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MAGAZINE

The robot revolution has arrived

Machines now perform all sorts of tasks: They clean big stores, patrol borders, and help autistic children. But will they make life better for humans?

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If you're like most people, you've probably never met a robot. But you will.

I met one on a windy, bright day last January, on the short-grass prairie near Colorado's border with Kansas, in the company of a rail-thin 31-year-old from San Francisco named Noah Ready-Campbell. To the south, wind turbines stretched to the horizon in uneven ranks, like a silent army of gleaming three-armed giants. In front of me was a hole that would become the foundation for another one.

A Caterpillar 336 excavator was digging that hole—62 feet in diameter, with walls that slope up at a 34-degree angle, and a floor 10 feet deep and almost perfectly level. The Cat piled the dug-up earth on a spot where it wouldn't get in the way; it would start a new pile when necessary. Every dip, dig, raise, turn, and drop of the 41-ton machine required firm control and well-tuned judgment. In North America, skilled excavator operators earn as much as $100,000 a year.

The seat in this excavator, though, was empty. The operator lay on the cab's roof. It had no hands; three snaky black cables linked it directly to the excavator's control system. It had no eyes or ears either, since it used lasers, GPS, video cameras, and gyroscope-like sensors that estimate an object's orientation in space to watch over its work. Ready-Campbell, co-founder of a San Francisco company called Built Robotics, clomped across the coarse dirt, climbed onto the excavator, and lifted the lid of a fancy luggage carrier on the roof. Inside was his company's product—a 200-pound device that does work that once required a human being.

"This is where the AI runs," he said, pointing into the collection of circuit boards, wires, and metal boxes that made up the machine: Sensors to tell it where it is, cameras to let it see, controllers to send its commands to the excavator, communication devices that allow humans to monitor it, and the processor where its artificial intelligence, or AI, makes the decisions a human driver would. "These control signals get passed down to the computers that usually respond to the joysticks and pedals in the cab."

When I was a child in the 20th century, hoping to encounter a robot when I grew up, I expected it would look and act human, like C-3PO from *Star Wars*. Instead, the real robots that were being set up in factories were very different. Today millions of these industrial machines bolt, weld, paint, and do other repetitive, assembly-line tasks. Often fenced off to keep the remaining human workers safe, they are what roboticist Andrea Thomaz at the University of Texas has called "mute and brute" behemoths.

Ready-Campbell's device isn't like that (although the Cat did have the words "CAUTION Robotic Equipment Moves Without

Warning" stamped on its side). And of course it isn't like C-3PO, either. It is, instead, a new kind of robot, far from human but still smart, adept, and mobile. Once rare, these devices—designed to "live" and work with people who have never met a robot—are migrating steadily into daily life.

Already, in 2020, robots take inventory and clean floors in Walmart. They shelve goods and fetch them for mailing in warehouses. They cut lettuce and pick apples and even raspberries. They help autistic children socialize and stroke victims regain the use of their limbs. They patrol borders and, in the case of Israel's Harop drone, attack targets they deem hostile. Robots arrange flowers, perform religious ceremonies, do stand-up comedy, and serve as sexual partners.

And that was before the COVID-19 pandemic. Suddenly, replacing people with robots—an idea majorities of people around the world dislike, according to polls—looks medically wise, if not essential.

Robots now deliver food in Milton Keynes, England, tote supplies in a Dallas hospital, disinfect patients' rooms in China and Europe, and wander parks in Singapore, nagging pedestrians to maintain social distance.

This past spring, in the middle of a global economic collapse, the robotmakers I'd contacted in 2019, when I started working on this article, said they were getting more, not fewer, inquiries from potential customers. The pandemic has made more people realize that "automation is going to be a part of work," Ready-Campbell told me in May. "The driver of that had been efficiency and productivity, but now there's this other layer to it, which is health and safety."

Even before the COVID crisis added its impetus, technological trends were accelerating the creation of robots that could fan out into our lives. Mechanical parts got lighter, cheaper, and sturdier. Electronics packed more computing power into smaller packages. Breakthroughs let engineers put powerful data-crunching tools into robot bodies. Better digital communications let them keep some robot "brains" in a computer elsewhere—or connect a simple robot to hundreds of others, letting them share a collective intelligence, like a beehive's.

