smith, an associate professor in the schools of law and engineering at the University of South Carolina.

This is not necessarily a terrible thing, says Smith, who suggests that such rich data could unlock valuable insights into which roads or intersections are dangerous. The wealth of data could also surface subtle problems in the vehicles themselves.

In many ways, the data genie is already out of the bottle, according to Verdi. "Individuals ought to think about their cars more like they think about their cellphones," he says. "The auto industry has a lot to learn from the ways that mobile-phone operating systems handle data permissions.... Both iOS and Android have made great strides in recent years in empowering consumers when it comes to data collection, data disclosure, and data use."

Tesla permits owners to control some data sharing, including Autopilot and road-segment analytics. And if they want to opt out of data collection completely, they can ask Tesla to disable the vehicle's connectivity altogether. But this would mean losing features such as remote services, Internet radio, voice commands, and Web-browser functionality, even safety-related over-the-air updates.

Green says he is not aware of anyone who has successfully exercised this nuclear option. The only real way to know you've prevented data sharing, he says, is to "go to a repair place and ask them to remove the modem out of the car."

Tesla almost certainly has the biggest empire of customer and vehicle data among automakers. But even though Tesla dominates the discussion around connected cars, others are not far behind. Elon Musk's insight—to embrace the data-driven world that our other digital devices already inhabit—is rapidly becoming the industry standard. And when our cars become as smart as our phones, it is hardly surprising that they suffer the same challenges around surveillance, privacy, and accountability. ■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HOW AUDIO IS GETTING ITS GROOVE BACK

Deep learning is delivering the century-old promise of truly realistic sound reproduction

By Qi "Peter" Li, Yin Ding & Jorel Olan

NOW THAT RECORDED SOUND has become ubiquitous, we hardly think about it. From our smartphones, smart speakers, TVs, radios, disc players, and car sound systems, it's an enduring and enjoyable presence in our lives. In 2017, a survey by the polling firm Nielsen suggested that some 90 percent of the U.S. population listens to music regularly and that, on average, they do so 32 hours per week. ● Behind this free-flowing pleasure are enormous industries applying technology to the long-standing goal of reproducing sound with the greatest possible realism. From Edison's phonograph and the horn speakers of the 1880s, successive generations of engineers in pursuit of this ideal invented and exploited countless technologies: triode vacuum tubes, dynamic loudspeakers, magnetic phonograph cartridges, solid-state amplifier circuits in scores of different topologies, electrostatic speakers, optical discs, stereo, and surround sound. And over the past five decades, digital technologies, like audio compression and streaming, have transformed the music industry.

Illustration by Stuart Bradford

ACCORDING TO THE MUSIC-METADATA COMPANY GRACENOTE, OVER 200 MILLION RECORDED SONGS ARE AVAILABLE NOW WORLDWIDE.

AND YET EVEN NOW, after 150 years of development, the sound we hear from even a high-end audio system falls far short of what we hear when we are physically present at a live music performance. At such an event, we are in a natural sound field and can readily perceive that the sounds of different instruments come from different locations, even when the sound field is criss-crossed with mixed sounds from multiple instruments. There's a reason why people pay considerable sums to hear live music: It is more enjoyable, exciting, and can generate a bigger emotional impact. • Today, researchers, companies, and entrepreneurs, including ourselves, are closing in at last on recorded audio that truly re-creates a natural sound field. The group includes big companies, such as Apple and Sony, as well as smaller firms, such as Creative. Netflix recently disclosed a partnership with Sennheiser under which the network has begun using a new system, Ambeo 2-Channel Spatial Audio, to heighten the sonic realism of such TV shows as "Stranger Things" and "The Witcher."

There are now at least half a dozen different approaches to producing highly realistic audio [see chart, "An Audio Taxonomy," opposite page]. We use the term "soundstage" to distinguish our work from other audio formats, such as the ones referred to as spatial audio or immersive audio. These can represent sound with more spatial effect than ordinary stereo, but they do not typically include the detailed sound-source location cues that are needed to reproduce a truly convincing sound field.

We believe that soundstage is the future of music recording and reproduction. But before such a sweeping revolution can occur, it will be necessary to overcome an enormous obstacle: that of conveniently and inexpensively converting the countless hours of existing recordings, regardless of whether they're mono, stereo, or multichannel surround sound (5.1, 7.1, and so on). No one knows exactly how many songs have been recorded, but according to the entertainment-metadata concern Gracenote, more than 200 million recorded songs are available now on planet Earth. Given that the average duration of a song is about 3 minutes, this is the equivalent of about 1,100 years of music.

