2030

HOW TODAY'S BIGGEST TRENDS WILL COLLIDE AND RESHAPE THE FUTURE OF EVERYTHING

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transistor did away with the vacuum tube, the jet engine outdid the propeller, the CD turned vinyl into a collector's item, the word processor rendered the typewriter obsolete, digital imaging supplanted chemical photography, and video games proved more entertaining than traditional toys. We use the term "disruption" to refer to such dramatic transformations, with the wristwatch being just one illustration of this pervasive pattern.

A NEW CAMBRIAN EXPLOSION OF CREATIVE DESTRUCTION

Technology disrupts the status quo by changing one or more of the following: the concept of the product, the way it is made, how it is sold, who uses it, how people use it, or how people interact with one another. The average lifetime of a company on the Standard & Poor's 500 stock index has declined from sixty years to a mere ten years over the last half century. By 2030, technological change will usher in a new reality in which there will be billions of computers, sensors, and robotic arms in factories, offices, hospitals, schools, homes, vehicles, and all types of infrastructure. For the first time, there will be more computers than human brains, more sensors than eyes, and more robotic arms than human labor in manufacturing. We're going through the technological equivalent of the Cambrian explosion, which took place 541 million years ago and lasted between 13 million and 25 million years. It was during the Cambrian that complex animal species appeared on land and marine ecosystems developed. Until that moment, most organisms were single-celled. During the Cambrian, small organisms every bit as intricate as today's animals emerged, including a five-eyed carnivore and a lace crab with a head, spine, thorax, legs, and two pairs of antennae.

From virtual reality to 3-D printing, and from artificial intelligence to nanotechnologies, it is only a mild exaggeration to compare today's transformation to the Cambrian explosion. These new technologies promise to address all manner of otherwise intractable problems, from poverty and disease to environmental degradation, climate change, and social isolation. They are giving rise to a new class of mostly young, visionary entrepreneurs, many of

them in their twenties, self-described as "masters of the universe," to borrow a line from Tom Wolfe.

Each technological wave of disruption is accompanied by the illusion that technology can liberate us from our problems, small and large. In fact, it is a force that tends to both create problems and generate solutions. Automation, for instance, frees humans from the boredom and often dire physical and psychological consequences of repetitive work, perhaps best illustrated by Charlie Chaplin in the classic movie *Modern Times*. However, it also has the effect of displacing workers from jobs that provided a reliable path into the middle class decades ago. If workers lack the flexibility or the resources to rotate into other occupations, they may find themselves displaced without a plan B, something that can be further complicated by one's age or ability to travel in search of new opportunities. Entire job categories and communities can be sunk because someone invented or innovated in a space traditionally reliant on human labor, oversight, and expertise.

The Austrian economist and political scientist Joseph Schumpeter came up with one of the most felicitous metaphors of all time—"creative destruction"—to describe the essence of what we've been exploring. He argued that the market economy's tendency to incorporate new technologies and their cascading impacts, which then displace older, inefficient ones, is both its corrosive aspect and its strength. "The fundamental impulse that sets and keeps the capitalist engine in motion," he wrote in 1942, "comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates." He described this dynamic as "the process of industrial mutation that incessantly revolutionizes the economic structure *from within*, incessantly destroying the old one, incessantly creating a new one." He concluded that "this process of Creative Destruction is the essential fact about capitalism."

Schumpeter thus reminds us that disruption is as normal as it is ubiquitous; it has reshaped human life since the beginning of the agricultural revolution about twelve thousand years ago. While it is not a new phenomenon, it seems to happen more frequently and more quickly as time goes on. It's a force

that transforms not just the economy but every aspect of life, from politics to interpersonal relationships.

"COMPUTERS ARE USELESS—THEY CAN ONLY GIVE YOU ANSWERS"

When technological disruption arrives—as happens time and again; witness the watch—the diabolical dynamic of creative destruction ensues: lives are dislocated, careers are derailed, and communities are shattered.