The workplace of the near future "will be an ecosystem of humans and robots working together to maximize efficiency," said Ahti Heinla, co-founder of the Skype internet-call platform, now co-founder and chief technology officer of Starship Technologies, whose six-wheeled, self-driving delivery robots are rolling around Milton Keynes and other cities in Europe and the United States.

"We've gotten used to having machine intelligence that we can carry around with us," said Manuela Veloso, an AI roboticist at Carnegie Mellon University in Pittsburgh. She held up her smartphone. "Now we're going to have to get used to intelligence that has a body and moves around without us."

Outside her office, her team's "cobots"—collaborative robots—roam the halls, guiding visitors and delivering paperwork. They look like iPads on wheeled display stands. But they move about on their own, even taking elevators when they need to (they beep and flash a polite request to nearby humans to push the buttons for them).

"It's an inevitable fact that we are going to have machines, artificial creatures, that will be a part of our daily life," Veloso said. "When you start accepting robots around you, like a third species, along with pets and humans, you want to relate to them."

We're all going to have to figure out how. "People have to understand that this isn't science fiction; it's not something that's going to happen 20 years from now," Veloso said. "It's started to happen."

Vidal Pérez likes his new co-worker.

For seven years, working for Taylor Farms in Salinas, California, the 34-year-old used a seven-inch knife to cut lettuce. Bending at the waist, over and over, he would slice off a head of romaine or iceberg, shear off imperfect leaves, and toss it into a bin.

Since 2016, though, a robot has done the slicing. It's a 28-foot-long, tractorlike harvester that moves steadily down the rows in a cloud of mist from the high-pressure water jet it uses to cut off a lettuce head every time its sensor detects one. The cut lettuce falls onto a sloped conveyor belt that carries it up to the harvester's platform, where a team of about 20 workers sorts it into bins.

I met Pérez early one morning in June 2019, as he took a break from working a 22-acre field of romaine destined for Taylor's fast-food and grocery store customers. A couple hundred yards away, another crew of lettuce cutters hunched over the plants, knives flashing as they worked in the old pre-robot style.

"This is better, because you get a lot more tired cutting lettuce with a knife than with this machine," Pérez said. Riding on the robot, he rotates bins on the conveyor belt. Not all the workers prefer the new system, he said. "Some people want to stay with what they know. And some get bored with standing on the machine, since they're used to moving all the time through a field."

Taylor Farms is one of the first major California agricultural companies to invest in robotic farming. "We're going through a generational change ... in agriculture," Taylor Farms California president Mark Borman told me while we drove from the field in his pickup. As older workers leave, younger people aren't choosing to fill the backbreaking jobs. A worldwide turn toward restrictions on cross-border migration, accelerated by COVID fears, hasn't helped either. Farming around the world is being roboticized, Borman said. "We're growing, our workforce is shrinking, so robots present an opportunity that's good for both of us."

It was a refrain I heard often last year from employers in farming and construction, manufacturing and health care: We're giving tasks to robots because we can't find people to do them.

At the wind farm site in Colorado, executives from the Mortenson Company, a Minneapolis-based construction firm that has hired Built's robots since 2018, told me about a dire shortage of skilled workers in their industry. Built robots dug 21 foundations at the wind farm.

"Operators will say things like, Oh, hey, here come the job killers," said Derek Smith, lean innovation manager for Mortenson. "But after they see that the robot takes away a lot of repetitive work and they still have plenty to do, that shifts pretty quickly."

Once the robot excavator finished the dig we'd watched, a human on a bulldozer smoothed out the work and made ramps. "On this job, we have 229 foundations, and every one is basically the same spec," Smith said. "We want to take away tasks that are repetitive. Then our operators concentrate on the tasks that involve more art."

The pandemic's tsunami of job losses hasn't changed this outlook, robotmakers and users told me. "Even with a very high unemployment rate, you can't just snap your fingers and fill jobs that need highly specialized skills, because we don't have the people that have the training," said Ben Wolff, chairman and CEO of Sarcos Robotics.