That is a *lot* of music. Any attempt to popularize a new audio format, no matter how promising, is doomed to fail unless it includes technology that makes it possible for us to listen to all this existing audio with the same ease and convenience with which we now enjoy stereo music—in our homes, at the beach, on a train, or in a car.

We have developed such a technology. Our system, which we call 3D Soundstage, permits music playback in soundstage on smartphones, ordinary or smart speakers, headphones, earphones, laptops, TVs, soundbars, and in vehicles. Not only can it convert mono and stereo recordings to soundstage, it also allows a listener with no special training to reconfigure a sound field according to their own preference, using a graphical user interface. For example, a listener can assign the locations of each instrument and vocal sound source and adjust the volume of each—changing the relative volume of, say, vocals in comparison with the instrumental accompaniment. The system does this by leveraging artificial intelligence (AI), virtual reality, and digital signal processing (more on that shortly).

To re-create convincingly the sound coming from, for instance, a string quartet in two small speakers, such as the ones available in a pair of headphones, requires a great deal of technical finesse. To understand how this is done, let's start with the way we perceive sound.

When sound travels to your ears, unique characteristics of your head—its physical shape, the shape of your outer and inner ears, even the shape of your nasal cavities—change the audio spectrum of the original sound. Also, there is a very slight difference in the arrival time from a sound source to your two ears. From this spectral change and the time difference, your brain perceives the location of the sound source. The spectral changes and time difference can be modeled mathematically as head-related transfer functions (HRTFs). For each point in three-dimensional space around your head, there is a pair of HRTFs, one for your left ear and the other for the right [see illustration, "Measuring a Head-Related Transfer Function," page 51].

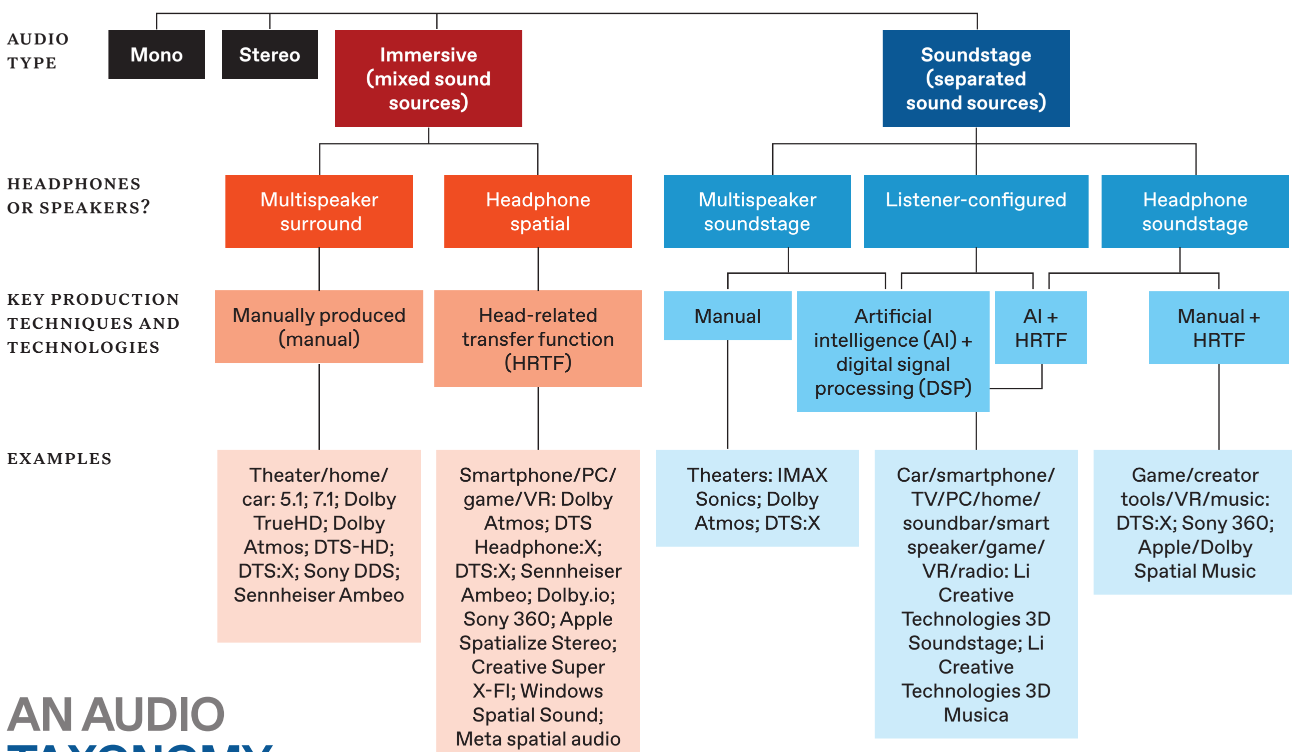
So, given a piece of audio, we can process that audio using a pair of HRTFs, one for the right ear, and one for the left. To re-create the original experience, we would need to take into account the location of the sound sources relative to the microphones that recorded them. If we then played that processed audio back, for example through a pair of headphones, the listener would hear the audio with the original cues, and perceive that the sound is coming from the directions from which it was originally recorded.