In terms of its potential consequences, the field of artificial intelligence (AI) is fertile ground for analysis. As with the watch, there are competing interests and beliefs regarding where we are right now and where we're headed. Back in 1992, the *Economist* editorialized about "Artificial Stupidity," saying that "there is no practical reason to create machine intelligences indistinguishable from human ones" because "people are in plentiful supply." They also observed that "should a shortage arise, there are proven and popular methods for making more of them." (That's assuming people want to procreate, which we now know was wishful thinking back in the 1990s.) In a similar vein, Elon Musk recently tweeted that "excessive automation at Tesla was a mistake," adding that "humans are underrated." And Pablo Picasso once observed that "computers are useless—they can only give you answers."

In reality, AI opens up a whole array of new opportunities, and that's one big reason why the world as we know it is coming to an end. AI includes a wide array of applications to perform tasks that have traditionally been the province of the human brain, such as speech recognition, visual perception, and decision-making. It is being deployed in self-driving cars and trucks, efficient and responsive infrastructure, and smart medical and living systems. In our lifetime, AI has accelerated considerably. In 1997 IBM's Deep Blue computer defeated chess champion Gary Kasparov. A year later, Tiger Electronics developed a robotic toy with voice-recognition technology. In 2000 Honda launched ASIMO, a humanoid robot serving as a multifunctional personal assistant. In 2011 Apple incorporated a virtual assistant, Siri, into its smartphones. From targeted social media advertising to photo tagging, AI is already all around

us. In China the state security apparatus is using AI-enabled face-recognition technology to monitor people in small villages in their everyday endeavors. The goal of this program, known as Sharp Eyes, is to calculate a score for each citizen based on actual behavior. It's eerily reminiscent of George Orwell's Big Brother in *1984*.

Some visionaries predict that the world will come to an end, literally, when the "singularity" arrives—that is, the point when AI is sophisticated and smart enough to take over and render us humans, as a whole, useless. It's a future in which machines program and control other machines. It would be, as the computer scientist Irving Good argued in 1965, "the *last* invention that man need ever make." His colleague Alan Turing, who led the effort to break Germany's Enigma secret code during World War II and helped pioneer the computer itself, declared in 1951 that AI would "outstrip our feeble powers" and "take control." Theoretical physicist Stephen Hawking added his two cents by saying that it "could spell the end of the human race."

Apocalypse aside, there is little doubt that AI will bring about epochal change. There are, as we speak, hundreds of thousands of programmers advancing the reach and power of intelligent machine learning and its applications.

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Meanwhile, back on the ground at a truck stop somewhere in the American heartland, tractor-trailer drivers are taking a quick rest. They do an essential job for the economy: hauling merchandise around the country. They labor long hours for little pay, especially if they are independent contractors. For those engaged in long-haul trucking, belonging to any one community is difficult. Truck drivers constitute the largest occupational group in twenty-nine of the fifty states of the Union. The only exceptions are most of New England, the Mid-Atlantic, California, and Texas, where either software developers, primary school teachers, farmers, secretaries, nursing aides, retail clerks, customer service representatives, or lawyers take the top spot. According to one study commissioned by the Obama White House, between 1.5 million and 2.2 million light- and heavy-truck drivers are at risk of losing their jobs as a result of autonomous vehicle technology. That's between 60 and 90 percent of the total number of drivers

employed in 2015. If one adds bus drivers, taxi drivers, chauffeurs, and self-employed drivers, the total potential job loss from this technology could top 3 million.

Current experiments with autonomous vehicles indicate a bright future because human beings are sloppy and unreliable. We can get distracted, bored, or tired. A computer can optimize a complex trip and adapt to traffic and road conditions, all while being fuel-efficient. Most importantly, computers can communicate with other computers. We communicate with each other on the road by relying on primitive means like lights, horns, and hand signals. By contrast, a self-driving car, in tandem with other cars in its vicinity, can collectively manage traffic flow (and reduce accidents) in a coordinated manner.

And it doesn't end there. In manufacturing, a single robot can displace an average of five to six workers. The number of people employed in repetitive manual labor jobs in the United States stood at 28 million in 1983. By 2015 that number had only increased to 30 million. During that time period, 300,000 robots were installed, doing the work of nearly 2 million workers. Technology is partly responsible for the stagnation of the American middle class of routine manual and non-manual or cognitive workers we discussed in Chapter 3. And now that 35,000 robots are being installed each year, the impact will accelerate over the next decade. By 2030 the manufacturing sector will employ more programmers and controllers than day laborers.