The Utah-based firm makes wearable robots called exoskeletons, which add the strength and precision of a machine to a worker's movements. Delta Air Lines had just begun to test a Sarcos device with aircraft mechanics when the pandemic decimated air travel.

When I reached Wolff last spring, he was upbeat. "There is a short-term slowdown, but long term we expect more business," he said.

Most employers are now looking to reduce contact among employees, and a device that lets one do the work of two might help. Since the pandemic began, Wolff told me, Sarcos has seen a jump in inquiries, some from companies he didn't expect—for example, a major electronics firm, a pharmaceutical company, a meat-packer. The electronics- and pillmakers wanted to move heavy supplies with fewer people. The meat-packer was interested in spreading out its crowded workers.

In a world that now fears human contact, it won't be easy to fill jobs caring for children or the elderly. Maja Matarić, a computer scientist and roboticist at the University of Southern California, develops "socially assistive robots"—machines that do social support rather than physical labor. One of her lab's projects, for example, is a robot coach that leads an elderly user through an exercise routine, then encourages the human to go outside and walk.

"It says, 'I can't go outside, but why don't you take a walk and tell me about it?'" Matarić told me. The robot is a white plastic

head, torso, and arms that sits atop a rolling metal stand. But its sensors and software allow it to do some of what a human coach would do—for example, saying, “Bend your left forearm inward a little,” during exercise, or “Nice job!” afterward.

We walked around her lab—a warren of young people in cubicles, working on the technologies that might let a robot help keep the conversation going in a support group, for example, or respond in a way that makes a human feel like the machine is empathizing. I asked Matarić if people ever got creeped out at the thought of a machine watching over Grandpa.

“We’re not replacing caregivers,” she said. “We’re filling a gap. Grown-up children can’t be there with elderly parents. And the people who take care of other people in this country are underpaid and underappreciated. Until that changes, using robots is what we’ll have to do.”

Days after I visited Matarić’s lab, in a different world 20 miles due south of the university, hundreds of longshoremen were marching against robots. This was in the San Pedro section of Los Angeles, where container cranes tower over a landscape of warehouses and docks and modest residential streets. Generations of people in this tight-knit community have worked as longshoremen on the docks. The current generation didn’t like a plan to bring robot cargo handlers to the port’s largest terminal, even though such machines already are common in ports worldwide, including others in the Los Angeles area.

The dockworkers don’t expect the world to stop changing, said Joe Buscaino, who represents San Pedro on the Los Angeles City Council. San Pedro has gone through economic upheavals before, as fishing, canning, and shipbuilding boomed and busted. The problem with robots, Buscaino told me, is the speed with which employers are dropping them into workers’ lives.

“Years ago my dad saw that fishing was coming to an end, so he got a job in a bakery,” he said. “He was able to transition. But automation has the ability to take jobs overnight.”

Economists disagree a great deal about how much and how soon robots will affect future jobs. But many experts do agree on one thing: Some workers will have a much harder time adapting to robots.

“The evidence is fairly clear that we have many, many fewer blue-collar production jobs, assembly jobs, in industries that are adopting robots,” said Daron Acemoglu, an economist at MIT who has studied the effects of robots and other automation. “That doesn’t mean that future technology cannot create jobs. But the notion that we’re going to adopt automation technologies left, right, and center and also create lots of jobs is a purposefully misleading and incorrect fantasy.”

For all the optimism of investors, researchers, and entrepreneurs at start-ups, many people, such as Buscaino, worry about a future full of robots. They fear robots won’t take over just grunt work but the whole job, or at least the parts of it that are challenging, honorable—and well paid. (The latter process is prevalent enough that economists have a name for it: “de-skilling.”) People also fear robots will make work more stressful, perhaps even more dangerous.

Beth Gutelius, an urban planner and economist at the University of Illinois at Chicago who has researched the warehouse industry, told me about one warehouse she visited after it introduced robots. The robots were quickly delivering goods to humans for packing, and this was saving the workers a lot of walking back and forth. It also made them feel rushed and eliminated their chance to speak to one another.

