Clues to COVID-19 Brain Fog | The Milky Way's Chaotic Heart

ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ FEBRUARY 26, 2022

THE DIGITAL REVOLUTION

Computers have made the unimaginable possible. What's next?

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VOL. 201 | NO. 4

ScienceNews

Features

News

Departments

COVER Can computers speed up science, expand creativity and make our lives easier without harming humankind? *Trout55/E+/Getty Images*

FROM TOP: M.J. HUSSEIN; A. ROUX *ET AL*/*PHYSICAL REVIEW FLUIDS* 2022; AJAX9/ISTOCK/GETTY IMAGES PLUS

Computing has changed everything. What next?

As I write this, my laptop has way too many open tabs. A Zoom meeting is about to start, and I'm getting pinged in the magazine production channel on Slack. The managing editor is asking if I can do a final approval on a news page. When done, I'll either mark it as "clean" on a Google Sheet or dive into InCopy to generate a corrected pdf and save it to Dropbox.

While the paragraph above makes perfect sense to Present Day Me, the me of the past would have no idea what's going on. Laptop? Is that some sort of clipboard?

In this issue, as part of our ongoing Century of Science project, we dig deep into how the extraordinary advances in computing over the last 100 years have transformed our lives, and we ponder implications for the future (Page 16). Who gets to decide how much control algorithms have over our lives? Will artificial intelligence learn how to really think like humans? What would ethical AI look like? And can we keep the robots from killing us?

That last question may sound hypothetical, but it's not. As freelance science and technology writer Matthew Hutson reports, lethal autonomous drones able to attack without human intervention already exist. And though killer drones may be the most dystopian vision of a future controlled by AI, software is already making decisions about our lives every day, from the advertisements we see on Facebook to influencing who gets denied parole from prison.

Even something as basic to human life as our social interactions can be used by AI to identify individuals within supposedly anonymized data, as staff writer Nikk Ogasa reports on Page 8. Researchers taught an artificial neural network to identify patterns in the date, time, direction and duration of weekly mobile phone calls and texts in a large anonymized dataset. The AI was able to identify individuals by the patterns of their behavior and that of their contacts.

Innovations in computing have come with astonishing speed, and we humans have adapted almost as quickly. I remember being thrilled with my first laptop, my first flip phone, my first BlackBerry. As we've welcomed each new marvel into our lives, we've bent our behavior. While I delight at being able to FaceTime with my daughter while she's away at college, I'm not so pleased to find myself reflexively reaching for the phone to ... hmm, avoid finishing this column. I could download a productivity app that promises to train me to stay focused, but using the phone to avoid the phone seems both too silly and too sad.

Not enough computer scientists and engineers have training in the social implications of their technologies, Hutson writes, including training in ethics. More importantly, they're not having enough conversations about how the algorithms they write could affect people's lives in unexpected ways, before the next big innovation gets sent out into the world. As the technology gets ever more powerful, those conversations need to happen long before the circuit is built or the code is written. How else will the robots know when they've gone too far? *—Nancy Shute, Editor in Chief*

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SOCIETY FOR SCIENCE

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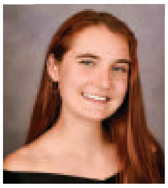
Regeneron and Society for Science salute the amazing young scientists selected from more than 1,800 entrants in the 2022 Regeneron Science Talent Search.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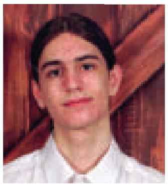
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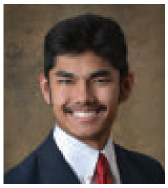
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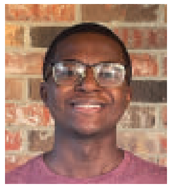
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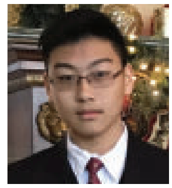
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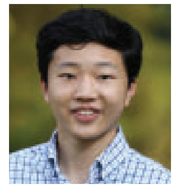
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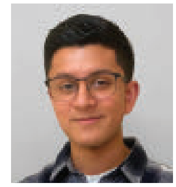
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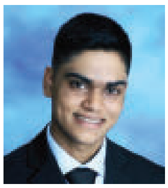
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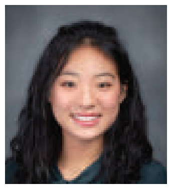
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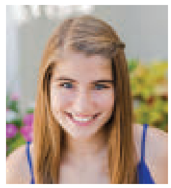
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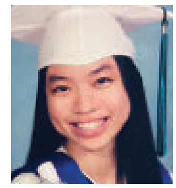
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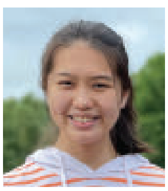
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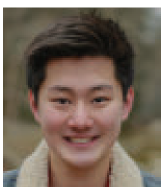
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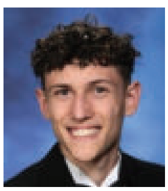
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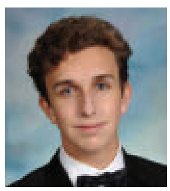
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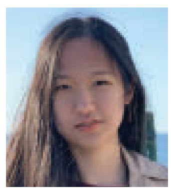
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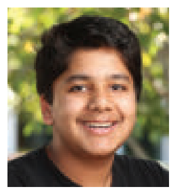
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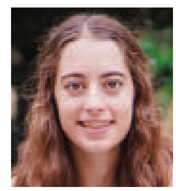
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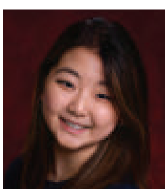
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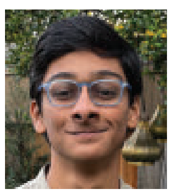
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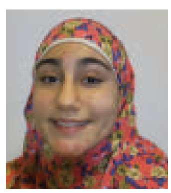
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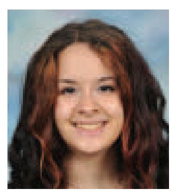
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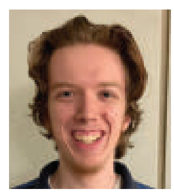
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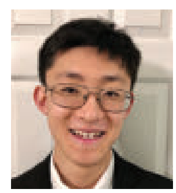
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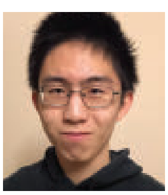
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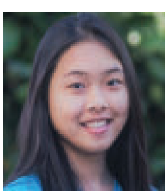
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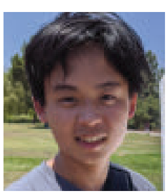
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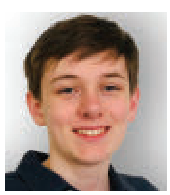
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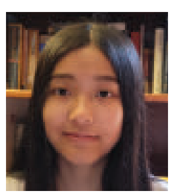
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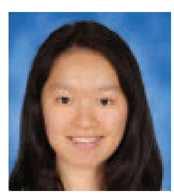
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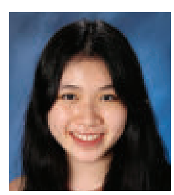
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The Regeneron Science Talent Search is the nation's oldest and most prestigious science and math competition for high school seniors. The competition is designed to engage and inspire the next generation of scientific leaders.

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Excerpt from the February 26, 1972 issue of *Science News*

50 YEARS AGO

The uncertainty of banking sperm

Many men contemplating vasectomies have been depositing a quantity of their semen with sperm banks where, for a fee, it is frozen and stored.... There is wide disagreement on the length of time that sperm may be frozen and then thawed and used successfully to impregnate a woman, with estimates ranging from only 16 months to as much as 10 years.

UPDATE: The ability to freeze sperm has helped make parenthood possible for millions of people, including infertile or same-sex couples and people who have undergone cancer treatment (*SN: 6/19/21, p. 16*). Sperm-freezing methods have improved since the 1970s, and studies have shown that frozen sperm can remain viable for many years, even decades. The rate of live births from sperm frozen for up to 15 years at a sperm bank in China was similar to rates from sperm stored for much shorter periods, scientists reported in 2019. In 2013, U.S. researchers reported the birth of healthy twins who were conceived using sperm that had been frozen for about 40 years.

Biologist Kristine Bohmann tests a vacuum's ability to trap airborne DNA, near a sloth in captivity. The method could help track species in the wild.

THE SCIENCE LIFE

Scientists vacuum animal DNA out of thin air

On a dreary day in December 2020, Elizabeth Clare, an ecologist at York University in Toronto, strolled through the Hamerton Zoo Park in England wielding a small vacuum pump. She paused outside animal enclosures, holding aloft a flexible tube attached to the machine. Her mission: Suck animal DNA out of the air.

The ability to sniff out animals' airborne genetic material has been on scientists' wish list for over a decade. DNA collected from water has been

HOW BIZARRE

'Everlasting' bubbles can linger for a long time

If you hate having your bubble burst, you'll love these "everlasting" bubbles. While soap bubbles are known for their fragile constitutions, the new bubbles can stick around for over a year before they pop, physicist Michael Baudoin of the University of Lille in France and colleagues report January 18 in *Physical Review Fluids*.

The bubbles are made with water, plastic microparticles and glycerol. That trio of ingredients staves off factors that normally hasten a soap bubble's death.

Researchers created an "everlasting" bubble (shown) that lasted for 465 days before popping. The bubble, which had a radius of about 3.7 millimeters, got its stamina from glycerol and plastic particles.

In soap bubbles, gravity pulls liquid to the bottom, leaving a thin film on the top that can easily rupture (*SN: 1/21/17, p. 32*). Evaporation also saps soap bubbles' stamina. In everlasting bubbles, plastic specks cling to water, maintaining the film's thickness. Meanwhile, glycerol absorbs moisture from the air, counteracting evaporation.

When the bubbles didn't rupture after days, "we were really astonished," Baudoin says. So his team waited to see how long the bubbles would last. One bubble persisted 465 days before bursting. It turned green just before its demise, hinting that microbes set up shop, causing it to pop. *—Emily Conover*

FROM TOP: CHRISTIAN BENDIX; A. ROUX *ET AL/PHYSICAL REVIEW FLUIDS* 2022 used to track aquatic critters such as salmon and sharks. Scientists knew they could use environmental DNA, or eDNA, in the air to monitor land-based species — if only they could trap it. Now, researchers have done just that by using vacuums, two groups report in the Feb. 7 *Current Biology*.

At the zoo, Clare and colleagues ran the vacuum for half-hour sessions in and around animal enclosures, collecting 72 samples from 20 sites. Once back at the lab, the team analyzed material caught in the vacuum's filter.

Meanwhile, a team at the University of Copenhagen was chasing the same idea. Biologist Kristine Bohmann and colleagues sought to trap airborne eDNA at the Copenhagen Zoo using a vacuum, as well as small fans similar to the ones that cool computers.

Both teams used a zoo for its roster of animals because they were still testing the technique. Air in the wild could host eDNA from unpredictable places, but at zoos, the teams could cross-reference the captured eDNA with animals listed in exhibits. That allowed the scientists to confirm sources of the eDNA and see how far it traveled between enclosures.

Dingoes inspect the thin tube of a vacuum that ecologist Elizabeth Clare uses to trap eDNA.

Bohmann's team identified 49 species in the Copenhagen Zoo, including animals living in the sampled enclosures, such as okapis (*Okapia johnstoni*) and a Dumeril's ground boa (*Acrantophis dumerili*). The team also picked up on mammals and birds from surrounding exhibits, as well as fish used as food.

At the Hamerton Zoo, Clare's team identified 25 species, including targeted zoo residents and unexpected ones. In the dingo enclosure, the team detected DNA from meerkats (*Suricata suricatta*) that live 245 meters away.

Zoo outsiders also turned up in each team's results. Clare's team detected the European hedgehog (*Erinaceus europaeus*) while Bohmann's group picked up mice and domesticated dogs. Both teams caught whiffs of human DNA too.

Sucking eDNA from the air could be a noninvasive way to identify where endangered species have been, Bohmann says. But this technology has yet to be tested in the wild.

Just as aquatic eDNA has progressed over the last decade, so too will airborne eDNA, Clare says. "I'm really looking forward to seeing other people go out and use the technique." *— Jude Coleman*

SCIENCE STATS

Drug resistance is a prolific killer

Bacterial infections that don't respond to treatment are a major cause of death around the world.

In 2019, antimicrobial resistance caused an estimated 1.27 million deaths, researchers report January 19 in the *Lancet*. Globally, that translates to a rate of 16.4 deaths per 100,000 people. More than twice as many people died from untreatable bacterial infections that year than from malaria, the fifth leading cause of death worldwide.

The estimate is based on an analysis of hospital, surveillance and other sources of data from 204 countries and territories by an international group of researchers called the Antimicrobial Resistance Collaborators. Resistance to two classes of antibiotics, beta-lactams (which include penicillins) and fluoroquinolones, was behind more than 70 percent of resistance-caused deaths. Those drugs are the first-line option for many bacterial infections.

Among the bacteria responsible were pathogens that commonly strike in health care settings, such as *E. coli* and *Staphylococcus aureus* (*SN: 10/29/16, p. 4*). *— Aimee Cunningham*

1.27
million
The estimated number of deaths caused by antibiotic-resistant infections in 2019

Gold and silver tubes that are more than 5,000 years old were probably used to drink flavored beer from a communal vessel, as shown in this illustration, scientists say.

THE –EST

Oldest known straws siphoned beer

Eight silver and gold tubes held in a Russian museum are the oldest surviving drinking straws, researchers say. People used the straws to drink beer from a communal vessel more than 5,000 years ago, conclude archaeologist Viktor Trifonov of the Russian Academy of Sciences in St. Petersburg and colleagues. Excavations in Russia uncovered the tubes in a burial mound containing three individuals from the Maikop culture, which dates to between about 5,700 and 4,900 years ago (*SN: 6/7/30, p. 367*). Residue from the inside of one tube contains remnants of barley, cereal and pollen from a lime tree — potential ingredients of a flavored beer — the team reports in the February *Antiquity*. Further work needs to confirm that the barley had been fermented. *— Bruce Bower*

FROM TOP: E. CLARE; KELVIN WILSON

News

GENES & CELLS

Frogs regrow amputated limbs

One multidrug drug therapy spurred growth of legs

BY CAROLYN WILKE

The cells of adult frogs seem to remember how to regrow lost legs, and a new chemical kick starter helps the cells hop to it.

Scientists have been seeking ways to spur the body to regrow limbs to help people who have undergone an amputation (*SN: 7/13/13, p. 14*). Like adult humans, fully grown frogs have a limited ability to replace lost body parts. But a new treatment — a sleeve that delivers a drug cocktail — jump-starts and improves limb regeneration after amputation in frogs, researchers report in the Jan. 28 *Science Advances*.