If we don't have the original location information, we can simply assign locations for the individual sound sources and get essentially the same experience. The listener is unlikely to notice minor shifts in performer placement—indeed, they might prefer their own configuration.

There are many commercial apps that use HRTFs to create spatial sound for listeners using headphones and earphones. One example is Apple's Spatialize Stereo. This technology applies HRTFs to playback audio so you can perceive a spatial sound effect—a deeper sound field that is more realistic than ordinary stereo. Apple also offers a head-tracker version that uses sensors on the iPhone and AirPods to track the relative direction between your head, as indicated by the AirPods in your ears, and your iPhone. It then applies the HRTFs associated with the direction of your iPhone to generate spatial sounds, so you perceive that the sound is coming from your iPhone. This isn't what we would call soundstage audio, because instrument sounds are still mixed together. You can't perceive that, for example, the violin player is to the left of the viola player.

Apple does, however, have a product that attempts to provide soundstage audio: Apple Spatial Audio. It is a significant improvement over ordinary stereo, but it still has a couple of difficulties, in our view. One, it incorporates Dolby Atmos, a surround-sound technology developed by Dolby Laboratories. Spatial Audio applies a set of HRTFs to create spatial audio for headphones and earphones. However, the use of Dolby Atmos means that all existing stereophonic music would have to be remastered for this technology. Remastering the millions of songs already recorded in mono and stereo would be basically impossible. Another problem with Spatial Audio is that it can only support headphones or earphones, not speakers, so it has no benefit for people who tend to listen to music in their homes and cars.

So how does our system achieve realistic soundstage audio? We start by using machine-learning software to separate the audio into multiple isolated tracks, each representing one instrument or singer or one group of instruments or singers. This separation



AN AUDIO TAXONOMY

For a listener seeking a high degree of spatial realism, a variety of audio formats and systems are now available for enjoyment through speakers or headphones. On the low end, ordinary mono and stereo recordings provide a minimal spatial-perceptual experience. In the middle range, multichannel recordings, such as 5.1 and 7.1 surround sound, offer somewhat higher levels of spatial realism. At the highest levels are audio systems that start with the individual, separated instrumental tracks of a recording and then recombine them, using audio techniques and tools such as head-related transfer functions, to provide a highly realistic spatial experience.

process is called upmixing. A producer or even a listener with no special training can then recombine the multiple tracks to re-create and personalize a desired sound field.

Consider a song featuring a quartet consisting of guitar, bass, drums, and vocals. The listener can decide where to "locate" the performers and can adjust the volume of each, according to his or her personal preference. Using a touch screen, the listener can virtually arrange the sound-source locations and the listener's position in the sound field, to achieve a pleasing configuration. The graphical user interface displays a shape representing the stage, upon which are overlaid icons indicating the sound sources—vocals, drums, bass, guitars, and so on. There is a head icon at the center, indicating the listener's position. The listener can touch and drag the head icon around to change the sound field according to their own preference.

Moving the head icon closer to the drums makes the sound of the drums more prominent. If the listener moves the head icon onto an icon representing an instrument or a singer, the listener will hear that performer as a solo. The point is that by allowing the listener to reconfigure the sound field, 3D Soundstage adds new dimensions (if you'll pardon the pun) to the enjoyment of music.