Similarly, the number of routine cognitive jobs grew from 28 to 33 million, including primarily office workers and shop attendants. By contrast, non-routine manual jobs such as skilled mechanics increased from 14 million to 27 million, and non-routine cognitive occupations like teachers, designers, programmers, and healthcare workers rose from 28 million to a whopping 57 million. At least for now, it seems as if there are certain jobs beyond the reach of technology's powers of creative destruction.

But it won't be long before routine cognitive occupations such as office and administration work are affected by AI, and in numbers as seismic as big data itself. Surgeons performing routine procedures, young lawyers helping put

together a legal case, and professors teaching introductory subjects are at risk of seeing their jobs performed by intelligent machines. The next, and perhaps final, step would be the elimination of some non-routine jobs, especially if the singularity does in fact arrive.

Consider the tasks performed by a surgeon, among the most complex and sophisticated in the world, for which nearly ten years of advanced education and on-the-job training are required. "In a robotic surgery breakthrough," the Institute of Electrical and Electronics Engineers reported in 2016, "a bot stitched up a pig's small intestines using its own vision, tools, and intelligence to carry out the procedure." More importantly, "the Smart Tissue Autonomous Robot (STAR) did a better job on the operation than human surgeons who were given the same task." The sutures made by human surgeons were less consistent and less resistant to leaks than the robot's stitches. In the words of Peter Kim, a pediatric surgeon who participated in the research, "Even though we surgeons take pride in our craft at doing procedures, to have a machine that works with us to improve outcomes and safety would be a tremendous benefit." He thinks robots will first offer human surgeons a helping hand, just like self-driving cars "started with parking, then a technology that tells you not to go into the wrong lane." In that sense, robotics would not necessarily displace workers, but it could help them be better at what they do.

Another attractive feature of robots is that they aren't judgmental—at least not yet. "We spend a lot of time talking to Alexa and Siri," argues journalist Laura Sydell. "Imagine if such artificial personalities were put inside a cute, adorable robot." Alexander Reben, a researcher at MIT, built a robot out of cardboard called Boxie. One day he found a man sharing his troubles with Boxie. He "just started talking to this thing like it was another person." Reben decided to team up with artist and filmmaker Brent Hoff to design a cute robot that would encourage people to open up. "It's the perfect smile," Hoff says. "It's open and engaging to make sure [it is] as nonjudgmental and nonthreatening as possible." And early results show that it's working. Sherry Turkle, an MIT expert on human-machine interactions, says that it isn't difficult to get humans to open up to a robot: "We are kind of cheap dates."

THE TROLLEY PROBLEM IN THE AGE OF THE INTELLIGENT MACHINE

Technology brings benefits—and ethical dilemmas. Imagine a driverless car approaching an intersection and planning to make a right turn. The sensors on the vehicle carefully monitor the biker on the right. Suddenly a toddler frees himself from his mother's hand and darts across the street. The computer must decide in a split second whether to spare the biker or the child. There's no time to collect more data or to make elaborate calculations about how to inflict the least damage, or to consider how to prioritize one life over another, the young child's or the biker's. What will the computer do?

This is a modified version of the classic thought experiment known as the "trolley problem." In this problem, a runaway tram speeding down the tracks is about to hit and kill five people. If you could switch the trolley to a different track where it would hit and kill one person, would you do it? The trolley problem reveals a conundrum that cannot be resolved on simple moral or ethical grounds. In the movie *Sophie's Choice*, Meryl Streep plays a Polish mother of two who was part of the resistance during the German occupation. She is captured and sent to Auschwitz, where a Nazi officer puts her in the impossible position of having to choose which of her children will go to the gas chamber and which to the labor camp. In the spur of the moment, Sophie has to make a terrifying choice, and so would the driver in our illustration above. This type of moral dilemma helps explain why drone pilots experience higher rates of post-traumatic stress disorder than conventional pilots. The drone pilots make decisions about life and death from the comfort of a control center thousands of miles away, while real pilots are actually putting their own lives at risk. In a *New York Times* article about a drone operator named Aaron, Eyal Press writes, "What unspooled before Aaron's eyes was jarringly intimate: coffins being carried through the streets after drone strikes." Although he was an experienced military drone operator, Aaron began to feel sick and emotionally distressed. He developed debilitating symptoms including nausea, skin welts, and chronic digestive problems. "I was very, very unwell," he told Press. He was reeling from

the decisions about whom to kill and whom to spare that he had made on a routine basis.