Employers should consider that this kind of stress on employees “is not healthy, and it’s real, and it has impacts on the well-being of the workers,” said Dawn Castillo, an epidemiologist who manages occupational robot research at the National Institute for Occupational Safety and Health at the CDC. The Center for Occupational Robotics Research actually expects robot-related deaths “will likely increase over time,” according to its website. This is because there are more robots in more places with each passing year, but also because robots are working in new settings—where they meet people who don’t know what to expect and situations that their designers didn’t necessarily anticipate.

In San Pedro, after Buscaino won a city council vote to block the automation plan, the International Longshore and Warehouse Union negotiated what the union’s local chapter president called a “bittersweet” deal with Maersk, the Danish conglomerate that

operates the container terminal. The dockworkers agreed to end the fight against robots in exchange for 450 mechanics getting "upskilled": trained to work on the robots. Another 450 workers will be "reskilled": trained to work at new, tech-friendly jobs.

How effective all that retraining will be, especially for middle-aged workers, remains to be seen, Buscaino said. A friend of his is a mechanic, whose background with cars and trucks leaves him well positioned to add robot maintenance to his skills. On the other hand, "my brother-in-law Dominic, who is a longshoreman today, he has no clue how to work on these robots. And he's 56."

The word "robot" is precisely 100 years old this year. It was coined by the Czech writer Karel Čapek, in a play that set the template for a century's machine dreams and nightmares. The robots in that play, *R.U.R.,* look and act like people, do all the work of humans—and wipe out the human race before the curtain falls.

Ever since, imaginary robots from the *Terminator* to Japan's *Astro Boy* to those *Star Wars* droids have had a huge influence on the plans of robotmakers. They also have shaped the public's expectations of what robots are and what they can do.

Tensho Goto is a monk in the Rinzai school of Japanese Zen Buddhism. A vigorous, sturdy man with a cheerful manner, Goto met me in a spare, elegant room at Kodai-ji, the 17th-century temple in Kyoto where he is the chief steward. He seemed the picture of tradition. Yet he has been dreaming of robots for many years. It began decades ago, when he read about artificial minds and thought about reproducing the Buddha himself in silicone, plastic, and metal. With android versions of the sages, he said, Buddhists could "hear their words directly."

Once he began collaborating with roboticists at Osaka University, though, robot reality dampened the robot dream. He learned that "as AI technology exists today, it is impossible to create human intelligence, let alone the personages of those who have attained enlightenment." But like many roboticists, he didn't give up, instead settling for what is possible today.

It stands at one end of a white-walled room on the temple grounds: a metal and silicone incarnation of Kannon, the deity who in Japanese Buddhism embodies compassion and mercy. For centuries, temples and shrines have used statues to attract people and get them to focus on Buddhist tenets. "Now, for the first time, a statue moves," Goto said.

Mindar, as the robot is called, delivers prerecorded sermons in a forceful, not-quite-human female voice, gently gesticulating with her arms and turning her head from side to side to survey the audience. When her eyes fall on you, you feel something—but it isn't her intelligence. There is no AI in Mindar. Goto hopes that will change over time, and that his moving statue will become capable of holding conversations with people and answering their religious questions.

Across the Pacific, in a nondescript house in a quiet suburb of San Diego, I met a man who seeks to provide a different kind of intimate experience with robots. Artist Matt McMullen is CEO of a company called Abyss Creations, which makes realistic, life-size sex dolls. McMullen leads a team of programmers, robotics specialists, special-effects experts, engineers, and artists who create robot companions that can appeal to hearts and minds as well as sex organs.

The company has made silicone-skin, steel-skeleton RealDolls for more than a decade. They go for about $4,000. But these days, for an additional $8,000, a customer receives a robotic head packed with electronics that power facial expressions, a voice, and an artificial intelligence that can be programmed via a smartphone app.

Like Siri or Alexa, the doll's AI gets to know the user via the commands and questions he or she gives it. Below the neck, for now, the robot is still a doll—its arms and legs move only when the user manipulates them.