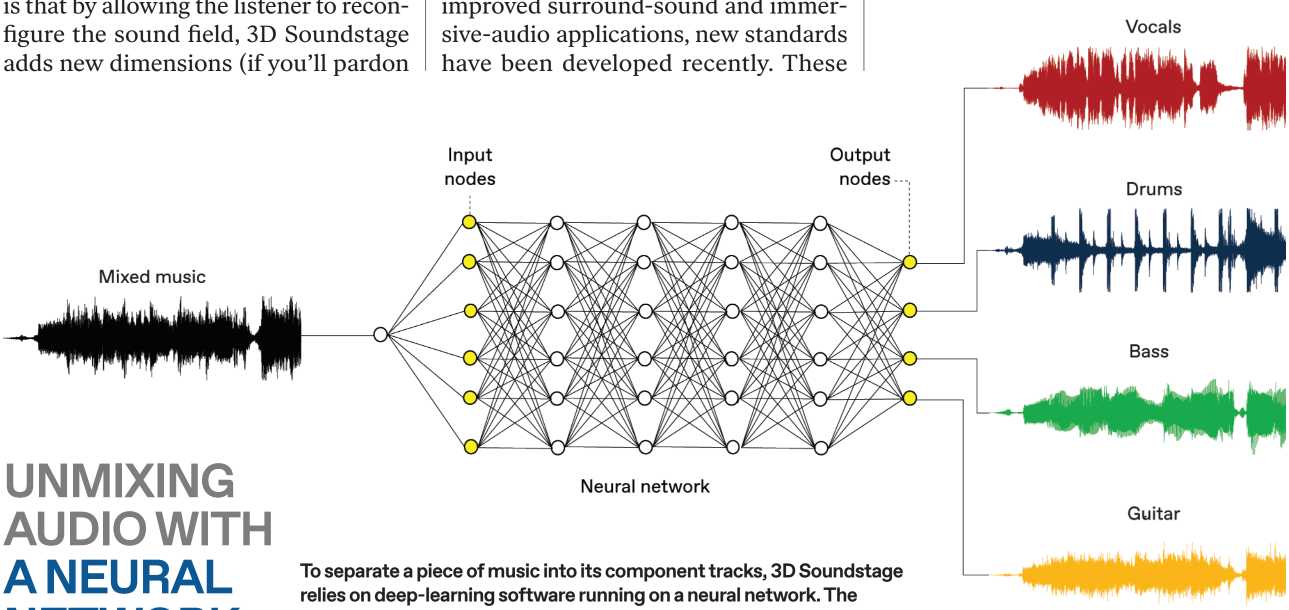
The converted soundstage audio can be in two channels, if it is meant to be heard through headphones or an ordinary left- and right-channel system. Or it can be multichannel, if it is destined for playback on a multiple-speaker system. In this latter case, a soundstage audio field can be created by two, four, or more speakers. The number of distinct sound sources in the re-created sound field can even be greater than the number of speakers.

This multichannel approach should not be confused with ordinary 5.1 and 7.1 surround sound. These typically have five or seven separate channels and a speaker for each, plus a subwoofer (the ".1"). The multiple loudspeakers create a sound field that is more immersive than a standard two-speaker stereo setup, but they still fall short of the realism possible with a true soundstage recording. When played through such a multichannel setup, our 3D Soundstage recordings bypass the 5.1, 7.1, or any other special audio formats, including multitrack audio-compression standards.

A word about these standards. In order to better handle the data for improved surround-sound and immersive-audio applications, new standards have been developed recently. These include the MPEG-H 3D audio standard for immersive spatial audio with Spatial Audio Object Coding (SAOC). These new standards succeed various multichannel audio formats and their corresponding coding algorithms, such as Dolby Digital AC-3 and DTS, which were developed decades ago.

While developing the new standards, the experts had to take into account many different requirements and desired features. People want to interact with the music, for example by altering the relative volumes of different instrument groups. They want to stream different kinds of multimedia, over different kinds of networks, and through different speaker configurations. SAOC was designed with these features in mind, allowing audio files to be efficiently stored and transported, while preserving the possibility for a listener to adjust the mix based on their personal taste.

To do so, however, it depends on a variety of standardized coding techniques. To create the files, SAOC uses an encoder. The inputs to the encoder are data files containing sound tracks; each



UNMIXING AUDIO WITH A NEURAL NETWORK

To separate a piece of music into its component tracks, 3D Soundstage relies on deep-learning software running on a neural network. The tracks are gradually separated as the digital music file progresses through successive layers of nodes. Finally, each of the isolated tracks are released on an output node.