In 2016 and 2017, a team of international researchers convened by MIT conducted a project they called the Moral Machine experiment to assess how people in different cultures deal with these kinds of dilemmas. Using an online platform, they gathered nearly 40 million decisions about driving from more than 2 million people in over two hundred countries and territories. Respondents were presented with thirteen scenarios in which someone's death was inevitable. Some of the decisions were arguably easier to make than others. For instance, should the driver spare a pet or a human? Should a greater or a smaller number of lives take priority? But others were very tough ethically and morally. Should the fit or the physically challenged be spared? What about a criminal or a law-abiding citizen? In the experiment, people displayed a marked tendency to spare humans over animals, more lives over fewer lives, and young lives over older lives. "Accordingly," the researchers reasoned, "these three preferences may be considered essential building blocks for machine ethics."

As would be expected, there were some differences. Both men and women were more inclined to spare females, with women displaying a stronger preference. People who were more religious had a stronger leaning toward sparing humans over animals. And the research unveiled some stark differences across countries. "The preference to spare younger characters rather than older characters is much less pronounced for countries in the Eastern cluster [Confucian countries in Asia and a few Muslim ones], and much higher for countries in the Southern cluster [Latin America and Francophone Africa]. The same is true for the preference for sparing higher status characters." In the Southern cluster people displayed "a much weaker preference for sparing humans over pets." Interestingly, "only the (weak) preference for sparing pedestrians over passengers and the (moderate) preference for sparing the lawful over the unlawful appear to be shared to the same extent in all clusters." In countries with more individualistic cultures people were more likely to spare the young, and in poorer countries people were more tolerant of jaywalkers than pedestrians who observe the rules.

Disturbingly, respondents in countries with more economic inequality were more willing to spare higher-status people.

One troubling implication of the research is that "people who think about machine ethics make it sound like you can come up with a perfect set of rules for robots," said Iyad Rahwan, one of the authors of the study. "What we show here with data is that there are no universal rules." Another co-author, Edmond Awad, noted that "more people have started becoming aware that AI could have different ethical consequences on different groups of people. The fact that we see people engaged with this—I think that that's something promising." As Barbara Wege, a manager at Audi's autonomous vehicle unit in Germany, puts it, "We need to come up with a social consensus about which risks we are willing to take."

The moral dilemmas involved in the trolley problem are not the only ones brought about by the rise of AI. As Srikar Reddy, the chief executive officer of Sonata Software, and I recently argued in a World Economic Forum blog, one must distinguish between deontological and teleological ethical standards, with the former focusing on the intention and the means, and the latter on the ends and outcomes. Which approach is best depends on the technology and the context. "In the case of autonomous vehicles, the end of an error-free transportation system that is also efficient and friendly towards the environment might be enough to justify large-scale data collection about driving under different conditions and also experimentation based on AI applications." By comparison, medical trials based on big data are hard to justify on teleological grounds, given the horrific history of medical experimentation on unsuspecting human subjects. A deontological approach based on intention and means makes more sense.

The ethical and moral dilemmas posed by automation, AI, and big data are becoming hard to ignore. "Never in the history of humanity have we allowed a machine to autonomously decide who should live and who should die, in a fraction of a second, without real-time supervision," the Moral Machine researchers concluded. "We are going to cross that bridge any time now," which, if you're betting on my opinion, is by 2030. "Before we allow our cars to make ethical decisions, we need to have a global conversation to express our preferences to

the companies that will design moral algorithms, and to the policymakers that will regulate them." The issue is that the ethics and morals of automation cannot be automated or laid out in algorithmic form.

"WHO NEEDS THE PARIS CLIMATE ACCORDS WHEN YOU HAVE 3-D PRINTING?"