"The cells of the frog already know how to make frog legs," having done so when the animal was a developing embryo, says Michael Levin, a developmental biologist at Tufts University in Medford, Mass. "Our goal is to figure out how to convince them to do it again."

Levin's team amputated the right back legs of 115 adult African clawed frogs (*Xenopus laevis*) at the knee. Roughly one-third of those frogs received "BioDomes," silicone sleeves that cover the wound. Another third of the frogs got BioDomes that held a silk-based gel containing five chemicals, including a growth hormone, a nerve growth promoter and an anti-inflammatory substance. The researchers removed the BioDomes after 24 hours. The remaining one-third of frogs acted as a control group and didn't receive any treatment before being placed back in their tanks.

In animals that received the drug cocktail, "around the four-month mark, we started to see a slight difference in the leg shape," says team member Nirosha Murugan, a cancer biologist now at Algoma University in Sault Ste. Marie, Canada. "With time, that bud ... started to take shape into a whole leg."

After 18 months, the frogs that received the chemicals had regrown the limbs and had nubs where toes would typically grow. These amputees kicked, stood and pushed off the walls of their tanks using their regrown legs, Levin says.

The BioDome alone promoted some regeneration: The stiffness and pressure at the wound site seemed to create conditions that spur some tissue growth, Murugan says. But frogs that received the drugs grew longer legs with thicker bones than the frogs that had only the BioDome. These frogs also had more blood vessels and nerves. And compared with the BioDome-only group, frogs that got the drug mix showed greater sensitivity to touch when their limbs were lightly prodded. Frogs in the control group grew spiky flaps — basically stumps with no function — at the wound site.

"It's actually remarkable that just a single treatment on one day can cause all this change," Murugan says.

This first attempt at using a chemical cocktail to coax limb regrowth is "a great start," says John Barker, an orthopedic researcher who recently retired from Goethe University Frankfurt and was not part of the work. With this approach, he says, "there's no end to what you could try."

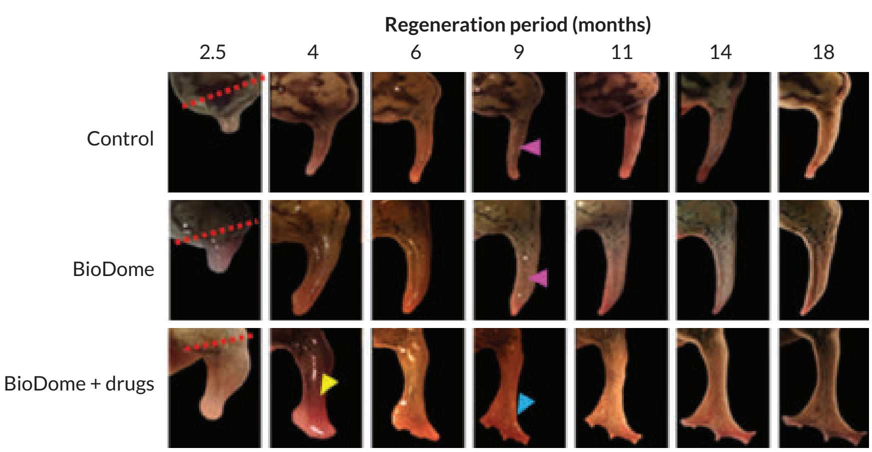
The team has moved on to similar work in mice, using the same cocktail and new ones. Levin's research also points to electricity's role in shaping the growth of body parts, so the researchers are adding compounds to the cocktail that alter the electrical state of cells (*SN: 12/31/11, p. 5*).

Scientists want to be able regrow human limbs and organs someday. As with the frog legs, human bodies know how to make hands, for example, Barker says. Children under the age of 10 or so can even regrow lost fingertips. If such treatments could be developed for health care, Barker says, "instead of treating symptoms, you could literally cure a disease." For instance, regenerated heart tissue could replace damaged tissue to improve heart function.

Limbs, however, are more complicated because several types of tissue must coordinate. And researchers lack fundamental information on how bodies form their parts.

"We don't understand how collections of cells solve problems" to decide what to build and when to stop, Levin says. "Cracking regenerative medicine is going to require us to do much better about understanding that." ■

New legs Over 18 months, frogs grew new limbs after an amputation (amputation site is marked with dashed lines, left column). Some frogs received no treatment (one shown in top row) while other frogs got either a silicone sleeve called a BioDome that covered the injury for 24 hours (middle row) or got both the BioDome and a drug cocktail for 24 hours (bottom row). Frogs in the last group grew the longest limbs with the greatest bone density. They also developed legs with a paddlelike shape (yellow arrow) and toelike buds (blue arrow), unlike the other frogs (pink arrows).



N.J. MURUGAN *ET AL*/*SCIENCE ADVANCES* 2022

BODY & BRAIN

Clues to COVID-19 brain fog emerge

Lingering neurological effects blamed on faulty immune response

BY LAURA SANDERS

A tussle with COVID-19 can leave people's brains fuzzy. SARS-CoV-2, the virus behind COVID-19, doesn't usually travel into the brain directly. But the immune system's response to even a mild case can affect the brain, new preliminary studies suggest. These reverberating effects may lead to fatigue, trouble thinking, difficulty remembering and even pain months after the infection is gone.

It's not a new idea. Immune systems gone awry have been implicated in cognitive problems that come with other viral infections such as HIV and influenza; with disorders such as myalgic encephalomyelitis/chronic fatigue syndrome, or ME/CFS; and even with chemotherapy.

What's different with COVID-19 is the scope of the problem. Millions of people have been infected during this pandemic with a new viral foe, says neurologist Avindra Nath of the National Institutes of Health in Bethesda, Md. "We are now faced with a public health crisis," he says.

To figure out ways to treat people for lingering symptoms, scientists are racing to determine what's causing them (*SN: 6/5/21, p. 10*). Having studied the effects of HIV on the brain, cognitive neurologist Joanna Hellmuth of the University of California, San Francisco had a head start. She quickly noted similarities in the neurological symptoms of HIV and COVID-19. The infections paint "the same exact clinical picture," she says.

HIV-related cognitive problems have been linked to immune activation. "Maybe the same thing is happening in COVID," Hellmuth says.

She and colleagues looked for differences in the fluid that surrounds the brain and spinal cord in 13 people who had lingering cognitive symptoms from COVID-19 and four people who had no cognitive symptoms. The four people without cognitive symptoms had normal cerebrospinal fluid. But 10 of the 13 people who had lasting symptoms had abnormalities in their fluid, some of which point to immune system reactions.

So far, the analyses can't pinpoint the precise changes that may be important. Possible suspects are antibodies that can mistakenly attack key proteins in the brain, the researchers say.

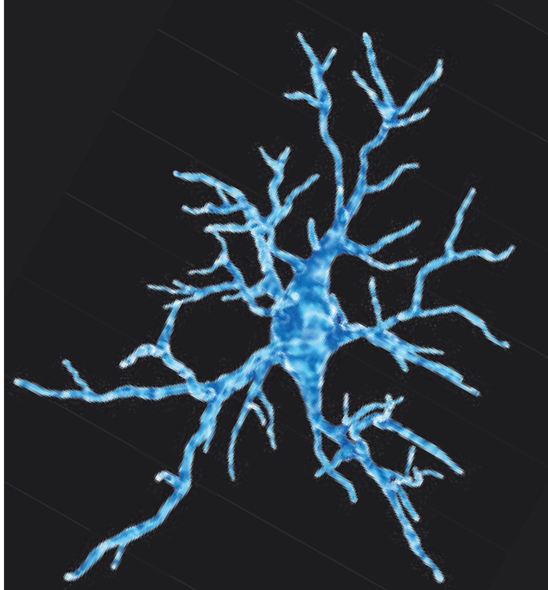
The results, published January 19 in *Annals of Clinical and Translational Neurology*, raise many questions but show that there's a true difference in the cerebrospinal fluid, Hellmuth says. "This is a very small study, but the data suggest that there's a real biological basis in these COVID-related cognitive changes," she says. "These are not just people who are stressed out."

More hints to what's causing the brain troubles come from studies of mice and people. Those results, which have not yet been peer-reviewed, were posted January 10 at bioRxiv.org. By analyzing human tissue and mice infected with SARS-CoV-2, researchers showed that immune cells called microglia are overactive in the brain. When microglia shift into high gear, they can damage tissue.

Toxic chemotherapy can cause the same kind of microglia overactivity, says study coauthor Michelle Monje, a neurologist at Stanford University. "When the reports started coming out about the frequency of persistent cognitive symptoms associated with long COVID, I noted striking similarities between 'chemo fog' and 'COVID fog,' and decided we needed to study this."

Microglia were more active in the brains of mice infected with SARS-CoV-2 than in uninfected mice. Researchers saw a similar pattern in postmortem brain tissue from nine people who died with COVID-19. It's not clear how well these samples represent the majority of people who have experienced mild COVID-19 and are living with the aftereffects.

Infected mice also had higher levels of immune proteins in their cerebrospinal fluid. One protein in particular, called CCL11, has been tied to cognitive trouble in people that comes with age and to certain psychiatric conditions. People with lingering neurological symptoms of COVID-19 also had more CCL11 in their blood plasma than people who didn't have those symptoms, the researchers found.



Immune cells in the brain called microglia (one illustrated) seem to be involved in cognitive troubles that can appear after a viral infection.

All of these results come with caveats, says Svetlana Blitshteyn, a neurologist at the University at Buffalo Jacobs School of Medicine and Biomedical Sciences in New York. "They're small studies, and obviously they are not definitive," she says, "but the preliminary evidence speaks for itself." It's becoming clearer now that the brain fog that comes after an infection may be "rooted in neuroinflammation," she says.

Identifying the cause of the neurological problems may reveal a treatment. Laboratory studies have pointed to potential therapies that can interrupt this immune system overreaction, particularly for brain inflammation caused by chemo, Monje says. She and colleagues are studying whether those same treatments might help with COVID-19.

Tragic as the pandemic is, it may lead to something good, says Nath, who is setting up a small clinical trial to study possible long COVID treatments. Syndromes such as ME/CFS that researchers struggle to understand "might benefit from what we learn here from long COVID," he says. "We might be able to develop treatments." ■

JUAN GAERTNER/SCIENCE PHOTO LIBRARY/GETTY IMAGES

MATH & TECHNOLOGY

AI picks people out of anonymous data

Weekly mobile phone interactions form unique signatures

BY NIKK OGASA

How you interact with a crowd may help you stick out from it, at least to artificial intelligence.

When fed details about an individual's mobile phone interactions, plus contacts' interactions, AI picked the target out of more than 40,000 anonymous mobile phone service subscribers more than half the time. The finding, reported January 25 in *Nature Communications*, suggests humans socialize in ways that can be used to ID people in anonymized datasets.

It's no surprise that people tend to remain within established social circles and that these interactions form a stable pattern, says Jaideep Srivastava, a computer scientist at the University of Minnesota in Minneapolis. "But the fact that you can use that pattern to identify the individual, that part is surprising."

Under some government regulations, companies that collect information about people's daily interactions can share or sell this data without user consent. The catch is that the data must be anonymized. The new study shows that this standard can't be met by simply giving users pseudonyms, says Yves-Alexandre de Montjoye, a computational privacy researcher at Imperial College London.

De Montjoye and colleagues taught an artificial neural network — an AI that attempts to mimic the neural circuitry of a brain — to recognize patterns in people's weekly calls and texts. The team trained the AI with data from an unidentified mobile phone service that detailed 43,606 subscribers' interactions over 14 weeks. The data included each interaction's date, time, duration, type (call or text), the pseudonyms of the involved parties and who initiated the communication.

Before training, each user's interaction data had been organized into webs consisting of nodes representing the user and their contacts. Connecting each pair of nodes were strings that contained all available information about the calls and texts between the two individuals. Once trained to recognize similarly structured webs, the AI was shown the web of a known person and set loose to search a fresh week of anonymized data for the web that bore the closest resemblance.

The AI tied 14.7 percent of individuals to their anonymized selves when shown webs that had info about a target's phone interactions that occurred one week after the latest records in the anonymized dataset. But the AI identified 52.4 percent of people when given info about both the target's interactions and those of contacts. When armed with such data collected 20 weeks after the anonymized dataset, the AI still ID'd users 24.3 percent of the time, suggesting social behavior remains identifiable over long periods. ■

ATOM & COSMOS

Computers hunt for meteorites

The search for meteorites has some new leads. A machine-learning algorithm has identified over 600 potential hot spots in Antarctica that may be home to a bounty of the space rocks, researchers report in the Jan. 28 *Science Advances*.

Antarctica is the best place to find meteorites, says glaciologist Veronica Tollenaar of the Université libre de Bruxelles in Belgium. Not only are the dark specks starkly visible against the white ice, but quirks of the ice sheet's flow can also concentrate meteorites in "stranding zones" (below, researchers find a meteorite during a 2019–2020 expedition).

Stranding zones can form under the right combination of geographical and climatological conditions. When a creeping ice sheet gets bent upward by a hidden mountain or rise, meteorites embedded in the ice are carried toward the surface.

So far, stranding zones have been found by luck. Satellites help, but poring through their images is time-consuming, and field reconnaissance is costly. So Tollenaar and colleagues turned to computers to find these zones more quickly. The team trained a machine-learning algorithm with data on the ice's velocity and thickness, surface temperatures, the shape of the bedrock and known stranding zones. The algorithm identified 613 probable meteorite hot spots. The team plans to test this map in Antarctica next year. — *Carolyn Gramling*

FIELD TEAM OF THE BELARE 2019–2020 METEORITE RECOVERY EXPEDITION ON THE NANSEN ICE FIELD

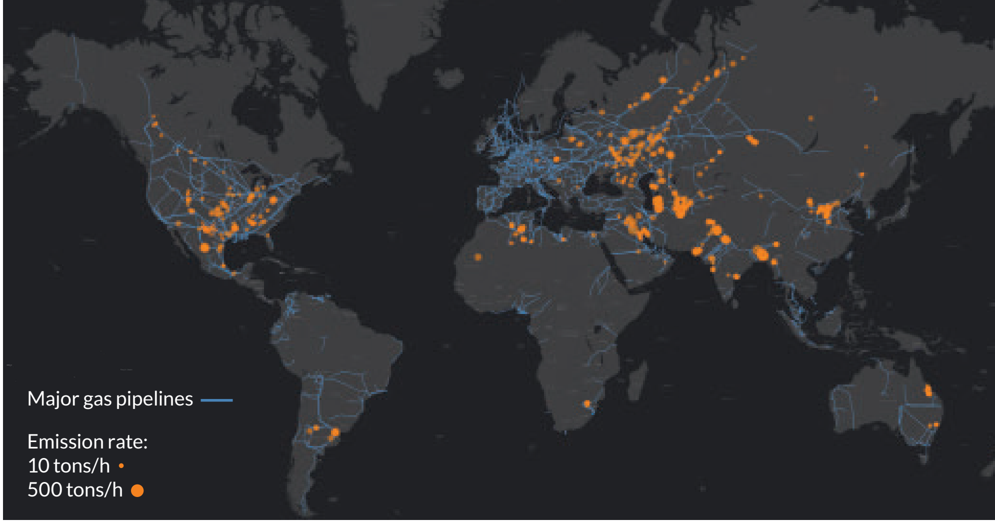
Explore a map of potential meteorite hot spots in Antarctica at **bit.ly/SN_MeteoriteMap**

EARTH & ENVIRONMENT

Major methane emitters ID'd

Biggest sources are in a few oil- and gas-producing nations

BY CAROLYN GRAMLING



Hot spots Satellite images revealed "ultra-emitters" of methane (orange circles) from oil and gas production in 2019 and 2020 (some regions are dark because satellite data were unavailable). The biggest emitters released as much as 500 metric tons of the gas per hour into the atmosphere. Some hot spots follow gas pipelines (blue), as seen in Russia and elsewhere.