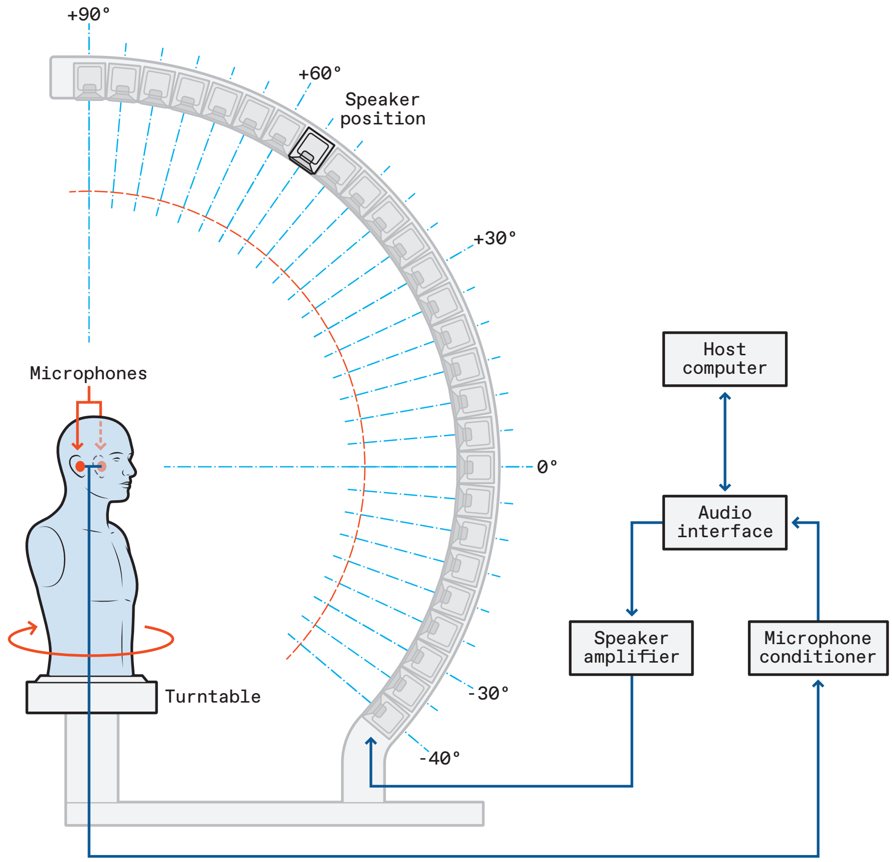
track is a file representing one or more instruments. The encoder essentially compresses the data files, using standardized techniques. During playback, a decoder in your audio system decodes the files, which are then converted back to the multichannel analog sound signals by digital-to-analog converters.

Our 3D Soundstage technology bypasses this. We use mono or stereo or multichannel audio data files as input. We separate those files or data streams into multiple tracks of isolated sound sources, and then convert those tracks to two-channel or multichannel output, based on the listener's preferred configurations, to drive multiple loudspeakers or headphones. We use AI technology to avoid multitrack rerecording, encoding, and decoding.

In fact, one of the biggest technical challenges we faced in creating the 3D Soundstage system was writing that machine-learning software that separates (or upmixes) a conventional mono, stereo, or multichannel recording into multiple isolated tracks in real time. The software runs on a neural network. We developed this approach for music separation in 2012 and described it in patents that were awarded in 2022 and 2015 (the U.S. patent numbers are 11,240,621 B2 and 9,131,305 B2).

A typical session has two components: training and upmixing. In the training session, a large collection of mixed songs, along with their isolated instrument and vocal tracks, are used as the input and target output, respectively, for the neural network. The training uses machine learning to optimize the neural-network parameters so that the output of the neural network—the collection of individual tracks of isolated instrument and vocal data—matches the target output.

A neural network is very loosely modeled on the brain. It has an input layer of nodes, which represent biological neurons, and then many intermediate layers, called "hidden layers." Finally, after the hidden layers there is an output layer, where the final results emerge. In our system, the data fed to the input nodes is the data of a mixed audio track. As this data proceeds through layers of hidden nodes, each node performs computations that produce a sum of weighted values [see illustration, "Unmixing Audio With a Neural Network," opposite page]. Then a nonlinear mathematical operation is performed on this sum. This calculation determines whether and how the audio data from that node is passed on to the nodes in the next layer.



MEASURING A HEAD-RELATED TRANSFER FUNCTION

To provide a high degree of spatial realism for a listener, you need to precisely map the details of how that listener's unique head shape, ears, and nasal cavity affect how he or she hears sound. This is done by determining the listener's head-related transfer function, which is accomplished by playing sounds from a variety of angles and recording how the user's head affects the sounds at each position.

PETER LI

Illustration by Chris Philpot

TO HEAR THE AUTHOR'S 3D SOUNDSTAGE AUDIO FOR YOURSELF, GRAB YOUR HEADPHONES AND HEAD OVER TO 3DSOUNDSTAGE.COM/IEEE

There are dozens of these layers. As the audio data goes from layer to layer, the individual instruments are gradually separated from one another. At the end, in the output layer, each separated audio track is output on a node in the output layer.

That's the idea, anyway. While the neural network is being trained, the output may be off the mark. It might not be an isolated instrumental track—it might contain audio elements of two instruments, for example. In that case, the individual weights in the weighting scheme used to determine how the data passes from hidden node to hidden node are tweaked and the training is run again. This iterative training and tweaking goes on until the output matches, more or less perfectly, the target output.

