TIME

SPECIAL EDITION

Artificial Intelligence

The Future of Humankind

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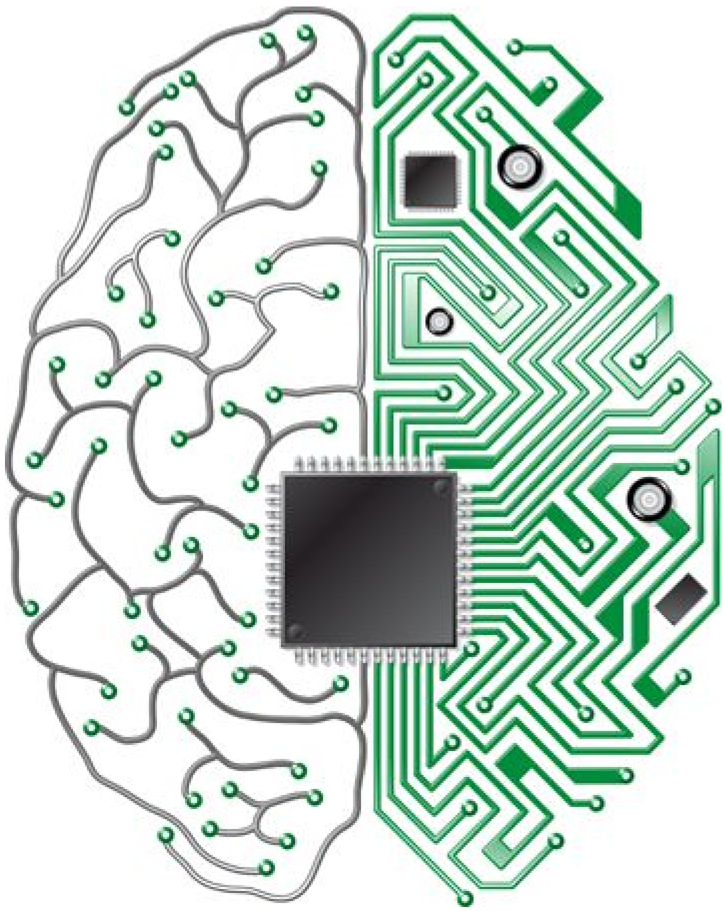

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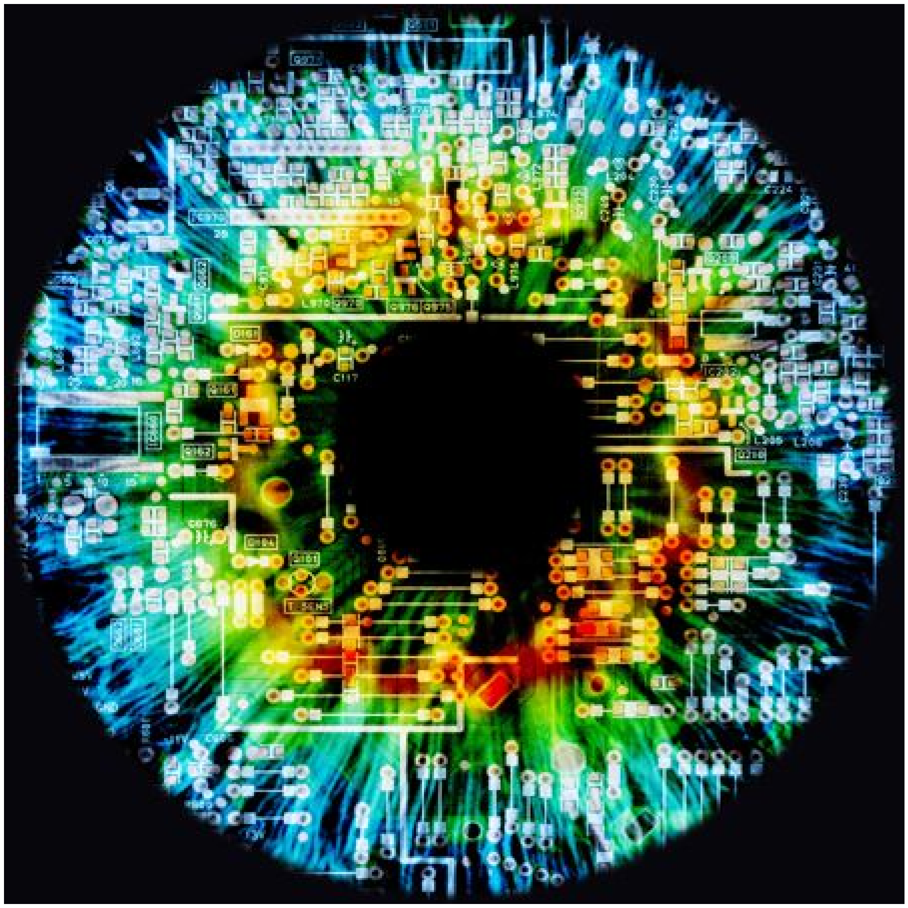