A small number of "ultra-emitters" of methane from oil and gas production contribute as much as 12 percent of methane emissions from oil and gas production every year — and now scientists know where many of these leaks are.

Analyses of satellite images from 2019 and 2020 reveal that a majority of the 1,800 biggest methane sources in the study are in six major oil- and gas-producing countries: Turkmenistan led the pack, followed by Russia, the United States, Iran, Kazakhstan and Algeria.

Plugging those leaks would not only be a boon to the planet, but also could save those countries billions of dollars, climate scientist Thomas Lauvaux of the University of Paris-Saclay and colleagues report in the Feb. 4 *Science*. Methane is the primary component of natural gas.

Ultra-emitters are sources that spurt at least 25 metric tons of methane per hour into the atmosphere. Such occasional massive bursts make up a sizable fraction of the methane from oil and gas production shunted into Earth's atmosphere annually.

Cleaning up such leaks would be a big first step in reducing overall emissions, says geochemist Euan Nisbet of Royal Holloway, University of London in Egham, who was not involved in the study. "If you see somebody badly injured in a road accident, you bandage up the bits that are bleeding hardest."

Methane has about 80 times the atmosphere-warming potential of carbon dioxide, though it tends to have a much shorter lifetime in the atmosphere: 10 to 20 years or so, compared with hundreds of years for carbon dioxide. Methane seeps into the atmosphere from both natural and human-made sources.

In oil and gas production, massive methane bursts might be the result of accidents or leaks, Lauvaux says. But these emissions can also be the result of routine maintenance practices, the team found. Rather than shut down for days to clear gas from pipelines, for example, managers might open valves on both ends of the line, releasing and burning off the gas quickly. That sort of practice stood out starkly in satellite images as "two giant plumes" along a pipeline track, Lauvaux says.

Stopping such practices and repairing leaky facilities are relatively easy, which is why such changes may be the low-hanging fruit when it comes to addressing greenhouse gas emissions. But identifying the particular sources of those huge methane emissions has been the challenge. Measurements from airplanes can help pinpoint some large sources, such as landfills, dairy farms and oil and gas producers, but such flights are limited by being both regional and of short duration.

Satellites such as the European Space Agency's TROPOspheric Monitoring Instrument, or TROPOMI, offer a much bigger window in both space and time. Scientists have previously used TROPOMI to estimate the overall leakiness of oil and gas production in the massive Permian Basin in Texas and New Mexico, finding that the region sends twice as much methane to the atmosphere as previously thought.

In the new study, the team didn't include sources in the Permian Basin among the ultra-emitters; the large emissions from that region are the result of numerous tightly clustered but smaller individual emissions sources. Because TROPOMI doesn't peer well through clouds, other regions around the globe, such as many parts of Canada and the equatorial tropics, also weren't included.

But that doesn't mean those regions are off the hook, Lauvaux says. "There's just no data available." On the heels of this broad-brush view from TROPOMI, Lauvaux and other scientists are now working to plug those data gaps using other satellites with better resolution and the ability to penetrate clouds.

Stopping all of these big leaks, which amount to an estimated 8 to 12 percent of total annual methane emissions from oil and gas production, would be about as beneficial to the planet as cutting all greenhouse gas emissions from Australia since 2005, or removing 20 million vehicles from the roads for a year.

Global data can also be helpful to countries in meeting their goals under the Global Methane Pledge launched in November at the United Nations' annual climate summit, says atmospheric scientist Daniel Jacob of Harvard University, who was not involved in the study.

Signatories to the pledge agreed to reduce global emissions of the gas by at least 30 percent relative to 2020 levels by 2030. The new research, Jacob says, can help achieve that target: It "encourages action rather than despair." ■

The James Webb Space Telescope launched in a folded position and then gradually unfurled in space. This artist's illustration depicts the fully deployed spacecraft as it will look when it's ready to start observing the universe.

ATOM & COSMOS

James Webb telescope gets in position

But there's still work to do before observations can begin

BY LISA GROSSMAN

The James Webb Space Telescope has finally arrived at its new home. After a Christmas launch and a month of unfolding and assembling itself in space, the observatory reached its final destination, a spot known as L2, on January 24.

Guiding the telescope to L2 was "an incredible accomplishment," Webb's commissioning manager Keith Parrish said in a January 24 news conference. It will be several months before the telescope is ready to peep at the earliest light in the universe or spy on exoplanet atmospheres (*SN: 10/9/21 & 10/23/21, p. 26*).

"That doesn't mean there's anything wrong," says Scott Friedman, an astronomer at the Space Telescope Science Institute in Baltimore who is managing the next phase of Webb's journey. "Everything could go perfectly," he says, "and it would still take six months" from launch for the telescope's science instruments to be ready for action. Here's what's next on the Webb team's to-do list.

Staying cool at L2

L2, technically known as the second Earth-sun Lagrange point, is a spot about 1.5 million kilometers from Earth in the direction of Mars, where the sun and Earth's gravity balance out the centripetal force that keeps a smaller object on a curved path. That lets objects at Lagrange points stay put without much effort. Pairs of massive objects in space have five such Lagrange points.

The telescope, also known as JWST, isn't just sitting tight, though. It's orbiting L2, even as L2 orbits the sun. That's because L2 is not precisely stable, Friedman says. It's like trying to stay balanced directly on top of a basketball. If you nudged an object sitting exactly at that point, it would be easy to make it wander off. Circling L2 in a 180-day "halo orbit" as L2 circles the sun is much more stable — it's harder to fall off the basketball when in constant motion. But it still takes some effort to stay there.

"JWST and other astronomical satellites, which are said to be at L2 but are really in halo orbits, need propulsion to maintain their positions," Friedman says. "For JWST, we will execute what we call station-keeping maneuvers every 21 days. We fire our thrusters to correct our position, thus maintaining our halo orbit."

The amount of fuel needed to maintain Webb's home in space will set the lifetime of the mission. Once the fuel runs out, the mission is over. Luckily, the spacecraft had a near-perfect launch and didn't use much fuel in transit to L2. As a result, it might last more than 10 years, longer than the original five- to 10-year estimate. The Webb team will put an exact number on that lifetime in the next few months.

From its vantage point at L2, Webb will observe space in infrared light. Humans experience infrared radiation as heat. "We're essentially looking at the universe in heat vision," says Webb project scientist Erin Smith, an astrophysicist at NASA's Goddard Space Flight Center in Greenbelt, Md.

The parts of the telescope that observe the sky have to be kept at about –233° Celsius, nearly matching the cold of space. That way, Webb will avoid emitting more heat than the distant sources in the universe that the telescope is observing, preventing it from obscuring those sources from view.

Most of Webb has been cooling down since the telescope's sun shield finished unfurling on January 4. That five-layer shield blocks and reflects heat and light, letting the telescope's mirrors and scientific instruments cool off from their temperature at launch. One of the instruments, the Mid-Infrared Instrument, MIRI, has extra coolant to bring it down to –266° C to enable it to see even dimmer and cooler objects than the rest of the telescope. For MIRI, "space isn't cold enough," Smith says.

Calibration time

Webb finished unfolding its roughly 6.5-meter-wide golden mirror on January 8, turning the spacecraft into a true telescope. That mirror, which collects and focuses light from the distant universe, is made up of 18 hexagonal segments. Each segment has to line up with a precision of about 10 or 20 nanometers so that the whole apparatus mimics a single mirror.

Webb will initially train its mirror on a single bright star called HD 84406 in the constellation Ursa Major. The star is "just near the bowl of the Big Dipper. You can't quite see it with your naked eye, but I'm told you can see it with binoculars," Lee Feinberg, Webb's optical telescope element manager at Goddard, said at the January 24 news conference.

Starting on January 12, 126 tiny motors on the back of the 18 segments

ADRIANA MANRIQUE GUTIERREZ/CIL/NASA GSFC started moving and reshaping them to make sure they all match up. Another six motors went to work on the secondary mirror, which is supported on a boom in front of the primary mirror.

This alignment process will take until at least April to finish. In part, that's because the movements are happening while the mirror is cooling. The changing temperature alters the shape of the mirrors, so they can't be put in the final alignment until after the telescope's suite of scientific instruments are fully cooled.

Once the initial alignment is done, light from distant space will first bounce off the primary mirror, then the secondary and tertiary mirrors and finally reach the instruments that will analyze the cosmic signals. The alignment of the mirror segments will be "a continuous process, just to make sure that they're always perfectly aligned," Scarlin Hernandez, a flight systems engineer at the Space Telescope Science Institute, said at a NASA Science Live event on January 24. The process will continue for the telescope's lifetime.

While the mirrors are aligning, Webb's science instruments will turn on and take the first pictures, says astronomer Klaus Pontoppidan, also of the Space Telescope Science Institute. "But they're not going to be pretty," Pontoppidan says. The first images will be out-of-focus views of HD 84406, a mere pinpoint of light.

After a few final adjustments, the telescope will be "performing as we want it to," Friedman says. "Then [the instruments] can start doing their work."

First science targets

Once all of the calibrations are complete, the Webb science team has a top secret plan for the first full color images to be released.

"These are images that are meant to demonstrate to the world that the observatory is working and ready for science," Pontoppidan says. "Exactly what will be in that package, that's a secret."

The secrecy stems partly from the fact that there's still some uncertainty in what the telescope will be able to look at when the time comes. If setting up the instruments takes longer than expected, Webb will be in a different part of its orbit and certain parts of the sky will be out of view for a while.

The team doesn't want to promise something specific and then be wrong, Pontoppidan says. But also, "it's meant to be a surprise," he says. "We don't want to spoil that surprise."

Webb's first science projects, however, are not under wraps. In the first five months of observations, Webb will begin a series of projects that will use every feature of every instrument to look at a broad range of targets, including everything from Jupiter to distant galaxies and from star formation to black holes and exoplanets.

Still, the scientists are eager for the pretty pictures. "I'm just very excited to get to see those first images, just because they will be spectacular," Smith says. "As much as I love the science, it's also fun to ooh and ah." ■

LIFE & EVOLUTION

Orcas are caught killing a blue whale

Even the world's largest animal is vulnerable to the predators

BY ANNA GIBBS

Killer whales are skilled assassins, hunting everything from herring to great white sharks. For the first time, scientists have witnessed a pod of killer whales bring down the world's largest animal: an adult blue whale.

"This is the biggest predation event on the planet," says Robert Pitman, a cetacean ecologist at Oregon State University's Marine Mammal Institute in Newport. "We haven't seen things like this since dinosaurs were here, and probably not even then."

It's been debated for decades whether killer whales, or orcas (*Orcinus orca*), are capable of preying on full-grown large whales. Past accounts have described attacks on blue whales, but scientists had not observed orcas completing the job until March 21, 2019.

It was an "ominous, bad weather day" off Western Australia's coast, says biologist John Totterdell of the Cetacean Research Centre in Esperance, Australia. Totterdell and colleagues, who recount their whale tale January 21 in *Marine Mammal Science*, were an hour from their orca-observing site when they slowed to remove debris from the water. In the rain, they almost missed the splashing — and the telltale dorsal fins of orcas. "Within seconds, we realized the killer whales were attacking something big," Totterdell says. Then, he says, the researchers realized, "Oh, my it's a blue whale."

The team had stumbled upon about a dozen orcas assailing an adult blue whale (*Balaenoptera musculus*), estimated at between 18 and 22 meters long. Tooth marks crisscrossed its flank, its dorsal fin was mostly bitten off, and the flesh of its snout was ripped away along the top lip, exposing bone. Three orcas slammed into the whale's side like a battering ram, and then another orca fed on the tongue.

The coordinated attack was consistent

An orca (upper left) maneuvers itself into a blue whale's open jaw and feasts on the tongue as two other orcas attack the blue whale's flank. The attack marks the first time scientists have seen orcas kill an adult blue whale.

LIFE & EVOLUTION

Some seals grow big or die trying

Male elephant seals take dining risks to win at mating

BY JAKE BUEHLER

If you're a male northern elephant seal, your car-sized bulk is crucial to your genetic legacy, since only a fraction of the very largest males have access to mates. Male elephant seals are so driven to eat and grow, scientists report, that they take on great personal risk and are much more likely than females to die while foraging.

That finding, described in the January *Royal Society Open Science*, reveals a dramatic divide in how and where males and females feed and how their mating strategies play a role in choosing those spots.

Male and female northern elephant seals (*Mirounga angustirostris*) look quite different from each other. Females can weigh hundreds of kilograms, but males are truly humongous, growing three to seven times as large as females.

Ecophysiologist Sarah Kienle of Baylor University in Waco, Texas, wanted to know how that size difference impacts feeding behavior. At Año Nuevo State Park in California, Kienle and colleagues attached depth loggers, as well as satellite and radio transmitters, to more than 200 elephant seals from 2006 to 2015. The team measured the seals' fat stores and used this information, along with location and depth data, to see how and where the animals were foraging and how well their efforts converted into blubber.

The two sexes hunt for food in very different places, the team found. Females spend most of their foraging time in the open ocean, diving deep for prey, while males stick to shallower, nearshore habitats, feeding continually on prey on the continental shelf. This helped males gain up to six times as much mass, on average, as females and gobble up calories more than four times as fast.