"We don't today have a real artificial intelligence that resembles a human mind," McMullen acknowledges. "But I think we will. I think that is inevitable." He has no doubt the market is there. "I think there are people who can greatly benefit from robots that look like people," he said.

We are getting attached already to ones that don't look much like us at all.

Military units have held funerals for bomb-clearing robots blown up in action. Nurses in hospitals tease their robot colleagues.

People in experiments have declined to rat out their robot teammates. As robots get more lifelike, people probably will invest them with even more affection and trust—too much, perhaps. The influence of fantasy robots leads people to think that today's real machines are far more capable than they really are. Adapting well to their presence among us, experts told me, must start with realistic expectations.

Robots can be programmed or trained to do a well-defined task—dig a foundation, harvest lettuce—better or at least more consistently than humans can. But none can equal the human mind's ability to do a lot of different tasks, especially unexpected ones. None has yet mastered common sense.

Today's robots can't match human hands either, said Chico Marks, a manufacturing engineering manager at Subaru's auto plant in Lafayette, Indiana. The plant, like those of all carmakers, has used standard industrial robots for decades. It's now gradually adding new types, for tasks such as moving self-guided carts that take parts around the plant. Marks showed me a combination of wires that would snake through a curving section near a future car's rear door.

"Routing a wiring harness into a vehicle is not something that lends itself well to automation," Marks said. "It requires a human brain and tactile feedback to know it's in the right place and connected."

Robot legs aren't any better. In 1996 Veloso, the Carnegie Mellon AI roboticist, was part of a challenge to create robots that would play soccer better than humans by 2050. She was one of a group of researchers that year who created the RoboCup tournament to spur progress. Today RoboCup is a well-loved tradition for engineers on several continents, but no one, including Veloso, expects robots to play soccer better than humans anytime soon.

"It's crazy how sophisticated our bodies are as machines," she said. "We're very good at handling gravity, dealing with forces as we walk, being pushed and keeping our balance. It's going to be many years before a bipedal robot can walk as well as a person."

Robots are not going to be artificial people. We need to adapt to them, as Veloso said, as to a different species—and most robotmakers are working hard to engineer robots that make allowances for our human feelings. At the wind farm site, I learned that "bouncing" the toothed bucket of a big excavator against the ground is a sign of inexperience in a human operator. (The resulting jolt can actually injure the person in the cab.) To a robot excavator, the bounce makes little difference. Yet Built Robotics changed its robot's algorithms to avoid bounce, because it looks bad to human professionals, and Mortenson wants workers of all species to get along.

It's not just people who change as robots come on line. Taylor Farms, Borman told me, is working on a new light bulb–shaped lettuce with a longer stalk. It won't taste or feel different; that shape is just easier for a robot to cut.

Bossa Nova Robotics makes a robot that roams thousands of stores in North America, including 500 Walmarts, scanning shelves to track inventory. The firm's engineers asked themselves how friendly and approachable their robot should look. In the end it looks like a portable air conditioner with a six-and-a-half-foot-high periscope attached—no face or eyes.

"It's a tool," explained Sarjoun Skaff, Bossa Nova's co-founder and chief technology officer. He and the other engineers wanted shoppers and workers to like the machine, but not too much. Too industrial or too strange, and shoppers would flee. Too friendly, and people would chat and play with it and slow down its work. In the long run, Skaff told me, robots and people will settle on "a common set of human-robot interaction conventions" that will enable humans to know "how to interpret what the robot is doing and how to behave around it." But for now, robotmakers and ordinary people are feeling their way there.

Outside Tokyo, at the factory of Glory, a maker of money-handling devices, I stopped at a workstation where a nine-member team was assembling a coin-change machine. A plastic-sheathed sheet of paper displayed photos and names of three women, two men, and four robots.

The gleaming white, two-armed robots, which looked a little like the offspring of a refrigerator and WALL·E, were named after currencies. As I watched the team swiftly add parts to a coin changer, a robot named Dollar needed help a couple of times—once

when it couldn't peel the backing off a sticker. A red light near its station went on, and a human quickly left his own spot on the line to fix the problem.