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Parts of this edition were previously published by TIME and *Fortune*.

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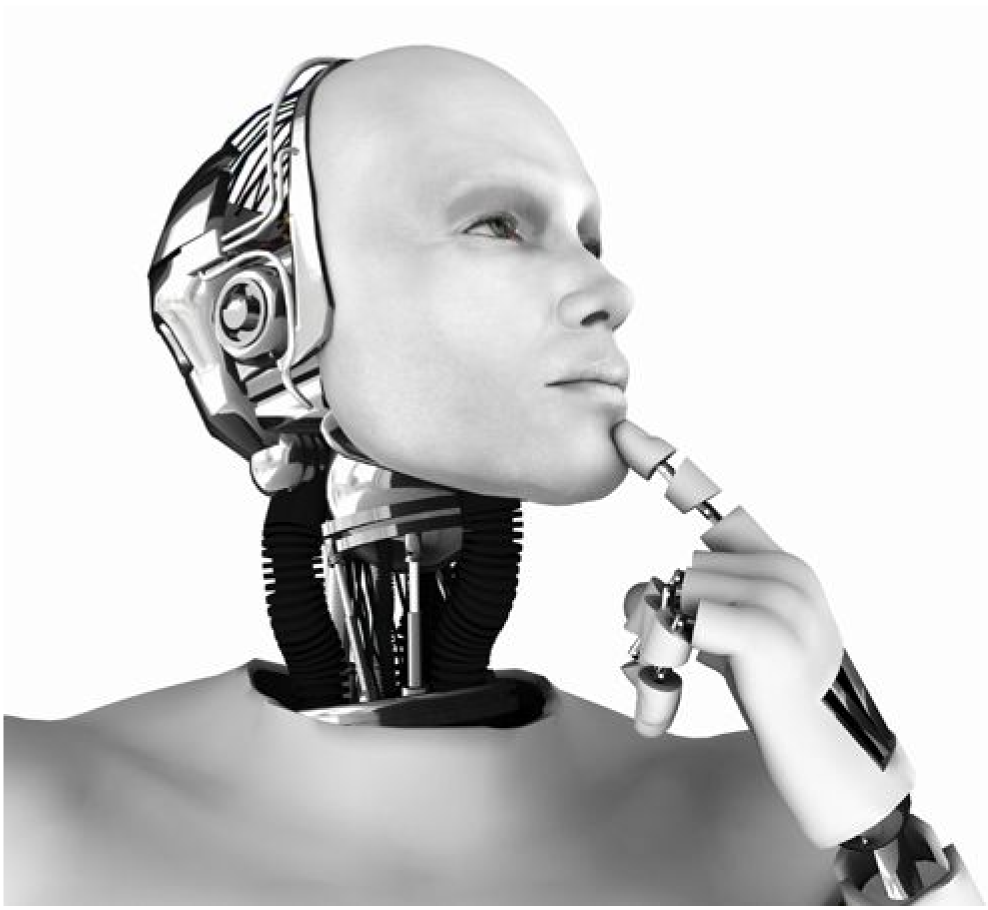
INTRODUCTION:

How A.I. Is Transforming Our World

Artificial intelligence is spreading into our homes, our jobs, our hospitals—and outer space

By Matt Vella



The field of artificial intelligence research was born on the leafy campus of Dartmouth College in the summer of 1956. Over the course of six weeks, a small group of mathematicians and scientists met daily on the top floor of the college's math department, abandoned by students and faculty for the midyear break. The workshop amounted to an extended brainstorming session, forgoing directed group research in favor of freewheeling discussion and debate. The group, credited with coining the term "artificial intelligence," proposed to show "that every aspect of learning or any other

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feature of intelligence can in principle be so precisely described that a machine can be made to simulate it." They went on: "We think that a significant advance can be made in one or more of these problems if a carefully selected group of scientists work on it together for a summer."