But there's a cost to that shallow-water smorgasbord. Males are six times as likely as females to die while foraging — a pattern that was apparent even during data collection. "I could have told you that from just putting out instruments on males, that it was a 50 percent chance whether or not I was going to get that instrument back," Kienle says.

Kienle suspects predation may explain the males' higher death rate. Orcas and great white sharks patrol throughout the seals' range in the North Pacific.

The waters of the continental shelf support more plankton, fish and other sea life than deeper waters, which in turn support hungry seals and sea lions. It's a relationship noticed by even bigger predators, says marine mammalogist Andrew Trites of the University of British Columbia in Vancouver, who was not involved with

CETREC WA, PROJECT ORCA

Watch orcas attack a blue whale at **bit.ly/SN_WhaleHunt** with methods observed during other orca takedowns of whales. Orcas will target the fins, tail and jaw, possibly to slow the whale. They will also push the whale's head underwater to prevent it surfacing for air, while others below push it up so it can't dive. "These are practiced large-whale hunters," says Pitman, a coauthor of the study. "They know how to do this."

The new paper describes two other successful attacks: on a blue whale calf in 2019 and a juvenile in 2021. All three events happened in an area where migrating blue whales pass by a population of over 150 orcas, possibly the world's largest aggregation of orcas.

It's uncertain if large whales played a significant role in orca diets before industrial whaling removed nearly 3 million whales from the oceans, including up to 90 percent of blue whales — but it's definitely possible, says Pete Gill, a whale ecologist at Blue Whale Study in Narrawong, Australia. Orcas and blue whales have been interacting for tens of thousands of years, he says. "I would imagine that orcas and [blue whales] have had this dynamic for quite a long time." ■

the research. "That's where the dinner bell is ringing all day long," he says.

The risk may be more than worth it to male elephant seals. Male and females both reach sexual maturity around age 3 to 4, Kienle says. Females can have pups every year or two for much of their roughly 20-year life span. But bulls live half as long on average and don't tend to reach peak poundage until later in life. If colossal enough to intimidate or fight off other bulls, males can then monopolize mating access to a group of females.

This reproductive divergence appears to encourage different feeding behaviors. Females are content to avoid the shallow buffet and the jaws of nearshore terrors, aiming instead to eat enough to repeatedly rear offspring over time. Males, meanwhile, search out the faster growth rewards but do so at a bigger risk of death.

"If you're a male, then you're going to roll the dice," Trites says. "And it's all or nothing because the payoff is huge." ■

LIFE & EVOLUTION

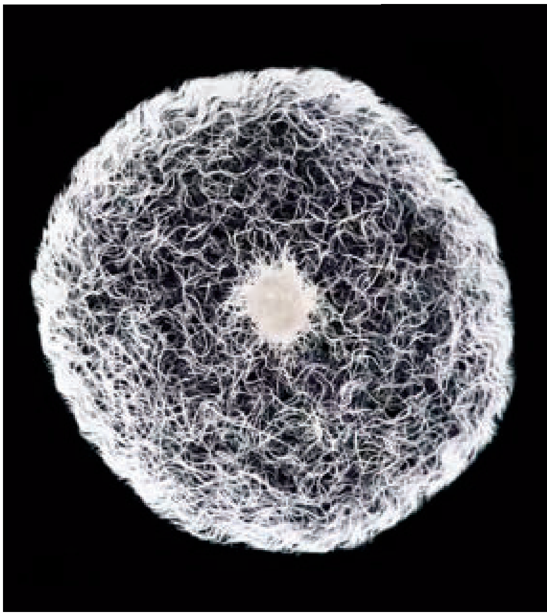
Vinegar eels can synchronize swim

Tiny worms exhibit coordination that's rare among animals

BY NIKK OGASA

Trapped within a bead of water, thousands of tiny worms wiggle in hypnotic synchrony as they stream around the globule's rim. At the center of this undulating gyre some of the creatures congregate into a writhing mass, like the pupil of a demonic eye.

These squiggling creatures belong to a species of nematode called *Turbatrix aceti*, commonly known as vinegar eels. Individual vinegar eels are often found swimming freely in jars of raw vinegar or in fish tanks. But when troupes of them assemble, vinegar eels perform a unique juggling act of behaviors: They can wiggle in sync as they move together in swarms, researchers report January 10 in *Soft Matter*.



As microscopic vinegar eels mob together, they synchronize their wiggling, forming collective waves that cascade through the swarm.

This captivating ability is rare in nature. Birds and fish can move collectively, and some bacteria can coordinate the waving of whiplike appendages (*SN: 8/8/15, p. 12*). Vinegar eels, however, are capable of more. "This is a combination of two different kinds of synchronization," says Anton Peshkov, a physicist at the University of Rochester in New York. "Motion and oscillation."

Peshkov and colleagues first heard rumors of vinegar eels' weird motions while studying the group movements of brine shrimp, another common aquarium dweller. Intrigued, the researchers packed thousands of *T. aceti* worms into droplets to observe under a microscope.

Within a droplet, nematodes first roamed randomly, but over the course of an hour, some began swarming at the edges, where they circled the rim. Smaller nematodes then began clustering in the middle. After a while, individual nematodes started oscillating in sync, and the swarm itself began undulating, like spectators doing the wave at a sports game.

These collective undulations stirred up flows that prevented the water drop's edge from contracting as it evaporated. But as evaporation progressed, the edge instead gradually tilted inward, weakening the swarm's outward push, until the walls finally began to close in. At this tipping point, the researchers measured the drop's dimensions, which let them estimate that each vinegar eel generated about a micronewton of force. Each eel could move objects hundreds of times its own weight, Peshkov says.

It remains unclear why vinegar eels exhibit this bizarre behavior. "Nematodes are too small to observe in their natural environment," says Serena Ding, a biologist at the Max Planck Institute of Animal Behavior in Konstanz, Germany, who was not involved in the study. Figuring out the natural cause for this behavior is difficult using lab observations, since captive creatures act differently, she says.

Peshkov speculates vinegar eels might swarm tightly to minimize their bodies' exposure to corrosive free radicals in water, or maybe they generate flows to move nutrients.

Regardless, Ding says, "this is cool." ■

Watch vinegar eels swim in sync at **bit.ly/SN_VinegarEels**

LIFE & EVOLUTION

City wildlife catch human microbes

Animals and people in urban areas have similar gut bacteria

BY RICHARD KEMENY

Animals moving into the big city could be getting more than they bargained for. Gut microbes from humans in cities may be spilling over into urban wildlife, potentially putting the animals' health at risk.

Fecal samples from humans and wild animals in various parts of the world show that urban critters harbor microbial communities that have more in common with those in urban humans than in rural people and wildlife, researchers report in a study posted online January 6 at bioRxiv.org and that has yet to be peer-reviewed. While previous research has found that captive animals can acquire human microbes — some linked with gastrointestinal disorders — this is the first time a humanizing effect on wildlife has been found in cities.

Anoles, like this one in Orlando, Fla., could be picking up microbes from humans in cities, new research suggests. Just how the microbes end up colonizing these reptiles remains unclear.

It's possible that wild animals could face negative health effects when they gain gut microbes that their bodies haven't coevolved with, says evolutionary biologist Andrew Moeller of Cornell University.

Moeller and colleagues analyzed 492 fecal samples taken from humans, coyotes and lizards in urban and rural locations as varied as Edmonton, Canada, and Amazonian villages in Venezuela. The team used genomic analysis to find the abundance of microbial DNA in each sample and then compared the microbial profiles of urban and rural hosts.

Urban lizards and coyotes had gut microbiome communities more similar to urban humans than to rural humans or wildlife, the researchers found. Notably, they discovered 18 lineages of bacteria in urban wildlife that did not appear in their rural counterparts.

The parallel changes in microbial communities seen among diverse animals from different urban locations form a convincing pattern, says Taichi Suzuki, an evolutionary biologist at the Max Planck Institute for Developmental Biology in Tübingen, Germany, who was not involved in the study. But the mechanism driving this pattern needs further investigation, he says.

The animals probably picked up microbes that humans shed while going about daily life, Moeller speculates. Some of the microbial shifts could also be a product of wildlife eating humans' high-fat, high-protein leftovers. ■

HUMANS & SOCIETY

Ancient 'paleo' diets included grains

A taste for wild cereals sowed farming's spread in Europe

BY BRUCE BOWER

People living along southeastern Europe's Danube River around 11,500 years ago never planted a crop but still laid the foundation for the rise of farming in the region some 3,000 years later.

Hunter-gatherers in this part of Europe gathered and ate wild cereal grains for several millennia before migrants from southwest Asia introduced the cultivation of domesticated cereals and other plants, say archaeologist Emanuela Cristiani of Sapienza University of Rome and colleagues. A taste for wild cereals among hunter-gatherers of the central Balkan Peninsula, near Turkey, smoothed the way for farming to take root in Europe, the team concludes January 21 in *eLife*.

Studies of human bones from Balkan sites indicate that hunter-gatherers ate animals. But plant remains have not preserved well at those sites, leaving uncertain any role for grains on the menu. Now it's evident that Balkan hunter-gatherers "balanced their diet with plant foods and did so for millennia before the arrival of agriculture," Cristiani says.

The new findings align with earlier evidence that hunter-gatherers in southwest Asia gradually domesticated wild plant species from around 11,700 to 9,800 years ago, rather than rapidly adopting a farming lifestyle (*SN: 8/24/13, p. 13*). In the Balkans, hunter-gatherers consumed wild cereals unrelated to domesticated strains later brought from southwest Asia, the scientists say.

The team looked for microscopic signs of plant-eating on the teeth of 60 people excavated from five sites in Serbia and Romania. The sites date to thousands of years before the introduction of farming and to hundreds of years after.

Food particles from crusty deposits on the teeth contained starch granules and cell structures typical of regional wild cereal species. Starch granules from the same wild cereals were found on the grinding surfaces of 17 stone tools, dating to as early as around 8,600 years ago, at one Balkan site. Hunter-gatherers at that location may have ground wild cereals into coarse flour, the team says.

The findings provide direct evidence that hunter-gatherers in the region added wild plants to their diets before anyone cultivated crops, says archaeobotanist Elena Marinova of the State Office for Cultural Heritage Baden-Württemberg in Germany. For those ancient people, "the 'paleolithic' diet included grains, not only meat and berries," Marinova says. ■

ATOM & COSMOS

Earth 'Trojan asteroid' has company

A recently found space rock is schlepping along with Earth around the sun. This "Trojan asteroid" is only the second one discovered that belongs to our planet.

First spotted in December 2020, the 1.2-kilometer-wide asteroid dubbed 2020 XL5 hangs out in a stable spot in space known as L4, astronomers report February 1 in *Nature Communications*. The first known Earth Trojan, called 2010 TK7, also resides there, orbiting tens to hundreds of millions of kilometers from Earth and leading our planet around the sun.

In 2021, measurements of 2020 XL5's brightness let Toni Santana-Ros, an astronomer at the University of Barcelona, and colleagues estimate the asteroid's size. The researchers also scoured archival data and found the object in images dating back to 2012. That decade's worth of observations let the team calculate the rock's orbit thousands of years into the future, confirming the asteroid's nature. It will hang around at L4 for at least 4,000 years, the team predicts. Meanwhile, 2010 TK7 will stick around for some 10,000 years.

The newfound Trojan asteroid hints that 2010 TK7 isn't a rarity or loner and might be part of a family or population, Santana-Ros says. *— Liz Kruesi*

A newfound "Trojan asteroid" (left in this illustration) will probably lead Earth around the sun for at least 4,000 years.

CTIO, NOIRLAB/NSF AND AURA, J. DA SILVA (USING SPACEENGINE)

EARTH & ENVIRONMENT

Extreme ocean heat waves of the past are now the new normal

Yesterday's scorching ocean extremes are today's new normal. In 2019, 57 percent of the ocean surface experienced toasty temperatures rarely seen a century ago, researchers report February 1 in *PLOS Climate*.

Marine ecologists Kisei Tanaka of the National Oceanic and Atmospheric Administration in Honolulu and Kyle Van Houtan of the Loggerhead Marinelife Center in Juno Beach, Fla., analyzed monthly sea-surface temperatures from 1870 through 2019, mapping where and when extreme heat events occurred decade to decade. Looking at monthly extremes revealed new benchmarks in how the ocean is changing.

More and more patches of water hit extreme temperatures over time, the team found. Then, in 2014, the entire ocean hit a tipping point. That year, at least half of the ocean's surface waters saw temperatures higher than the most extreme events from 1870 to 1919. Marine heat waves — defined as at least five days of unusually high temperatures for a patch of ocean — wreak havoc on ecosystems, leading to coral bleaching, dying kelp forests and migration of wildlife in search of cooler waters (*SN: 9/12/20, p. 13*).

In May 2021, NOAA announced that it was updating its climate normals, used to put daily weather events in historical context, from 1981–2010 averages to the higher 1991–2020 averages (*SN: 6/19/21, p. 32*). This study emphasizes that ocean heat extremes are now the norm, Van Houtan says. "Extreme heat became common in our ocean in 2014. It's a documented historical fact, not a future possibility." *— Carolyn Gramling*

GENES & CELLS

Genetic engineering has kept two people cancer-free for a decade

In 2010, two people with blood cancer went into remission after receiving an experimental therapy in which their own genetically engineered immune cells tracked down and killed cancerous cells. Ten years later, the cancer-fighting cells — called CAR-T cells — were still around, a sign the treatment can be long-lasting, scientists report February 2 in *Nature*.

"We can now conclude that CAR-T cells can actually cure patients with leukemia," cancer immunologist Carl June of the University of Pennsylvania said at a February 1 news briefing. Both patients had chronic lymphocytic leukemia and responded well to initial treatment. But it was unclear how long the modified cells would stick around, preventing the cancer's return.

While the therapy has performed "beyond our wildest expectations," added oncologist David Porter, also of the University of Pennsylvania, the biggest disappointment is that it doesn't work for everyone (*SN: 2/15/20, p. 12*). But scientists are trying to figure out how to make it work for more people, he said.
— Erin Garcia de Jesús

LIFE & EVOLUTION

An Arctic hare's journey across northern Canada breaks records

Arctic hares can go the distance. A member of *Lepus arcticus* in northern Canada has traveled farther than anyone knew possible. BBYY, as the adult female is known, made a dash of at least 388 kilometers in 49 days — the longest distance ever recorded among hares, rabbits or their relatives — scientists report December 22 in *Ecology*.

Hares and their kin typically spend their lives within a familiar territory. But 25 Arctic hares tracked by researchers in Nunavut, Canada, thumped that trend. Most traveled anywhere from 113 to 310 kilometers. None surpassed BBYY, who died of unknown causes about a month after reaching her destination.