That's the provocative question posed by Richard A. D'Aveni, a professor at Dartmouth College's Tuck School of Business. New 3-D printers create a three-dimensional object by printing ultra-thin sheets in sequence and stacking them on top of each other to form a three-dimensional shape; the technical term is "additive manufacturing." This technique reduces waste by using only the precise amount of material needed to make everything from plastic parts to dental pieces or human replacement tissue. Like traditional manufacturing, it needs energy, but "it gives off less smoke and other toxic fumes." And the biggest benefits of all will come from the possibility that with "printer farms and mini-factories closer to customers, companies will need much less shipping." We've too readily accepted the idea that in manufacturing, economies of scale are essential to delivering low-cost goods. Mini-mills and flexible production methods began a trend in the 1980s that 3-D printing will accelerate and enlarge, much to the benefit of the environment. "We're going to move away from the throwaway ethic of the 20th century," he predicts. "People will buy less, and be happier with what they get—just what environmentalists have been telling us to do. As we make fewer goods with less material, we'll put much less carbon in the atmosphere."

In other words, 3-D printing will catch on if managers and customers abandon old assumptions and change their habits; if they step out of well-trodden territory to imagine new possibilities; if they think laterally. Instead of manufacturing to stock (storing what they produce in a warehouse so that it's ready to use), companies should learn to produce to real-time demand. Industrial customers should also learn how to wait until they actually need something. "Freight transportation . . . accounts for about a quarter of all carbon emissions in the affluent countries," D'Aveni notes. And the shipping behemoth UPS

relies on an extensive network of warehouses to cater to the needs of its industrial customers. "It recently installed a hundred large 3-D printers at its central hub in Louisville, with the goal of reducing warehouse space and shipping distances. More and more parts will be made only as needed." In 2017 UPS launched a partnership with SAP, the German technology consulting firm, to print spare parts for clients on demand. UPS is effectively reinventing itself "as a logistics company, not a shipper."

The technology of 3-D printing is ideal for customized parts, but don't limit your thinking to dentures. Cities increasingly under the threat of flooding (see Chapter 5) can benefit from 3-D-printed seawalls, Volvo, the Swedish car company, notes, with "complex curved cement surfaces that disperse wave energy in many directions." It has partnered with local organizations in Sydney, Australia, to build an artificial reef resembling mangrove trees, providing a locus for marine life the way a real reef would. The ensuing biodiversity helps remove heavy metals and particulate matter such as plastic from the water. The tiles are made of concrete using 3-D-printed molds.

And there are many other applications that may help us avert the worst of a future climate crisis. As an architect, Platt Boyd grew increasingly frustrated by the limitations of traditional building materials and how wasteful the construction industry is. He decided to become an entrepreneur in the incipient field of 3-D printing. In 2015 he moved his company, Branch Technologies, to a startup accelerator in Chattanooga, Tennessee, because it was the only such facility wired to a citywide gigabit network, as we saw in Chapter 5. Branch uses "a revolutionary technology that combines industrial robots, sophisticated algorithms, and a novel 'freeform' extrusion technology that allows material to solidify in free space," he proudly explains. "This technology, called Cellular Fabrication (C-FABTM), draws inspiration from the way that nature creates form and structure and stands to revolutionize the construction industry through unprecedented design freedom and resource stewardship." The advantages of 3-D printing are manifold. "Branch is democratizing design freedom and developing a new construction product than can be lighter, stronger, faster on-site, and with ten times greater design freedom through a process that is inherently waste-free (additive manufacturing vs. 'subtractive' manufacturing,

which is what nearly every construction method to date has been)." At its headquarters, the company boasts the biggest freeform 3-D printer in the world and holds the record for the world's largest 3-D-printed structure: a bandshell at a Nashville park commemorating the United Nations' Sustainable Development Goals.

Annie Wang and Zach Simkin decided to seize opportunities in 3-D printing as well. They met as MBA students at Wharton. Like most of her classmates, Annie was intent on pursuing a traditional career path upon graduation, working for a large company or bank, whereas Zach was focused exclusively on entrepreneurship. They knew little about 3-D printing. Their first encounter with it occurred while they were taking an innovation class shortly before graduating in 2013. They saw an opportunity to combine artificial intelligence and machine learning to help industrial clients design parts and components that could be made using a 3-D printer. Annie gave up a coveted full-time position with the cosmetics firm Estée Lauder to pursue this visionary but risky project. Seven years later, their company, Senvol, counts multiple U.S. defense agencies, the U.S. Navy, and industrial corporations among its clients. It is one of hundreds of companies, ventures, and initiatives that are contributing to a revival of American manufacturing.