As with any training data set for machine learning, the greater the number of available training samples, the more effective the training will ultimately be. In our case, we needed tens of thousands of songs and their separated instrumental tracks for training; thus, the total training music data sets were in the thousands of hours.

After the neural network is trained, given a song with mixed sounds as input, the system outputs the multiple separated tracks by running them through the neural network using the system established during training.

After separating a recording into its component tracks, the next step is to remix them into a soundstage recording. This is accomplished by a soundstage signal processor. This soundstage processor performs a complex computational function to generate the output signals that drive the speakers and produce the soundstage audio. The inputs to the generator include the isolated tracks, the physical locations of the speakers, and the desired locations of the listener and sound sources in the re-created sound field. The outputs of the soundstage processor are multitrack signals, one for each channel, to drive the multiple speakers.

The sound field can be in a physical space, if it is generated by speakers, or in a virtual space, if it is generated by headphones or earphones. The function performed within the soundstage processor is based on computational acoustics and psychoacoustics, and it takes into account sound-wave propagation and interference in the desired sound field and the HRTFs for the listener and the desired sound field.

For example, if the listener is going to use earphones, the generator selects a set of HRTFs based on the configuration of desired sound-source locations, then uses the selected HRTFs to filter the isolated sound-source tracks. Finally, the soundstage processor combines all the HRTF outputs to generate the left and right tracks for earphones. If the music is going to be played back on speakers, at least two are needed, but the more speakers, the better the sound field. The number of sound sources in the re-created sound field can be more or less than the number of speakers.

We released our first soundstage app, for the iPhone, in 2020. It lets listeners configure, listen to, and save soundstage music in real time—the processing causes no discernible time delay. The app, called 3D Musica, converts stereo music from a listener's personal music library, the cloud, or even streaming music to soundstage in real time. (For karaoke, the app can remove vocals, or output any isolated instrument.)

Earlier this year, we opened a Web portal, 3dsoundstage.com, that provides all the features of the 3D Musica app in the cloud plus an application programming interface (API) making the features available to streaming music providers and even to users of any popular Web browser. Anyone can now listen to music in soundstage audio on essentially any device.

We also developed separate versions of the 3D Soundstage software for vehicles and home audio systems and devices to re-create a 3D sound field using two, four, or more speakers. Beyond music playback, we have high hopes for this technology in videoconferencing. Many of us have had the fatiguing experience of attending videoconferences in which we had trouble hearing other participants clearly or being confused about who was speaking. With soundstage, the audio can be configured so that each person is heard coming from a distinct location in a virtual room. Or the "location" can simply be assigned depending on the person's position in the grid typical of Zoom and other videoconferencing applications. For some, at least, videoconferencing will be less fatiguing and speech will be more intelligible.

Just as audio moved from mono to stereo, and from stereo to surround and spatial audio, it is now starting to move to soundstage. In those earlier eras, audiophiles evaluated a sound system by its fidelity, based on such parameters as bandwidth, harmonic distortion, data resolution, response time, lossless or lossy data compression, and other signal-related factors. Now, soundstage can be added as another dimension to sound fidelity—and, we dare say, the most fundamental one. To human ears, the impact of soundstage, with its spatial cues and gripping immediacy, is much more significant than incremental improvements in harmonic distortion. For the first time, recorded audio can tap into psychoacoustics and broader brain activity beyond those related to fidelity. This extraordinary feature offers capabilities beyond the experience of even the most deep-pocketed audiophiles.

Technology has fueled previous revolutions in the audio industry, and it is now launching another one. Artificial intelligence, virtual reality, and digital signal processing are leveraging psychoacoustics to give audio enthusiasts capabilities they've never had. At the same time, these technologies are giving recording companies and artists new tools that will breathe new life into old recordings and open up new avenues for creativity. At last, the century-old goal of convincingly re-creating the sounds of the concert hall has been achieved. ■

Rowan University

The Henry M. Rowan College of Engineering invites applications for multiple, open-rank positions in areas of electrical and computer engineering, including cyber-physical systems and hardware security, IoT, modern VLSI and chip design, electromagnetics and antenna design, systems architecture with software/hardware integration for wireless communication and networking, energy and power systems, and AI integration with autonomous, modern control systems and robotics.

An open rank position is also available to help grow our state-of-the-art Virtual Reality Center that consists of multiple facilities with multi-million-dollar existing awards and contracts related to augmented, virtual, and mixed reality applications.

Candidates with cross-cutting research interests and diverse backgrounds that cover overlapping areas of the above-listed topics are encouraged to apply as are candidates with an outstanding record in other related areas. Applicants with exceptional records of scholarly excellence will be considered for the Henry M. Rowan Foundation Professorship.