For a hare to endure such a journey, it must balance the need to forage without becoming food for foxes and wolves, says Dennis Murray, a terrestrial ecologist at Trent University in Peterborough, Canada, who wasn't involved in the work. That makes BBYY's excursion even more impressive, he says. *— Ariana Remmel*

THE FUTURE OF COMPUTING

How far can we push this life-changing technology?

By Matthew Hutson

This article was written, edited and designed on laptop computers. Such foldable, transportable devices would have astounded computer scientists just a few decades ago, and seemed like sheer magic before that. The machines contain billions of tiny computing elements, running millions of lines of software instructions, collectively written by countless people across the globe. You click or tap or type or speak, and the result seamlessly appears on the screen.

Computers were once so large they filled rooms. Now they're everywhere and invisible, embedded in watches, car engines, cameras, televisions and toys. They manage electrical grids, analyze scientific data and predict the weather. The modern world would be impossible without them.

Scientists aim to make computers faster and programs more intelligent, while deploying technology in an ethical manner. Their efforts build on more than a century of innovation.

In 1833, English mathematician Charles Babbage conceived a programmable machine that presaged today's computing architecture, featuring a "store" for holding numbers, a "mill" for operating on them, an instruction reader and a printer. This Analytical Engine also had logical functions like branching (if X, then Y). Babbage constructed only a piece of the machine, but based on its description, his acquaintance Ada Lovelace saw that the numbers it might manipulate could represent anything, even music. "A new, a vast, and a powerful language is developed for the future use of analysis," she wrote. Lovelace became an expert in the proposed machine's operation and is often called the first programmer.

In 1936, English mathematician Alan Turing introduced the idea of a computer that could rewrite its own instructions, making it endlessly programmable. His mathematical abstraction could, using a small vocabulary of operations, mimic a machine of any complexity, earning it the name "universal Turing machine."

The first reliable electronic digital computer, Colossus, was completed in 1943 to help England decipher wartime codes. It used vacuum tubes — devices for controlling the flow of electrons — instead of moving mechanical parts like the Analytical Engine's cogwheels. This made Colossus fast, but engineers had to manually rewire it every time they wanted to perform a new task.

Perhaps inspired by Turing's concept of a more easily reprogrammable computer, the team that created the United States' first electronic digital computer, ENIAC, drafted a new architecture for its successor, EDVAC. Mathematician John von Neumann, who penned EDVAC's design in 1945, described a system that could store programs in its memory alongside data and alter the programs, a setup now called the von Neumann architecture. Nearly every computer today follows that paradigm.

In 1947, researchers at Bell Telephone Laboratories invented the transistor, a piece of circuitry in which the application of voltage (electrical pressure) or current controls the flow of electrons between two points. It came to replace the slower and less-efficient vacuum tubes.

In 1958 and 1959, researchers at Texas Instruments and Fairchild Semiconductor independently invented integrated

ScienceNews 100

To celebrate our 100th anniversary, we're highlighting some of the biggest advances in science over the last century.
To see more from the series, visit the Century of Science site at www.sciencenews.org/century

circuits, in which transistors and their supporting circuitry were fabricated on a chip in one process.

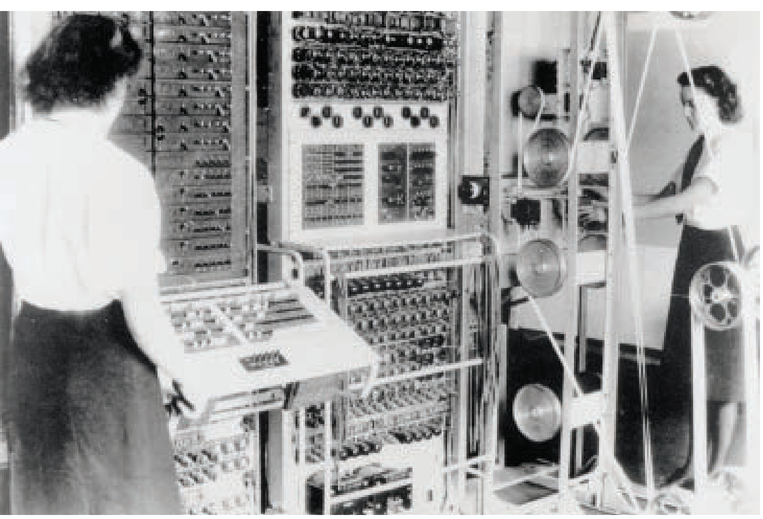
For a long time, only experts could program computers. Then in 1957, IBM released FORTRAN, a programming language that was much easier to understand. It's still in use today. In 1981, the company unveiled the IBM PC, and Microsoft released its operating system called MS-DOS, together expanding the reach of computers into homes and offices. Apple further personalized computing with the operating systems for their Lisa, in 1982, and Macintosh, in 1984. Both systems popularized graphical user interfaces, or GUIs, offering users a mouse cursor instead of a command line.

Meanwhile, researchers had been working to transform how people communicate with each other. In 1948, U.S. mathematician Claude Shannon published "A Mathematical Theory of Communication," which popularized the word *bit* (for binary digit) and laid the foundation for information theory. His ideas have shaped computation and in particular the sharing of data over wires and through the air. In 1969, the U.S. Advanced Research Projects Agency created a computer network called ARPANET, which later merged with other networks to form the internet. And in 1990, researchers at CERN — a European laboratory near Geneva — developed rules for transmitting data that would become the foundation of the World Wide Web.

These technological advances have made it possible for people to work, play and connect in ways that continue to change at a dizzying pace. But how much better can the processors get? How smart can algorithms become? And what kinds of benefits and dangers should we expect to see as technology advances? Stuart Russell, a computer scientist at the University of California, Berkeley who coauthored a popular textbook on artificial intelligence, sees great potential for computers in "expanding artistic creativity, accelerating science, serving as diligent personal assistants, driving cars and — I hope — not killing us."

BLETCHLEY PARK TRUST/SSPL/GETTY IMAGES

Colossus, the world's first reliable electronic programmable computer, helped British intelligence forces decipher code in World War II.



Chasing speed

Computers, for the most part, speak the language of bits. They store information — whether it's music, an application or a password — in strings of 1s and 0s. They also process information in a binary fashion, flipping transistors between an "on" and "off" state. The more transistors in a computer, the faster it can process bits, making possible everything from more realistic video games to safer air traffic control.

Combining transistors forms one of the building blocks of a circuit, called a logic gate. An AND logic gate, for example, is on if both inputs are on, while an OR is on if at least one input is on. Together, logic gates compose a complex traffic pattern of electrons, the physical manifestation of computation. A computer chip can contain millions of logic gates.

So the more logic gates, and by extension the more transistors, the more powerful the computer. In 1965, Gordon Moore, a cofounder of Fairchild Semiconductor and later of Intel, wrote a paper on the future of chips titled "Cramming More Components onto Integrated Circuits." From 1959 to 1965, he noted, the number of components (mostly transistors) crammed onto integrated circuits (chips) had doubled every year. He expected the trend to continue.

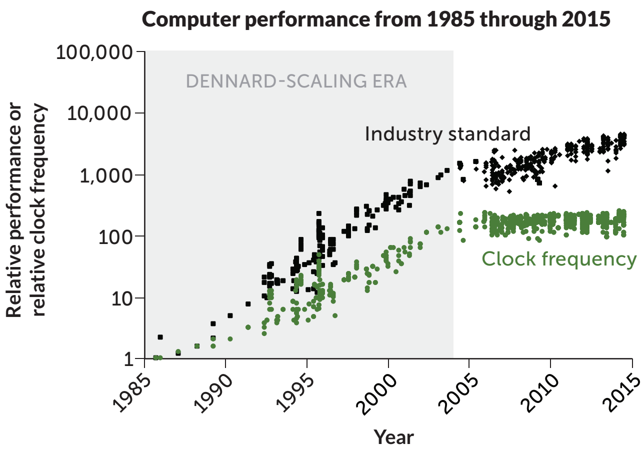
In a 1975 talk, Moore identified three factors behind this exponential growth: smaller transistors, bigger chips and "device and circuit cleverness," such as less wasted space. He expected the doubling to occur every two years. It did, and continued doing so for decades. That trend is now called Moore's law.

Moore's law was meant as an observation about economics. There will always be incentives to make computers faster and cheaper — but at some point, physics interferes. Chip development can't keep up with Moore's law forever, as it becomes more difficult to make transistors tinier. According to what's jokingly called Moore's second law, the cost of chip fabrication plants doubles every few years. The semiconductor company TSMC is reportedly considering building a plant that will cost $25 billion.

Today, Moore's law no longer holds; doubling is happening at a slower rate. We continue to squeeze more transistors onto chips with each generation, but the generations come less frequently. Researchers are looking into several ways forward: better transistors, more specialized chips, new chip concepts and software hacks.

"We've squeezed, we believe, everything you can squeeze" out of the current transistor architecture, called FinFET, says Sanjay Natarajan, who leads transistor design at Intel. In the next few years, chip manufacturers will start producing transistors in which a key element resembles a ribbon instead of a fin, making devices faster and requiring less energy and space.

Even if Natarajan is right and transistors are nearing their minimum size limit, computers still have a lot of runway to improve, through Moore's "device and circuit cleverness." Today's electronic devices contain many kinds of accelerators — chips designed for special purposes such as AI, graphics or



The slowdown Until about 2004, the shrinking of transistors came with improvements in computer performance (black above shows an industry benchmark) and clock frequency — the number of cycles of operations performed per second (green). As this "Dennard scaling" no longer held, shrinking transistors stopped yielding the same benefits.

communication — that can execute intended tasks faster and more efficiently than general-purpose processing units.

Some types of accelerators might one day use quantum computing, which capitalizes on two features of the subatomic realm (*SN: 7/8/17 & 7/22/17, p. 28*). The first is superposition, in which particles can exist not just in one state or another, but in some combination of states until the state is explicitly measured. So a quantum system represents information not as bits but as qubits, which can preserve the possibility of being either 0 or 1 when measured. The second is entanglement, the interdependence between distant quantum elements. Together, these features mean that a system of qubits can represent and evaluate exponentially more possibilities than there are qubits — all combinations of 1s and 0s simultaneously.

Qubits can take many forms, but one of the most popular is as current in superconducting wires. These wires must be kept at a fraction of a degree above absolute zero, around –273° Celsius, to prevent hot, jiggling atoms from interfering with the qubits' delicate superpositions and entanglement. Quantum computers also need many physical qubits to make up one "logical," or effective, qubit, with the redundancy acting as error correction (*SN: 11/6/21, p. 8*).

Quantum computers have several potential applications: machine learning, optimization of things like train scheduling and simulating real-world quantum mechanics, as in chemistry. But they will not likely become general-purpose computers. It's not clear how you'd use one to, say, run a word processor.

New chip concepts

There remain new ways to dramatically speed up not just specialized accelerators but also general-purpose chips. Tom Conte, a computer scientist at Georgia Tech in Atlanta who leads the IEEE Rebooting Computing Initiative, points to two paradigms. The first is superconduction, in which chips run at a temperature low enough to eliminate electrical resistance.

The second paradigm is reversible computing, in which bits are reused instead of expelled as heat. In 1961, IBM physicist Rolf Landauer merged information theory and thermodynamics, the physics of heat. He noted that when a logic gate takes in two bits and outputs one, it destroys a bit, expelling it as entropy, or randomness, in the form of heat. When billions of transistors operate at billions of cycles per second, the wasted heat adds up, and the machine needs more electricity for computing and cooling. Michael Frank, a computer scientist at Sandia National Laboratories in Albuquerque who works on reversible computing, wrote in 2017: "A conventional computer is, essentially, an expensive electric heater that happens to perform a small amount of computation as a side effect."

But in reversible computing, logic gates have as many outputs as inputs. This means that if you ran the logic gate in reverse, you could use, say, three out-bits to obtain the three in-bits. Some researchers have conceived of reversible logic gates and circuits that could not only save those extra out-bits but also recycle them for other calculations. Physicist Richard Feynman had concluded that, aside from energy loss during data transmission, there's no theoretical limit to computing efficiency.

Combine reversible and superconducting computing, Conte says, and "you get a double whammy." Efficient computing allows you to run more operations on the same chip without worrying about power use or heat generation. Conte says that, eventually, one or both of these methods "probably will be the backbone of a lot of computing."

Software hacks

Researchers continue to work on a cornucopia of new technologies for transistors, other computing elements, chip designs and hardware paradigms: photonics, spintronics, biomolecules, carbon nanotubes. But much more can still be eked out of current elements and architectures merely by optimizing code.

In a 2020 paper in *Science*, for instance, researchers studied the simple problem of multiplying two matrices, grids of numbers used in mathematics and machine learning. The calculation ran more than 60,000 times faster when the team picked an efficient programming language and optimized the code for the underlying hardware, compared with a standard piece of code in the Python language, which is considered user-friendly and easy to learn.

Neil Thompson, a research scientist at MIT who coauthored the paper in *Science*, recently coauthored a paper looking at historical improvements in algorithms, sets of instructions that make decisions according to rules set by humans, for tasks like sorting data. "For a substantial minority of algorithms," he says, "their progress has been as fast or faster than Moore's law."

People, including Moore, have predicted the end of Moore's law for decades. Progress may have slowed, but human innovation has kept technology moving at a fast clip.

Chasing intelligence

From the early days of computer science, researchers have aimed to replicate human thought. Alan Turing opened a 1950 paper titled "Computing Machinery and Intelligence" with: "I propose to consider the question, 'Can machines think?'" He proceeded to outline a test, which he called "the imitation game" (now called the Turing test), in which a human communicating with a computer and another human via written questions had to judge which was which. If the judge failed, the computer could presumably think.

The term "artificial intelligence" was coined in a 1955 proposal for a summer institute at Dartmouth College. "An attempt will be made," the proposal goes, "to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves." The organizers expected that over two months, the 10 summit attendees would make a "significant advance."

Even with the stickers shown, a human would recognize this as a stop sign. But when tested, a self-driving car algorithm did not.

More than six decades and untold person-hours later, it's unclear whether the advances live up to what was in mind at that summer summit. Artificial intelligence surrounds us in ways invisible (filtering spam), headline-worthy (self-driving cars, beating us at chess) and in between (letting us chat with our smartphones). But these are all narrow forms of AI, performing one or two tasks well. What Turing and others had in mind is called artificial general intelligence, or AGI. Depending on your definition, it's a system that can do most of what humans do.

We may never achieve AGI, but the path has led, and will lead, to lots of useful innovations along the way. "I think we've made a lot of progress," says Doina Precup, a computer scientist at McGill University in Montreal and head of the AI company DeepMind's Montreal research team. "But one of the things that, to me, is still missing right now is more of an understanding of the principles that are fundamental in intelligence."