Another revolutionary application for 3-D printing involves some areas of healthcare, including dentistry and "printed tissue" for transplants. And Chinese companies are printing entire homes, a move that may speed up disaster relief and recovery after events such as hurricanes—which are becoming more frequent and devastating because of climate change. Perhaps the most tantalizing prospect for 3-D printing will be space exploration and colonization. Imagine a human settlement on Mars that, instead of asking for equipment, parts, and components to be shipped from Earth, has a 3-D printer available to create everything it needs using local raw materials. That would save not only money but also time, given that it takes seven months to travel from Earth to Mars.

There may be a panoply of benefits from 3-D printing, but it will also endanger some of the most skilled and best-paying blue-collar occupations, especially those involved in certain parts of the supply chain. The political implications could be significant as well (consider the fact that simple firearms can now be made using 3-D printers). What's essential to grasp about automation, AI,

and 3-D printing is that they truly change the rules of the game. Automation redefines the relationship between people and work. AI replaces human mental activity with machine learning and human speech with natural language processing. The 3-D printing technology reconfigures the very way in which buyers and suppliers interact in the economy, and it reshapes our existing transportation ecosystem.

MAKING INSURANCE MORE EXCITING—AND FAIR

Insurance companies are expected to err on the safe side. They calculate risks meticulously, carefully picking and choosing the customers they insure. They are boring because their role in the economy is to shield everyone and everything from catastrophic loss. Unlike manufacturing, nothing truly revolutionary ever happens in the insurance industry. For centuries, insurers have charged higher premiums to people in "high-risk categories" such as smokers, male drivers under the age of thirty, and extreme-sports enthusiasts. This type of classification frequently results in biases and outright discrimination against disadvantaged groups. But in the future, real-time data collection will enable insurance companies to charge pay-as-you-drive rates depending on people's actual behavior on the road, as opposed to generalized stereotypes of certain "at-risk" groups. Bad or high-risk individual drivers will end up paying more for insurance, regardless of whether they are men or women, young or old. The Big Brother connotations are ominous, but many people might agree to the real-time monitoring of their driving behavior if it means lower rates.

The constellation of technologies behind these potential advancements is called the "Internet of Things"—all of the interconnected sensors and other devices designed to run factories, mines, energy systems, transportation systems, retail facilities, vehicles, homes, offices, and even people. It has the potential to revolutionize not just insurance but the entire economy and society. By 2030 there will be about 200 billion devices and sensors connected to it. The fastest areas of growth include factories, cities, healthcare, retail, and transportation. The ecosystem required to implement a comprehensive Internet of Things is expansive, including not just the devices themselves but data transmission and

storage facilities, analysis hubs, and feedback loops. Arguably, a large number of jobs will be created to support this mammoth infrastructure. This wave of creative destruction promises to both eliminate and generate jobs.

TRAINING YOUR BRAIN TO MAKE YOU HAPPIER AND HEALTHIER

Until a few years ago, I thought that virtual reality (VR) appealed only to addicted video game players. Turns out it's far more useful and revolutionary. In healthcare, surgeons and their assistants are now starting to wear VR goggles to visualize the best way to perform complex types of surgery. Psychologists are using VR as a therapy for patients with fear of heights, vertigo, anxiety disorders, and post-traumatic stress disorder. Two researchers at the University of Oxford are using VR to help patients with persecutory delusions, a form of paranoia. "The most effective way to do that is to help the individual learn from experience that the situations they dread are actually safe," they explain. "As the feeling of safety increases, so the delusion diminishes." Their patients experience rapid improvement, even after just one session. "Virtual reality isn't merely here to stay in the gaming world," they note. "We believe it's likely to play a central role in assessment and treatment in the mental health centers of the future." This technology is also being used to reduce anxiety at the dentist's office or while undergoing an MRI.