Candidates must have 1) a Ph.D. in Electrical/Computer Engineering (or closely related field), 2) a proven record (for Associate/Full Professors) or outstanding potential (for Assistant Professors) for developing a sustainable and externally funded research program, and 3) a strong commitment to excellence in both research and teaching.

Rowan is a comprehensive public research institution with 23,000 students enrolled in fifteen schools and colleges including two medical schools. The Henry M. Rowan College of Engineering, created with a $100M gift in 1992, enrolls over 1800 students in six departments.

For more information about us, please visit **www.rowan.edu/ece**. Applications are accepted online at **https://go.rowan.edu/joinRowanECE** and **https://go.rowan.edu/joinRowanVRCenter** where additional information is also available. Questions can be directed to Dr. Robi Polikar, at **polikar@rowan.edu**.

UNIVERSITY OF NOTRE DAME

The Electrical Engineering Department at the University of Notre Dame invites applications for two tenured or tenure-track faculty positions. Applications in the broad areas of electrical engineering are encouraged, and applications at all ranks will be considered.

The first position is in the areas of semiconductor materials, devices and micro/nanoelectronic systems; broadly defined. Areas of interest include, but are not limited to, experimental research in novel circuit technologies, devices, and materials that address grand challenges in electronics and high-speed electronics; smart sensors; optics and optoelectronics; energy-efficient and high-performance computing; devices and/or circuits for wireless communication.

The second position is in the areas of signal processing, power systems, control, communications and networking, and bio-medical and health-related technologies; broadly defined. Areas of interest include, but are not limited to, system-level methods and technologies that address grand challenges in reliable and affordable power delivery; environmental monitoring; smart manufacturing; hardware for broad autonomy and autonomous machines; wireless communications; bio-medical and health-related technologies; and hardware security.

The Department seeks to attract excellent faculty members with strong academic and research track records. The Department is especially interested in candidates who will contribute to the diversity and excellence of the University's academic community through their research, teaching, and service.

Applicants must submit a cover letter, curriculum vitae, teaching statement, research statement, and diversity statement. The application must include the names, titles and email addresses of three or more individuals who will provide letters of recommendation. All materials can be submitted at **http://apply.interfolio.com/112123** for the first position and **http://apply.interfolio.com/112479** for the second. For fullest consideration, applicants are encouraged to apply by **November 30, 2022**.

Notre Dame is located in South Bend, Indiana, a vibrant and affordable community not far from Lake Michigan and a short train ride to Chicago. The University is an Equal Opportunity and Affirmative Action employer; we strongly encourage applications from women, minorities, veterans, individuals with a disability and those candidates attracted to a university with a Catholic identity. Notre Dame is responsive to the needs of dual career couples, and is interested in candidates who will bring to their research the perspective that comes from a nontraditional educational background or understanding of the experiences of those underrepresented in higher education.

MIT EECS

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, MA
FACULTY POSITIONS

The Massachusetts Institute of Technology Department of Electrical Engineering and Computer Science (EECS) seeks candidates for faculty positions starting July 1, 2023, or on a mutually agreed date thereafter. We welcome outstanding applicants with research and teaching interests in any area of electrical engineering, computer science, and artificial intelligence and decision making. EECS believes that the intellectual, cultural and social diversity of our faculty, staff, and students is vitally important to the distinction and excellence of our academic and research programs. The Department seeks candidates who support our institutional commitment to ensuring that MIT is inclusive, equitable, and diverse.

Appointment will be at the assistant or untenured associate professor level. In special cases, a senior faculty appointment may be possible, commensurate with experience. Faculty duties include teaching at the undergraduate and graduate levels, research, and supervision of student research. Candidates should hold a Ph.D. in electrical engineering and computer science or a related field by the start of employment.

Candidates must register with the EECS search website at **https://faculty-searches.mit.edu/eecs**, and must submit application materials electronically to this website. Applications must include a cover letter, curriculum vitae, a research statement (2-4 pages) and a teaching statement (1-2 pages). In addition, candidates should provide a statement regarding their views on diversity, inclusion, and belonging, including past and current contributions as well as their vision and plans for the future in these areas. Each application should include the names and addresses of three or more individuals who will provide letters of recommendation. Letter writers should submit their letters directly to MIT, preferably on the website or by mailing to the address below. Complete applications should be received by December 1, 2022. Applications will be considered complete only when both the applicant materials and **at least three letters of recommendation are received**.

It is the responsibility of the candidate to arrange reference letters to be uploaded at https://faculty-searches.mit.edu/eecs by December 1, 2022.