World chess champion Garry Kasparov beat IBM supercomputer Deep Blue in a 1996 match (shown). But the computer won in a 1997 rematch.

FROM TOP: K. EYKHOLT *ET AL*/ARXIV.ORG 2018; TOM MIHALEK/AFP VIA GETTY IMAGES

AI has made great headway in the last decade, much of it due to machine learning. Previously, computers relied more heavily on symbolic AI, which uses algorithms based on human-set rules. Machine-learning programs, on the other hand, process data to find patterns on their own. One form uses artificial neural networks, software with layers of simple computing elements that together mimic certain principles of biological brains. Neural networks with several, or many more, layers are currently popular and make up a type of machine learning called deep learning.

Deep-learning systems can now play games like chess and Go better than the best human. They can probably identify dog breeds from photos better than you can. They can translate text from one language to another. They can control robots and compose music and predict how proteins will fold.

But they also lack much of what falls under the umbrella term of common sense. They don't understand fundamental things about how the world works, physically or socially. Slightly changing images in a way that you or I might not notice, for example, can dramatically affect what a computer sees. Researchers found that placing a few innocuous stickers on a stop sign can lead software to interpret the sign as a speed limit sign, an obvious problem for self-driving cars.

Types of learning

How can AI improve? Computer scientists are leveraging multiple forms of machine learning, whether the learning is "deep" or not. One common form is called supervised learning, in which machine-learning systems, or models, are trained by being fed labeled data such as images of dogs and their breed names. But that requires lots of human effort to label them. Another approach is unsupervised or self-supervised learning, in which computers learn without relying on outside labels, the way you or I predict what a chair will look like from different angles as we walk around it.

Another type of machine learning is reinforcement learning, in which a model interacts with an environment, exploring sequences of actions to achieve a goal. Reinforcement learning has allowed AI to become an expert at board games like Go and video games like *StarCraft II*.

To learn efficiently, machines (and people) need to generalize, to draw abstract principles from experiences. "A huge part of intelligence," says Melanie Mitchell, a computer scientist at the Santa Fe Institute in New Mexico, "is being able to take one's knowledge and apply it in different situations." Much of her work involves analogies, in rudimentary form: finding similarities between strings of letters. In 2019, AI researcher François Chollet of Google created a kind of IQ test for machines called the Abstraction and Reasoning Corpus, or ARC, in which computers must complete visual patterns according to principles demonstrated in example patterns. The puzzles are easy for humans, but so far, challenging for machines

Much of our abstract thought, ironically, may be grounded in our physical experiences. We use conceptual metaphors like important = big, and argument = opposing forces. To realize AGI that can do most of what humans can do may require embodiment, such as operating with a physical robot. Researchers have combined language learning and robotics by creating virtual worlds where virtual robots simultaneously learn to follow instructions and to navigate within a house.

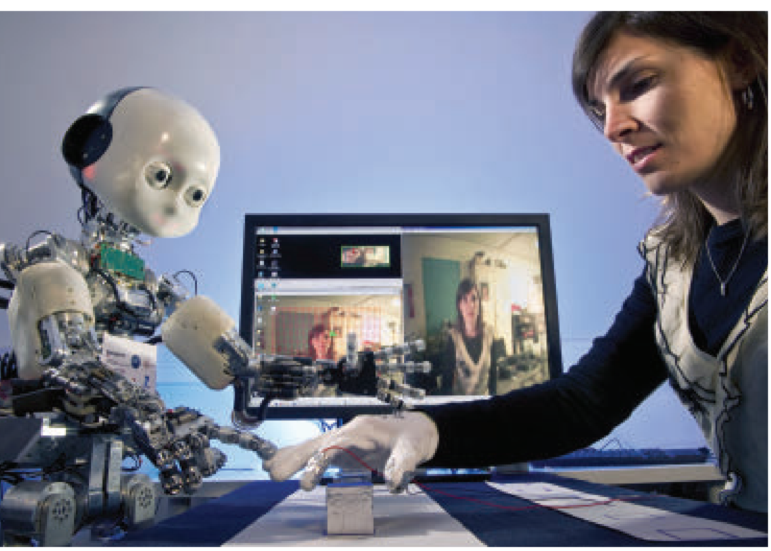
GPT-3 is a trained language model released in 2020 by the research lab Open AI that has shown that disembodied language may not be enough. With prompts, it can write humanlike news articles, short stories and poems. But in one demo, it wrote: “It takes two rainbows to jump from Hawaii to seventeen.”

“I’ve played around a lot with it,” Mitchell says. “It does incredible things. But it can also make some incredibly dumb mistakes.”

AGI might also require other aspects of our animal nature, like emotions, especially if humans expect to interact with machines in natural ways. Emotions are not mere irrational reactions. We’ve evolved them to guide our drives and behaviors. According to Ilya Sutskever, a cofounder and the chief scientist at OpenAI, they “give us this extra oomph of wisdom.” Even if AI doesn’t have the same conscious feelings we do, it may have code that approximates fear or anger. Already, reinforcement learning includes an exploratory element akin to curiosity.

Humans aren’t blank slates. We’re born with certain predispositions to recognize faces, learn language and play with objects. Machine-learning systems also require the right kind of innate structure to learn certain things quickly. How much structure, and what kind, is a matter of intense debate. Sutskever says building in how we think we think is “intellectually seductive.” However, “we want the best blank slate.”

The humanoid robit iCub has become a research tool in labs worldwide for the study of human cognition and artificial intelligence.



PHILIPPE PSAILA/SCIENCE SOURCE

One general neural-network structure Sutskever likes is called the transformer, a method for paying greater attention to important relationships between elements of an input. It’s behind current language models like GPT-3, and has also been applied to analyzing images, audio and video. “It makes everything better,” he says.

Thinking about thinking

AI itself may help us discover new forms of AI. There’s a set of techniques called AutoML, in which algorithms help optimize neural-network architectures or other aspects of AI models. AI also helps chip architects design better integrated circuits. Last year, Google researchers reported in *Nature* that reinforcement learning performed better than their in-house team at laying out some aspects of an accelerator chip they’d designed.

AGI’s arrival may be decades away. “We don’t understand our own intelligence,” Mitchell says, as much of it is unconscious. “And therefore, we don’t know what’s going to be hard or easy for AI.” What seems hard can be easy and vice versa — a phenomenon known as Moravec’s paradox, after the roboticist Hans Moravec. In 1988, Moravec wrote, “it is comparatively easy to make computers exhibit adult-level performance in solving problems on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a 1-year-old when it comes to perception and mobility.” Babies are secretly brilliant. In aiming for AGI, Precup says, “we are also understanding more about human intelligence, and about intelligence in general.”

Turing differentiated between general intelligence and humanlike intelligence. In his 1950 paper on the imitation game, he wrote, “May not machines carry out something which ought to be described as thinking but which is very different from what a man does?” His point: You don’t need to think like a person to have genuine smarts.

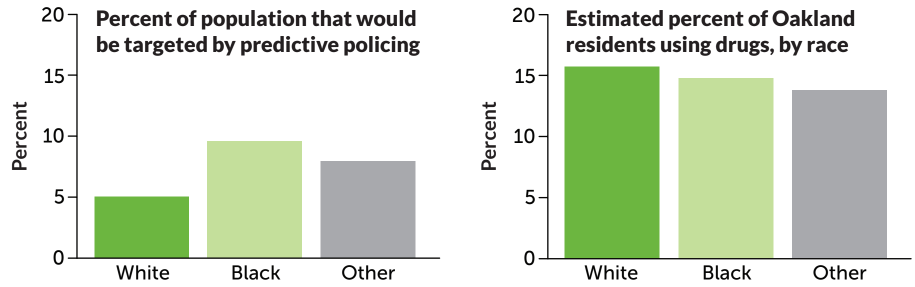
Grappling with ethics

In the 1942 short story “Runaround,” one of Isaac Asimov’s characters enumerated “the three fundamental Rules of Robotics.” Robots avoided causing or allowing harm to humans, they obeyed orders and they protected themselves, as long as following one rule didn’t conflict with preceding decrees.

We might picture Asimov’s “positronic brains” making autonomous decisions about harm to humans, but that’s not actually how computers affect our well-being every day. Instead of humanoid robots killing people, we have algorithms curating news feeds. As computers further infiltrate our lives, we’ll need to think harder about what kinds of systems to build

Predictive policing problems

A predictive policing algorithm tested in Oakland, Calif., would target Black people at roughly twice the rate of white people (near right) even though data from the same time period, 2011, show that drug use was roughly equivalent across racial groups (far right).
SOURCE: K. LUM AND W. ISAAC/*SIGNIFICANCE* 2016



and how to deploy them, as well as meta-problems like how to decide — and who should decide — these things.

This is the realm of ethics, which may seem distant from the supposed objectivity of math, science and engineering. But deciding what questions to ask about the world and what tools to build has always depended on our ideals and scruples. Studying an abstruse topic like the innards of atoms, for instance, has clear bearing on both energy and weaponry. "There's the fundamental fact that computer systems are not value neutral," says computer scientist Barbara Grosz of Harvard University, "that when you design them, you bring some set of values into that design."

One topic that has received a lot of attention from scientists and ethicists is fairness and bias. Algorithms increasingly inform or even dictate decisions about hiring, college admissions, loans and parole. Even if they discriminate less than people do, they can still treat certain groups unfairly, not by design but often because they are trained on biased data. They might predict a person's future criminal behavior based on prior arrests, for instance, even though different groups are arrested at different rates for a given amount of crime.

And confusingly, there are multiple definitions of fairness, such as equal false-positive rates between groups or equal false-negative rates between groups. A researcher at one conference listed 21 definitions. And the definitions often conflict. In one paper, researchers showed that in most cases it's mathematically impossible to satisfy three common definitions simultaneously.

Another concern is privacy and surveillance, given that computers can now gather and sort information on their use in a way previously unimaginable. Data on our online behavior can help predict aspects of our private lives, like sexuality. Facial recognition can also follow us around the real world, helping police or authoritarian governments. And the emerging field of neurotechnology is already testing ways to connect the brain directly to computers (*SN: 2/13/21, p. 24*). Related to privacy is security — hackers can access data that's locked away, or interfere with pacemakers and autonomous vehicles.

Computers can also enable deception. AI can generate content that looks real. Language models might be used to fill the internet with fake news and recruiting material for extremist groups (*SN: 5/8/21 & 5/22/21, p. 22*). Generative adversarial networks, a type of deep learning that can generate realistic content, can assist artists or create deepfakes, images or videos showing people doing things they never did (*SN: 9/15/18, p. 12*).

On social media, we also need to worry about polarization in people's social, political and other views. Generally, recommendation algorithms optimize engagement (and platforms profit through advertising), not civil discourse. Algorithms can also manipulate us in other ways. Robo-advisers — chatbots for dispensing financial advice or providing customer support — might learn to know what we really need, or to push our buttons and upsell us on extraneous products.

Multiple countries are developing autonomous weapons that have the potential to reduce civilian casualties as well as escalate conflict faster than their minders can react. Putting guns or missiles in the hands of robots raises the sci-fi specter of Terminators attempting to eliminate humankind. They might not even be acting with bad intent, falsely reasoning that they are helping humankind by eliminating human cancer (an example of having no common sense). More near-term, automated systems let loose in the real world have already caused flash crashes in the stock market and sudden big leaps in book prices on Amazon. If AIs are charged with making life-and-death decisions, they then face the famous trolley problem, deciding whom or what to sacrifice when not everyone can win. Here we're entering Asimov territory.

That's a lot to worry about. Russell, of UC Berkeley, suggests where our priorities should lie: "Lethal autonomous weapons are an urgent issue, because people may have already died, and the way things are going, it's only a matter of time before there's a mass attack," he says. "Bias and social media addiction and polarization are both arguably instances of failure of value alignment between algorithms and society, so they are giving us early warnings of how things can easily go wrong."

There are also social, political and legal questions about how to manage technology in society. Who should be held accountable when an AI system causes harm? (For instance, "confused" self-driving cars have killed people.) How can we ensure more equal access to the tools of AI and their benefits, and make sure they don't discriminate against groups or individuals? How will continuing automation of jobs affect employment? Can we manage the environmental impact of data centers, which use a lot of electricity? Should we preferentially employ explainable algorithms — rather than the black boxes of many neural networks — for greater trust and debuggability, even if it makes the algorithms poorer at prediction?

E. OTWELL

What can be done

Michael Kearns, a computer scientist at the University of Pennsylvania and coauthor of the 2019 book *The Ethical Algorithm*, puts the problems on a spectrum of manageability. At one end is what's called differential privacy, the ability to add noise to a dataset of, say, medical records so that it can be shared usefully with researchers without revealing much about the individual records. We can now make mathematical guarantees about exactly how private individuals' data should remain.

Somewhere in the middle of the spectrum is fairness in machine learning. Researchers have developed methods to increase fairness by removing or altering biased training data, or maximize certain types of equality — in loans, for instance — while minimizing reduction in profit. Still, some types of fairness will forever be in mutual conflict, and math can't tell us which ones we want.

At the far end is explainability. As opposed to fairness, which can be analyzed mathematically in many ways, the quality of an explanation is hard to describe in mathematical terms. "I feel like I haven't seen a single good definition yet," Kearns says. "You could say, 'Here's an algorithm that will take a trained neural network and try to explain why it rejected you for a loan,' but [the explanation] doesn't feel principled." Ultimately, if the audience doesn't understand it, it's not a good explanation, and measuring its success — however you define success — requires user studies.

Something like Asimov's three laws won't save us from robots that hurt us while trying to help us. And even if the list were extended to a million laws, the letter of a law is not identical to its spirit. One possible solution is what's called inverse reinforcement learning, in which computers might learn to decipher what we really value based on our behavior.

Engineer, heal thyself

In the 1950 short story "The Evitable Conflict," Asimov articulated what became a "zeroth law," a law to supersede all others: "A robot may not harm humanity, or, by inaction, allow humanity to come to harm." It should go without saying that the rule should apply with "roboticist" in place of "robot." For sure, many computer scientists avoid harming humanity, but many also don't actively engage with the social implications of their work, effectively allowing humanity to come to harm, says Margaret Mitchell, a computer scientist who co-led Google's Ethical AI team and now consults with organizations on tech ethics. (She's no relation to computer scientist Melanie Mitchell.)

One hurdle, according to Grosz, of Harvard, is that too many researchers are not properly trained in ethics. But she hopes to change that. Grosz and philosopher Alison Simmons began a program at Harvard called Embedded EthiCS, in which teaching assistants with training in philosophy are embedded in computer science courses and teach lessons on privacy or discrimination or fake news. The program has spread to MIT, Stanford and the University of Toronto.