VR is proving to be effective at stimulating motor functions for people with lesions in certain regions of the brain. Researchers in South Korea have found that "VR equipment can be used to carry significant and appropriate stimulations to an individual's nervous system and thus take advantage of neuroplasticity to stimulate both motor and cognitive systems." In a similar vein, VR is helping some children manage autism. "Both kids and adults use smartphones, computers, smart watches, TVs, and gaming technology on a daily basis and think nothing of it except that it's a good time," notes VR Fitness Insider, a website dedicated to VR applications in the area of well-being. "Some kids and adults with autism who are minimally verbal or are non-verbal use iPads and voice apps to speak for them and as an educational tool every day." By monitoring brain

activity during a VR session, doctors can study the cognitive and social aspects of behavior in kids with and without autism. A therapist can then help patients practice facial and body cues to overcome barriers in social interaction. VR can also help children with autism build social skills in school so that they can learn more easily and effectively. By 2030, this type of technology—coupled with the experience accumulated by doctors and therapists over the decades—might reduce the prevalence of psychological disorders by several orders of magnitude.

ARRESTING CLIMATE CHANGE WITH NANOTECHNOLOGIES

One of the biggest contributors to climate change is the clothing industry. Estimates indicate that it is responsible for about 8 percent of total carbon emissions. That's more than international flights and maritime shipping combined. The new field of nanotechnology could vastly reduce our dependence on synthetic fibers made from fossil fuels. The process of making a T-shirt from polyester emits more than twice as much carbon as making it from cotton. The phenomenon of "fast fashion," with new designs appearing every few weeks, has exacerbated the problem. "There are 20 new garments manufactured per person each year and we are buying 60 percent more than we were in 2000," noted an editorial in *Nature* in 2018. "Each garment is worn less before being disposed of and this shorter lifespan means higher relative manufacturing emissions. . . . There will be continued growth as the middle class expands and purchases increase to match this demographic shift." In addition, there has sometimes been a stigma attached to buying used clothes. By contrast, savvy automobile buyers shop for "pre-owned" vehicles as opposed to new ones.

Nanotechnologies offer other paths to addressing the issue of clothing's contribution to climate change. These technologies involve the manipulation of matter on an atomic, molecular, or supramolecular scale. We're talking here about designing particles as tiny as one-billionth of an inch in size with the goal of arriving at stronger, cheaper, or more environmentally friendly materials. Perhaps the most pervasive application of nanotechnologies will be programmable matter—materials endowed with the ability to change their physical properties, such as shape, density, conductivity, or optical properties,

in response to signals or sensors. By 2030, we may not have to rearrange our closets seasonally; the same garment might provide us with warmth in the winter and relief from heat in the summer. It could even change color in response to the temperature outdoors. The MIT Self-Assembly Lab holds that "clothing that you can wear whatever the weather is no longer a sci-fi dream." Researchers have created "a smart material that works just like the pores on human skin, expanding and contracting depending on the surrounding temperature." The material tightens in cold weather to provide insulation and loosens as the temperature rises, thus allowing for air to circulate.

Nanotechnologies may also help avert the climate tipping point of 2030 by improving energy efficiency. Higher-strength composites are already being used in all manner of goods, from aircraft and automobiles to skis and tennis racquets. They help reduce the amount of energy needed to do the job. The building industry will change as a result of the use of materials that are more durable and energy-saving. "Nanotechnology promises to make thermal insulation more efficient, less reliant on non-renewable resources," and will be "an important strategy on the pathway to green buildings," recent research indicates. "The application of nano insulation materials to limit the wall thickness is one of the greatest potential energy-saving characteristics for the existing buildings, as well as for the architectural heritage."

Programmable matter can also be used as a "universal spare part." The Defense Advanced Research Projects Agency (DARPA) is focused on military applications. Mitchell Zakin, a program manager there, explains that "in the future a soldier will have something that looks like a paint can in the back of his vehicle . . . filled with particles of varying sizes, shapes and capabilities [such as] small computers, ceramics, biological systems—potentially anything the user wants them to be." If in the midst of battle "the soldier needs a wrench of a specific size, [he] broadcasts a message to the container, which causes the particles to automatically form the wrench. After the wrench has been used, the soldier realizes that he needs a hammer. He puts the wrench back into the can where it disassembles itself back into its components and re-forms into a hammer." Similarly, programmable matter would enable an aircraft to change the shape, density, or flexibility of its wings, making them more energy-efficient