Send all materials not submitted on the website to:
Professor Asu Ozdaglar
Department Head, Electrical Engineering and Computer Science
Massachusetts Institute of Technology
Room 38-403
77 Massachusetts Avenue
Cambridge, MA 02139

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NYU | TANDON SCHOOL OF ENGINEERING

Tenure-Track Faculty, Department of Electrical and Computer Engineering, New York University, Brooklyn, NY

The Department of Electrical and Computer Engineering at the NYU Tandon School of Engineering invites applications for three tenure-track Assistant Professor positions, to start on September 1, 2023.

NYU Tandon has nationally renowned research centers that ECE faculty lead and participate in, including the Center for Cybersecurity, NYU Wireless, the Center for Advanced Technology in Telecommunications (CATT), and the Center for Urban Science + Progress (CUSP). ECE faculty are also highly engaged in several school-wide research initiatives (including communications, cybersecurity, data science/AI/robotics, and sustainability).

We are looking to hire in the broad areas of Computer Engineering (including architecture, circuits, hardware devices, and systems), Control Systems, Energy/Power, and Wireless Communications (including antennas/radio propagation, circuits, networking, and theory). The applicant should have a Ph.D. degree in Electrical Engineering, Computer Engineering, or a closely related discipline. The individual should have the potential to develop a strong record of scholarship, leadership, curricular innovation, and an excellent funding record. The applicant should demonstrate excellence in research, teaching and mentoring.

For application instructions and more information about NYU Tandon, see: **https://apply.interfolio.com/112470**.

Applications should be submitted by **December 15, 2022** for full consideration.

NUS National University of Singapore

Faculty Positions in Computer Science

The Department of Computer Science at the National University of Singapore (NUS) invites applications for tenure-track and educator-track positions in all areas of computer science. Candidates for Assistant Professor positions on the tenure track should be early in their academic careers and yet demonstrate outstanding research potential, and a strong commitment to teaching.

For Senior Lecturer and Associate Professor on the educator-track, teaching experience or relevant industry experience will be preferred. Besides relevant background and experience, we are also looking for someone with a passion for imparting the latest knowledge in computing to students in our programs.

The Department enjoys ample research funding, moderate teaching loads, excellent facilities, and extensive international collaborations. We have a full range of faculty covering all major research areas in computer science and boasts a thriving PhD program that attracts the brightest students from the region and beyond. More information is available at **www.comp.nus.edu.sg/careers**.

NUS is an equal opportunity employer that offers highly competitive salaries, and is situated in Singapore, an English-speaking cosmopolitan city that is a melting pot of many cultures, both the east and the west. Singapore offers high-quality education and healthcare at all levels, as well as very low tax rates.

Application Details:
Submit the following documents (in a single PDF) online via: **https://faces.comp.nus.edu.sg**

- A cover letter that indicates the position applied for and the main research interests
- Curriculum Vitae
- A teaching statement
- A research statement
- A diversity statement (optional)
- Contact information of 3 referees

To ensure maximal consideration, please submit your application by 16 December 2022.

Job requirement:
A PhD degree in Computer Science or related areas

AUBURN UNIVERSITY
SAMUEL GINN COLLEGE OF ENGINEERING

The Department of Electrical and Computer Engineering in the Samuel Ginn College of Engineering at Auburn University invites applications for tenure-track Assistant Professor positions in the areas of control systems, computer engineering and microelectronics. Please visit **www.eng.auburn.edu/elec** for details about these positions and application instructions.

Auburn University is an EEO/Vet/Disability Employer. Auburn University is understanding of and sensitive to the family needs of faculty, including dual career couples.

BY ALLISON MARSH

Past Forward

The violet ray machine became a popular electrotherapy in the first half of the 20th century.

HISTORICAL MEDICAL LIBRARY/COLLEGE OF PHYSICIANS OF PHILADELPHIA

The Electric Purple Snake-Oil Machine

In 1917, Detroit inventor James Henry Eastman took advantage of the electrotherapy rage sweeping the United States and opened the Renulife Electric Co. to manufacture and sell violet ray machines. These quasi-medical devices, according to the company, could cure ailments ranging from abscess to writer's cramp, and dozens of others in between. The machines employed a Tesla coil to produce a high-frequency, low-current beam, which was then applied to the skin via partially evacuated glass cylinders known as Geissler tubes. The high voltage ionized the gas within the tube, creating the purple glow that gave the device its name.

Renulife was just one of a number of companies that produced violet ray machines, which became ubiquitous in the first half of the 20th century. A 1951 court ruling found the devices ineffective for most medical conditions. And yet they are still used today by aestheticians and sold for home use. ■

FOR MORE ON THE HISTORY OF THE VIOLET RAY GENERATOR, SEE spectrum.ieee.org/pastforward-oct2022


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