The existence of lethal autonomous weapons, like these STM Kargu drones made in Turkey, has caused experts to call for a ban on devices that can launch attacks with no human intervention.

MEHMET KAMAN/ANADOLU AGENCY VIA GETTY IMAGES

"We try to get students to think about values and value trade-offs," Grosz says. Two things have struck her. The first is the difficulty students have with problems that lack right answers and require arguing for particular choices. The second is, despite their frustration, "how much students care about this set of issues," Grosz says.

Another way to educate technologists about their influence is to widen collaborations. According to Mitchell, "computer science needs to move from holding math up as the be-all and end-all, to holding up both math and social science, and psychology as well." Researchers should bring in experts in these topics, she says.

Going the other way, Kearns says, they should also share their own technical expertise with regulators, lawyers and policy makers. Otherwise, policies will be so vague as to be useless. Without specific definitions of privacy or fairness written into law, companies can choose whatever's most convenient or profitable.

When evaluating how a tool will affect a community, the best experts are often community members themselves. Grosz advocates consulting with diverse populations. Diversity helps in both user studies and technology teams. "If you don't have people in the room who think differently from you," Grosz says, "the differences are just not in front of you. If somebody says not every patient has a smartphone, boom, you start thinking differently about what you're designing."

According to Margaret Mitchell, "the most pressing problem is the diversity and inclusion of who's at the table from the start. All the other issues fall out from there." ■

Explore more

- Charles E. Leiserson *et al*. "There's plenty of room at the Top: What will drive computer performance after Moore's law?" *Science*. June 5, 2020.

Matthew Hutson is a freelance science and technology writer based in New York City.

Look to the OUTLIERS

Learning why some people succeed when others fail can boost public health and sustainability

By Sujata Gupta

Northern Somalia's economy relies heavily on livestock. About 80 percent of the region's annual exports are meat, milk and wool from sheep and other animals. Yet years of drought have depleted the region's grazing lands. By zeroing in on a few villages that have defied the odds and maintained healthy rangelands, an international team of researchers is asking if those rare successes might hold the secret to restoring rangelands elsewhere.

Answering this question requires turning traditional data processing on its head. Statistically speaking, success stories like those Somali villages with sustainable grazing are the outliers, says Basma Albanna, a development researcher at the University of Manchester in England. "The business as usual is that when you have outliers in data, you take them out."

Yet those outliers can hold vital information, say Albanna and others who use the "positive deviance" approach. They sift through data to find signals in what many deem noise. The researchers search for "deviants" — outliers in big datasets — to uncover why some individuals or communities succeed when others facing nearly identical circumstances fail. Then, armed with these insights, the researchers develop strategies that help those in the languishing majority attain positive results.

Positive deviance has the potential to address a nagging problem, says statistician Megan Higgs, of Bozeman, Mont. "In research in general we have an overemphasis on quantifying averages," says Higgs, editor of the International Statistical Institute's blog *Statisticians React to the News*. She notes that few people in a research pool may actually fit the average. Sometimes, averages obscure vital information.

Without approaches such as positive deviance that look at groups and individuals in the margins, "I just worry that we are missing a hugely important part of the picture," Higgs says.

Rebels among us

The term "positive deviance" first appeared in the mid-1970s, but the approach did not gain traction until nearly two decades later. In 1990, Monique Sternin and her husband Jerry Sternin, then aid workers with the humanitarian organization Save the Children, piloted a positive deviance project in Vietnam to address the country's soaring rates of childhood malnutrition. Vietnamese government officials asked the couple to help communities without resorting to food handouts or other common, yet unsustainable, aid practices.

So the Sternins sought to identify children in impoverished communities who remained well fed against tremendous odds. Working in four villages in Thanh Hóa province, which combined had 2,000 children under age 3, the Sternins trained villagers to weigh the children. Roughly 65 percent of the children were malnourished; about half of those were at higher risk of death.

The couple then asked the villagers to identify children with healthier weights among the poorest families. Each village had a handful of families that fit the bill. "We went to talk to those people," says Monique Sternin, now a positive deviance consultant in Boston.

The Sternins discovered that kids with healthier weights came from families who fed their children sweet potato greens found along roadsides and tiny shrimp and crabs that lived in rice paddies. Village wisdom regarded these foods as "taboo," or dangerous, Sternin says. The families

HERMANN MUELLER/GETTY IMAGES, ADAPTED BY E. OTWELL with healthier kids also fed their children three to four meals per day instead of the customary two meals.

On the surface, the solution seemed simple: Get more families to feed their children this way, including the taboo foods. But implementing this solution was not at all easy. "The positive deviants are outliers, rebels," Sternin explains. The Sternins could not ethically "out" families that were bucking social norms and traditions.

Instead, they promised villagers free rice. In exchange, villagers attended cooking sessions with their kids, facilitated by aid workers and taught by village women. Those sessions provided villagers with an extra meal every day for 12 days. But to participate, the villagers had to bring and take turns preparing the tiny shrimp and crabs, along with wild greens. Over those 12 days, parents and caregivers saw for themselves that the foods made the children healthier, not sicker.

Although the work was not based on a formal study, "what we found quickly was children were putting on weight," Sternin says. And the children stayed healthy thanks to their altered diets; after a year, more than a thousand children in the villages were no longer malnourished.

The couple went on to establish similar programs around the country. Others adopted the positive deviance method, and today, programs based on that idea exist worldwide.

After a year, more than a thousand children in the villages were no longer malnourished.

Going bigger

The Sternins' work was inspirational but required a personalized approach to gather data. Albanna wondered if a different approach might get the job done with lower startup costs. That approach would combine several types of data, including traditional government surveys and census counts, along with nontraditional data, such as satellite images, social media content and mobile phone records. That big data would be coupled with qualitative research.

Big data offers several benefits, Albanna says. The datasets already exist, so data collection is initially less labor intensive than going door to door. And identifying outliers at the level of villages or neighborhoods instead of individuals reduces privacy concerns.

"Positive deviants are very rare to find. We're talking 2 to 10 percent of whatever sample you are investigating," Albanna says. So the larger the dataset, the more outliers you would be able to identify, she notes.

A woman feeds a child rice as part of a program to reduce childhood malnutrition in Vietnam in the 1990s. Villagers received rice in exchange for bringing and preparing foods considered unsafe or taboo, including tiny crabs and shrimp, as well as greens that grow along the side of the road.

LOIS RAIMONDO

In 2020, Albanna and several international partners cofounded the Data Powered Positive Deviance initiative. Pilot projects in the collaboration are identifying the safest public spaces for women in Mexico City and mapping communities producing the most millet in Niger. A project locating districts that were best at slowing the spread of COVID-19 in Germany reported its findings in September in the *International Journal of Environmental Research and Public Health*. The collaboration also conducts the healthy rangeland project in Somalia.

There, the team first had to find successful villages. "We started, hoping that we would be able to identify communities that are able to sustain and maintain the numbers of their livestock after the 2016–2017 drought," Albanna says. That drought was severe, leaving more than half the country with food shortages (*SN: 1/19/19, p. 7*).

Counting livestock directly proved tricky. So the team focused on a different metric: rangeland health. Healthy vegetation likely makes for healthier livestock, Albanna explains.

The team then zoomed in on 314 villages in northern Somalia's mountainous West Golis region and looked at three sets of data. The researchers grouped similar villages together using rainfall and land cover data. Earth-observing satellite data from 2016 to 2020 provided a gauge of vegetation density. That process helped the team identify 13 potential positive deviants, villages that had maintained healthier vegetation over the five-year study period.

Detailed satellite images of those outliers revealed unique conservation techniques that helped preserve nearby rangeland. For instance, some villages used shrub barriers around settlements to limit erosion or carved basins shaped like half-moons into landscapes to retain water, the researchers reported online December 28 in *Development Engineering*.

To find out what propelled the villagers to adopt those successful practices, the team sent a local consultant, Mohamed Jama Hussein, to sleuth around. Hussein compared 10 of the potential positive deviant villages with two villages showing average levels of vegetation density and eight hard-hit, low-vegetation villages — the negative deviants. He discovered that the leaders of positive deviant villages had aggressively blocked private citizens from enclosing communal lands for personal use. By contrast, "squatting" on public lands remained common in the other villages.

Hussein also observed that farmers in the successful villages were diversifying their sources of income. Some had started growing their own livestock feed. And many women had started keeping bees, which offered an unexpected perk, Albanna says. The bees' presence deterred people from cutting down rangeland shrubs and trees for fuel.

Targeted interventions

Besides giving researchers and policy makers the information they need to design new interventions, the positive deviance approach can also strengthen existing efforts, says behavioral science and public policy expert Kai Ruggeri of Columbia University.

"It's such an easy adaptation that could potentially have major impact," says Ruggeri, who wrote a commentary with computer scientist Tomas Folk of Rutgers University in Newark, N.J., encouraging researchers to consider using the positive deviance approach in the November *Perspectives on Psychological Science*.

A focus on outliers could increase the power of nudges, the two wrote. Nudges, which discretely guide people toward making better decisions, were defined and popularized by behavioral economists Richard Thaler and Cass Sunstein (*SN Online: 10/9/17*). Researchers have tested whether nudging people with reminders to attend doctor appointments can reduce no-shows. For instance, a 2011 report in the *Journal of Telemedicine and Telecare* showed that, across 29 studies, automated phone or text reminders increased attendance by almost 30 percent.

But when another research team, which included Ruggeri, zoomed in on a low-income population, a group that can miss up to 45 percent of appointments, the researchers could not replicate those results. They scoured the electronic medical records of almost 64,000 low-income urban patients at a health care center for disadvantaged populations and found that a robocall followed by a text message failed to increase attendance. Those results were published in 2020 in *BMC Health Services Research*.

Nudge interventions often target the average participant, Ruggeri says. "If you look at the way nudging is largely done, it speaks to a middle-class-and-above population." But researchers attempting to shrink societal inequalities could use a positive deviance approach to help the neediest individuals, Ruggeri says.

That would mean identifying low-income participants who attended all their scheduled doctor appointments. Mapping those individuals' paths could potentially lead to nudges and other behavioral interventions targeting potential no-shows in similar groups. That way, Ruggeri says, policy makers could more effectively reach the cohort that would benefit greatly from preventive care.

Back in Somalia, Hussein wrapped up his fieldwork in late 2021. The team is now investigating how to do just what Ruggeri suggests: use its newfound knowledge of successful outliers to develop behavioral and policy interventions.

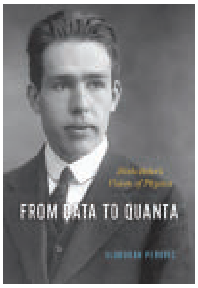
Such interventions have an added benefit: They empower communities to harness the wisdom of their own people, Sternin says. The solutions exist within the community and implementing those solutions, she notes, "is transformational." ■

Residents of a village in northern Somalia share ideas on how they contend with the region's frequent droughts.

M.J. HUSSEIN

Explore more

- Data Powered Positive Deviance initiative: bit.ly/DPPDInitiative



From Data to Quanta
Slobodan Perović
UNIV. OF CHICAGO, $45

BOOKSHELF

A defense of Niels Bohr's view of quantum physics

Ever since Max Planck introduced the idea of the quantum to the world, physicists have argued about whether reality is more like sand or water.

Planck's famous 1900 discovery that energy is grainy — at least when absorbed or emitted — moved him to label those smallest bits of energy grains "quanta." But he believed that once emitted, as in light from a fire, those grains merged into smooth, continuous waves, just as water seems a smooth liquid to human perception. Einstein, on the other hand, insisted that light quanta traveled through space on their own, behaving like particles later called photons.

By the mid-1920s, both the wave and particle views of light had gained experimental support, with the additional paradox that electrons — supposedly particles — could sometimes disguise themselves as waves.

Into this arena of controversy stepped the famed Danish physicist Niels Bohr, the pioneer of exploring the architecture of the atom. Bohr announced that resolving the wave-particle paradox required a new view of reality, in which both notions shared a role in explaining experimental phenomena. In experiments designed to observe waves, waves you would find, whether electrons or light. In experiments designed to detect particles, you'd see particles. But in no experiment could you demonstrate both at once. Bohr called this viewpoint the principle of complementarity, and it successfully guided the pursuit of quantum mechanics during the following decades.

More recently, as philosopher Slobodan Perović recounts in *From Data to Quanta*, Bohr's success has been questioned by some physicists and philosophers and even popular science writers (*SN: 1/19/19, p. 26*). Complementarity has been derided as an incoherent application of vague philosophy expressed in incomprehensible language. But as Perović's investigations reveal, such criticisms are rarely rooted in any deep understanding of Bohr's methods. Rather than Bohr's philosophy contaminating his science, Perović argues, it is his opponents' philosophical prejudices that have led to misstatements, misunderstandings and misrepresentations of Bohr's physics. And Bohr can't be understood by attempting to understand his philosophy, Perović asserts, because philosophy did not guide him — experiments did.

In fact, Bohr's drive to understand the wave-particle paradox was fueled by a deep devotion to comprehending the experimental evidence in its totality. It was the same approach the younger Bohr took when developing his model of the atom in 1913 (*SN: 7/13/13, p. 20*). Various experiments suggested properties of the atom that seemed irreconcilable. But Bohr forged those experimental clues into a "master hypothesis" that produced a thoroughly novel understanding of the atom and its structure.

Perović describes how Bohr's process began with lower-level hypotheses stemming from features directly given by experiment. Spectral lines — different specific colors of light emitted by atoms — led to basic hypotheses that some vibratory process, of an atom itself or its constituents, produced electromagnetic radiation exhibiting precise patterns. Intermediate hypotheses about the structure of the atom did not explain such lines, though. And then Ernest Rutherford, on the basis of experiments in his lab, inferred that an atom was mostly empty space. It contained a dense, tiny central nucleus encompassing most of the mass, while lightweight electrons orbited at a distance. But that hypothesis didn't mesh with the precise patterns of spectral lines. And such an atom would be unstable, persisting for less than a millisecond. From all these disparate experiment-based hypotheses, Bohr applied Planck's quantum idea to construct a master hypothesis. He reconciled the spectral lines and Rutherford's nuclear atom with a new atomic model, in which electrons maintained stability of the atom but jumped from one orbit to another, emitting specific patterns of spectral lines in the process.

As Perović demonstrates, Bohr followed a similar course in arriving at complementarity. While numerous experiments showed that light was a wave, by the early 1920s other experiments established that X-rays, highly energetic light, collided with electrons just as though both were particles (momentum and energy were conserved in the collisions just as the particle view required). Bohr's master hypothesis, complementarity, seemed the only way forward.