Dollar has cameras on its "wrists," but it also has a head with two camera eyes. "Conceptually it is meant to be a human-shaped robot," explained manager Toshifumi Kobayashi. "So it has a head."

That little accommodation didn't immediately convince the real humans, said Shota Akasaka, 32, a boyish and smiling team leader. "I was really not sure that it would be able to do human work, that it would be able to screw in a screw," he said. "When I saw the screw go in perfectly, I realized we were at the dawn of a new era."

In a conference room northeast of Tokyo, I learned what it's like to work with a robot in the closest way: by wearing it.

The exoskeleton, manufactured by a Japanese firm called Cyberdyne, consisted of two connected white tubes that curved across my back, a belt at my waist, and two straps on my thighs. It felt like being strapped into a parachute or an amusement park ride. I bent at the waist to lift a 40-pound container of water, which should have hurt my lower back. Instead, a computer in the tubes used the change in position to deduce that I was lifting an object, and motors kicked in to assist me. (More advanced users would have worn electrodes so the device could read the signals their brain was sending to their muscles.)

The robot was designed to assist only my back muscles; when I squatted and put the effort into my legs, as you're supposed to, the device didn't help much. Still, when it worked, it seemed like a magic trick—I felt the weight, then I didn't.

Cyberdyne sees a large market in medical rehabilitation; it also makes a lower-limb exoskeleton that is being used to help people regain the use of their own legs. For many of its products, "another market will be for workers, so they can work longer and without risking injuries," Cyberdyne spokesman Yudai Katami said.

Sarcos Robotics, the other maker of exoskeletons, is thinking along similar lines. One purpose of his devices, said CEO Wolff, was "allowing humans to be more productive so they can keep up with the machines that enable automation."

Will we adapt to the machines more than they adapt to us? We might be asked to. Roboticists dream of machines that make life better, but companies sometimes have incentives to install robots that don't. Robots, after all, don't need paid vacations or medical insurance. Beyond that, many nations get a lot of tax revenue from labor, while encouraging automation with tax breaks and other incentives. Companies thus save money by cutting employees and adding robots.

"You get a lot of subsidies for installing equipment, especially digital equipment and robots," Acemoglu said. "So that encourages firms to go for machines rather than humans, even if machines are no better." Robots also are just more exciting than mere humans.

There is "a particular zeitgeist among many technologists and managers that humans are troublesome," Acemoglu said. There's this feeling of, "You don't need them. They make mistakes. They make demands. Let's go for automation."

After Noah Ready-Campbell decided to go into construction robots, his father, Scott Campbell, spent more than three hours on a car ride gently asking him if this was really such a good idea. The elder Campbell, who used to work in construction himself, now represents the town of St. Johnsbury in Vermont's general assembly. He quickly came to believe in his son's work, but his constituents worry about robots, he told me, and it's not all about economics. Perhaps it will be possible to give all our work to robots someday—even the work of religious ministry, even "sex work." But Campbell's constituents want to keep something for humanity: the work that makes humans feel valued.

"What is important about work is not what you get for it but what you become by doing it," Campbell said. "I feel like it's profoundly true. That's the most important thing about doing a job."

A century after they were first dreamed up for the stage, real robots are making life easier and safer for some people. They're also making it a bit more robot-like. For many companies, that's part of the attraction.

“Right now every construction site is different, and every operator is an artist,” said Gaurav Kikani, Built Robotics’ vice president for strategy, operations, and finance. Operators like the variety; employers not so much. They save time and money when they know that a task is done the same way every time and doesn’t depend on an individual’s decisions. Though construction sites will always need human adaptability and ingenuity for some tasks, “with robots we see an opportunity to standardize practices and create efficiencies for the tasks where robots are appropriate,” Kikani said.

In the moments when someone has to decide whose preferences ought to prevail, technology itself has no answers. However far they advance, there’s one task that robots won’t help us solve: Deciding how, when, and where to use them.

David Berreby’s feature “The Things That Divide Us” appeared in the special Race Issue, April 2018. Photographer **Spencer Lowell** documented the construction of the Mars Curiosity rover for NASA.