Throughout the book, Perović relates how Bohr has been misinterpreted, his views misleadingly conflated with those of others (like John von Neumann and Werner Heisenberg), and his philosophy incorrectly portrayed as antirealist — suggesting that only observations brought reality into existence. Bohr never said any such thing, and in fact cautioned against using language so loosely.

Perović's account offers a thorough survey of other historical investigations into Bohr's work and draws liberally from Bohr's own writings. It's a nuanced and insightful presentation of the interplay of experiment and theory in the scientific process. This book is not easy reading, though. It's not the place to seek clear explanations of quantum physics and Bohr's interpretation of it. Perović opts for scholarly thoroughness and careful reasoning with a propensity for long sentences. But then again, Bohr's writings were no breeze, either. In fact, a major complaint against Bohr has been expressed by authors who say his writings are very difficult to understand. It's unfortunate that so many seem to think that because they can't understand Bohr, he must have been wrong. Perović's book provides a useful antidote to that attitude. — *Tom Siegfried*

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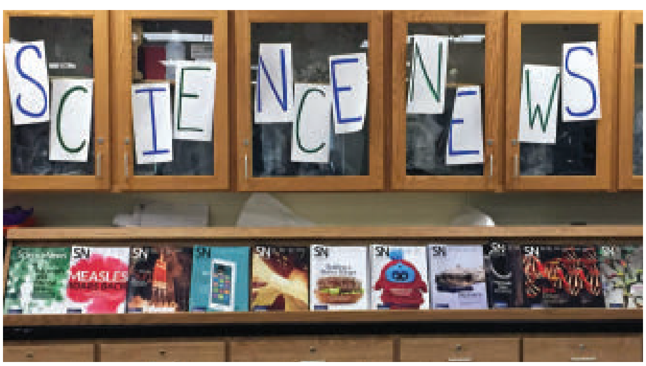

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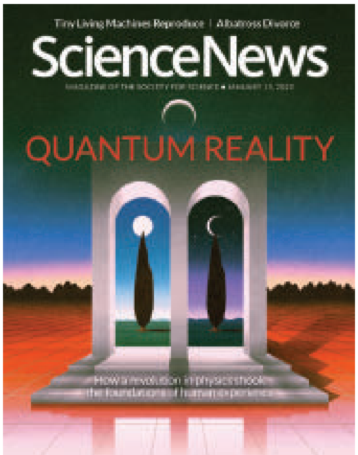

JANUARY 15, 2022

SOCIAL MEDIA

Bird breakup

Monogamous albatrosses (shown below) on the Falkland Islands ditch their partners more often when the ocean is unusually warm, **Richard Kemeny** reported in "Warming drives albatrosses to divorce" (*SN: 1/15/22, p. 11*). Twitter user **@sarah_relford** quipped: "Bird divorce is a real water fowl."

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Troubled water

*A new study shows that Tangier Island could be lost to rising sea levels sooner than previously realized, **Trishla Ostwal** reported in "Time is running out to save Virginia's Tangier Island" (*SN: 1/15/22, p. 4*).*

Reader **John T. Hanou** wondered if groundwater extraction near the island is contributing to its plight.

It's true that groundwater pumping can significantly affect the rate at which land sinks in the southern Chesapeake Bay region. But its impact is smaller on Tangier Island, which is far from any major groundwater pumping source, say the study's coauthors, marine biologist **David Schulte** of the U.S. Army Corps of Engineers and his son **Zehao Wu**, a student researcher at Biogenic Solutions Consulting in Newport News, Va. Data from the U.S. Geological Survey suggest that groundwater extraction is responsible for about 20 percent of the sea level rise around the island, the duo say. The majority "is due to human-accelerated climate change."

Mammoth musings

*Researchers contend that the ancient Clovis people of North America used stone points to butcher scavenged mammoths rather than hunt the giant beasts, **Bruce Bower** reported in "Pointed takedown of the mammoth hunters" (*SN: 1/15/22, p. 22*).*

Several readers asked if methods such as coating stone points in poison or driving mammoths into pits would have allowed the Clovis people to hunt the animals.

Evidence of such methods has never been discovered, says archaeologist **Metin Eren** of Kent State University in Ohio. The Clovis people could have occasionally hunted mammoths, he says, possibly by wounding and tracking the beasts until they died. But these people likely did not hunt mammoths regularly and successfully, he contends.

Dust it off

*NASA's Ingenuity helicopter is still helping the Perseverance rover do science, **Lisa Grossman** reported in "Ingenuity's Mars flight plan extended" (*SN: 1/15/22, p. 12*).*

Reader **Sherry Kadrmas** wondered if Ingenuity could help give other rovers and landers on Mars a power boost by removing dust from their solar panels.

Using Ingenuity to dust off rovers is probably impractical, says **Michael Mischna**, an atmospheric scientist at NASA's Jet Propulsion Laboratory in Pasadena, Calif. First and foremost, dusty solar panels aren't a major concern because they haven't significantly hindered solar-powered rovers from doing science, he says. Second, Martian dust is extremely fine, similar to talcum powder. Gravity and electrostatic forces "stick" the fine dust to spacecraft surfaces. Winds stronger than what Ingenuity could produce might not even effectively clear the dust, **Mischna** says. What's more, the helicopter could collide accidentally with a rover while clearing dust, damaging both.

Most importantly, Ingenuity would "never be able to travel the distance" to other space probes on Mars, **Mischna** says. The nearest active solar-powered mission, called InSight, is about 3,500 kilometers away from the helicopter. To date, Ingenuity has traveled about 3.5 kilometers, he says. The helicopter can't wander far from Perseverance because it relies on the rover for instructions from scientists on Earth.

Correction

"Mental gymnastics" (*SN: 1/29/22, p. 24*) mischaracterized Tommy Minkler's specialty. He is a mindfulness researcher and sports psychology graduate student.

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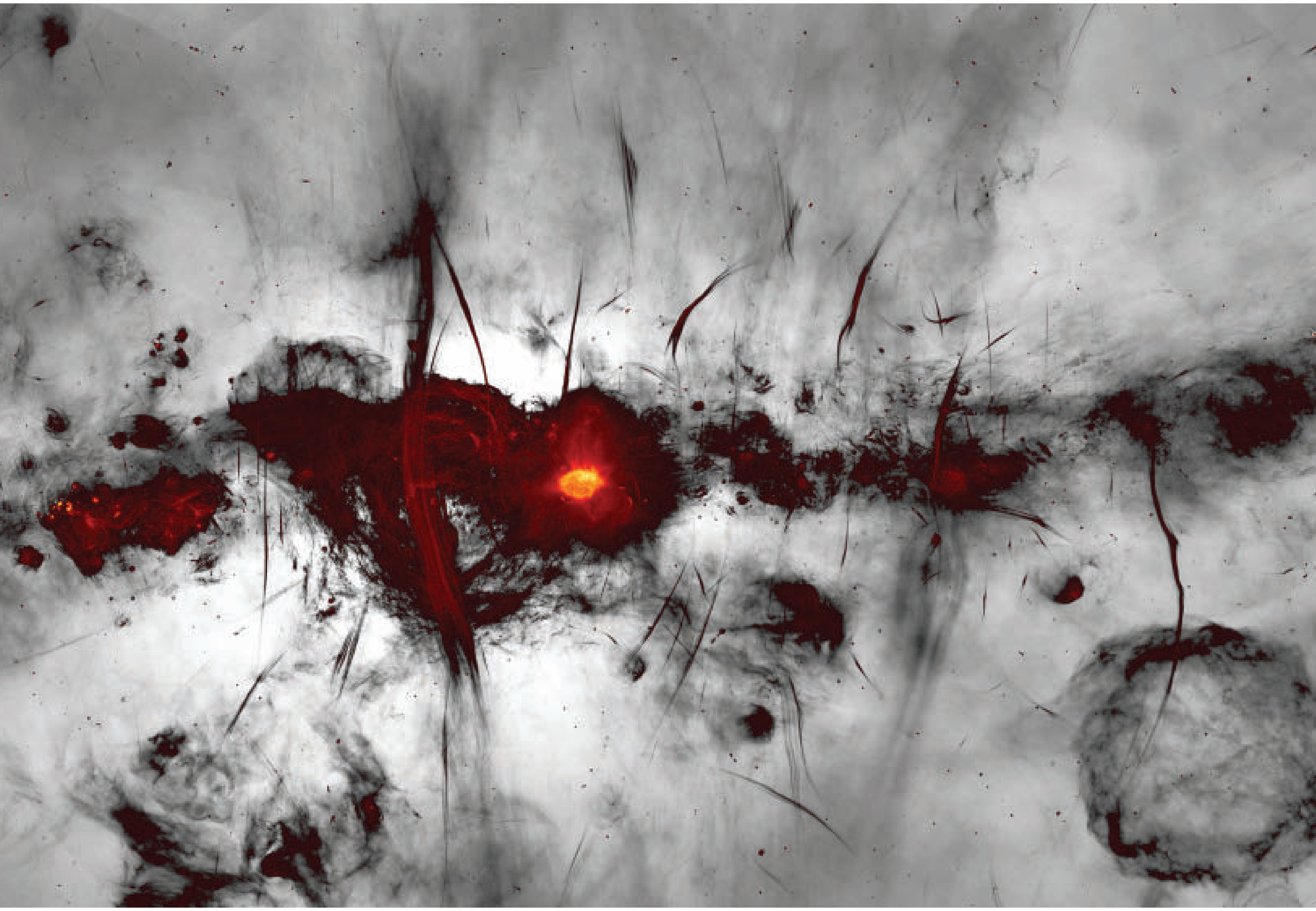

I. HEYWOOD/SARAO

The Milky Way's heart shines in radio waves

An image that looks like a trippy Eye of Sauron is actually a new detailed look at the Milky Way's chaotic center, as seen in radio wavelengths.

The image was taken with the MeerKAT radio telescope array in South Africa over the course of three years and 200 hours of observing. The new view combines 20 separate images into a single mosaic (above), with the bright, star-dense galactic plane running horizontally. Stronger radio signals are shown in red and orange false color. Fainter zones are colored in gray scale, with darker shades indicating stronger emissions.

MeerKAT captured radio waves from several astronomical treasures, including supernovas, stellar nurseries and the energetic region around the supermassive black hole at the Milky Way's center (*SN: 10/12/19 & 10/26/19, p. 4*). One puffy supernova remnant can be seen (bottom right), and the supermassive black hole shows up as a bright orange "eye" (center). The MeerKAT team describes the image in a paper to be published in the *Astrophysical Journal*.

Other intriguing features are the many wispy-looking radio filaments that slice mostly vertically through the image. These filaments, a handful of which were first spotted in the 1980s, are created by accelerated electrons gyrating in a magnetic field and creating a radio glow. But the filaments are hard to explain because there's no obvious engine to accelerate the particles.

"They were a puzzle. They're still a puzzle," says astrophysicist Farhad Yusef-Zadeh of Northwestern University in Evanston, Ill., who discovered the filaments serendipitously as a graduate student.

Previously, scientists knew of so few filaments that they could study the features only one at a time. Now MeerKAT has revealed hundreds of them, Yusef-Zadeh says. Studying the strands all together could help reveal their secrets, he and colleagues report in a paper to be published in the *Astrophysical Journal Letters*. "We're definitely one step closer to seeing what these guys are about." *— Lisa Grossman*

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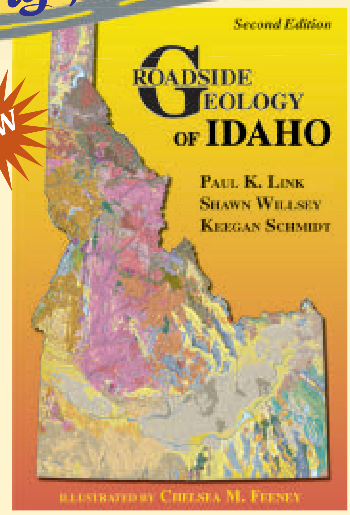

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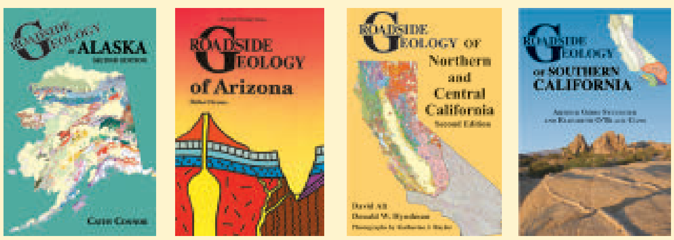

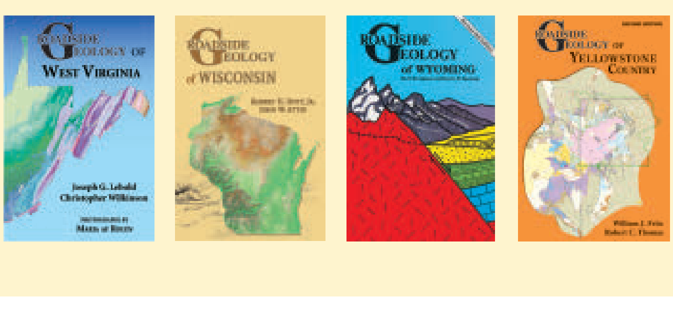

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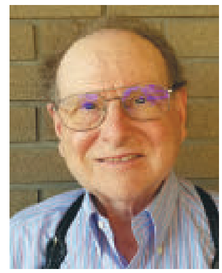
MAKE A DIFFERENCE
JON GRAFF DID

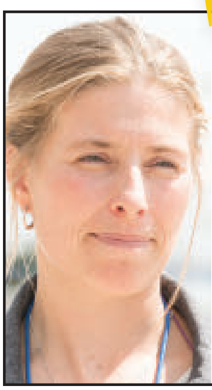
Jon Graff was a lifelong *Science News* reader who greatly admired the communications skills of its writers and editors. During his life, Jon helped devise the secure methods we use every day to make online credit card transactions. He also loved taking long trips in the Southwest on his beloved green bike.



When Jon looked back over his life as he grew older, he thought about the things that mattered to him most—his biking friends, his seminal work as a cryptographic architect and decades of reading *Science News*.

Sadly, Jon died in January 2021 at the age of 77. Before he died, Jon made a bequest intention to create an endowment—The Jon C. Graff Fund for *Science News*—whose income will benefit both the Society for Science and *Science News* journalism in perpetuity.

Bequest gifts are the right kind of gift for many of us, enabling us to support the organizations we most admire after our lifetimes.



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