It may have been a midcentury humblebrag, but they did what they set out to do. And in the process, they founded the discipline now clearly on the verge of revolutionizing the world. Artificial intelligence, as the pages that follow show, is poised to dramatically change everything from how astronomers explore the edges of our universe to whether your stereo understands you were asking for more John Lennon, not John Legend. Almost all the hallmarks of our current technological moment—talkative digital personal assistants like Siri and Alexa, genomic-research breakthroughs, instantaneous language translation, self-driving cars—have at their foundation one key, if broad, thing in common: artificial intelligence, or A.I. Several decades after that summer of theory at Dartmouth, the field is experiencing something akin to the Cambrian explosion, the geological era when most higher animal species suddenly burst onto the Earth.

What few realize is that all these breakthroughs are, in fact, one big breakthrough. They have more or less been made possible by a subset of A.I. known as deep learning, or deep neural networks, as academics refer to them. These concepts, some of which were debated at Dartmouth all those decades ago, essentially describe self-teaching computer programs. Rather than programming for every conceivable scenario, engineers have given the computers behind, say, advanced voice recognition a learning algorithm and proceeded to feed it terabytes of data—years' worth of speech samples, for example. Then the computer attempts to figure it out for itself. This basic formula is being repeated in medical diagnoses, self-piloting vehicles, crash-proof drones, you name it. The combination of today's vast computational power and the enormous storehouse of data that is the internet proved to be the catalyst to make the A.I. revolution move from theory to world-changing practice.

This volume explores the recent evolution of that practice. Roger Parloff's story on the deep-learning revolution shows how broad the A.I. movement has become in recent years, and the thread of his argument extends to fields ranging from the military and astronomy to medicine and the labor market. Other stories in this special edition show how A.I. is creeping into our day-

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to-day lives, especially in the ever-smarter technology consumers find they can't live without—their phones and voice-controlled home gadgets and so on. The final section looks at the culture's attempts to quantify and understand what all of this means.

What this book will not do is try to scare you about the impending doom for humanity A.I. supposedly represents. This has been a common trope of science fiction for decades and, more recently, a crutch a little too easily leaned on by Hollywood, from *Terminator* to the latest *Avengers*. Evil A.I. is, after all, the literal deus ex machina.

To be sure, some very smart people legitimately fret over the future of A.I. In 2014, Stephen Hawking didn't mince words with the BBC, saying, "The development of full artificial intelligence could spell the end of the human race." Elon Musk, the multi-hyphenate genius behind PayPal, SpaceX and Tesla, says the technology is "potentially more dangerous than nukes." He nevertheless maintains some investment in the field to keep an eye on its advancements. "With artificial intelligence, we are summoning the demon," Musk once said. "In all those stories where there's the guy with the pentagram and the holy water, it's like—yeah, he's sure he can control the demon. Doesn't work out." Perhaps. But as plentiful as the advances have been in recent years, the so-called singularity—the period of machines capable of reasoning exceeding the human mind—is still nowhere in sight. Even those most wary of A.I.'s advancement and future admit this in conversation sooner or later.

The anxiety around A.I. is part of a much deeper vein of fear. Because, though that summer of 1956 was a fundamental turning point, the absolute history of A.I. began in antiquity, with myths and stories of artificial beings endowed with consciousness by master craftsmen. As Pamela McCorduck, a prolific historian of A.I., put it, artificial intelligence began as "an ancient wish to forge the gods." Examples include the mechanical beings that appear in Greek myths, such as Pygmalion's Galatea and the golden robots of Hephaestus. Middle Ages rumors told of secret alchemical means of imbuing matter with mind: there was Jabir ibn Hayyan's Takwin, Paracelsus's homunculus and Rabbi Judah Loew's Golem, for example. By the 19th century, similar ideas had become cornerstones of Mary Shelley's and, later, Karel Čapek's fiction. Human beings, in other words, have been preoccupied with the idea of artificial intelligence—its potential and its potential pitfalls—for a very long time. And now a new era begins.

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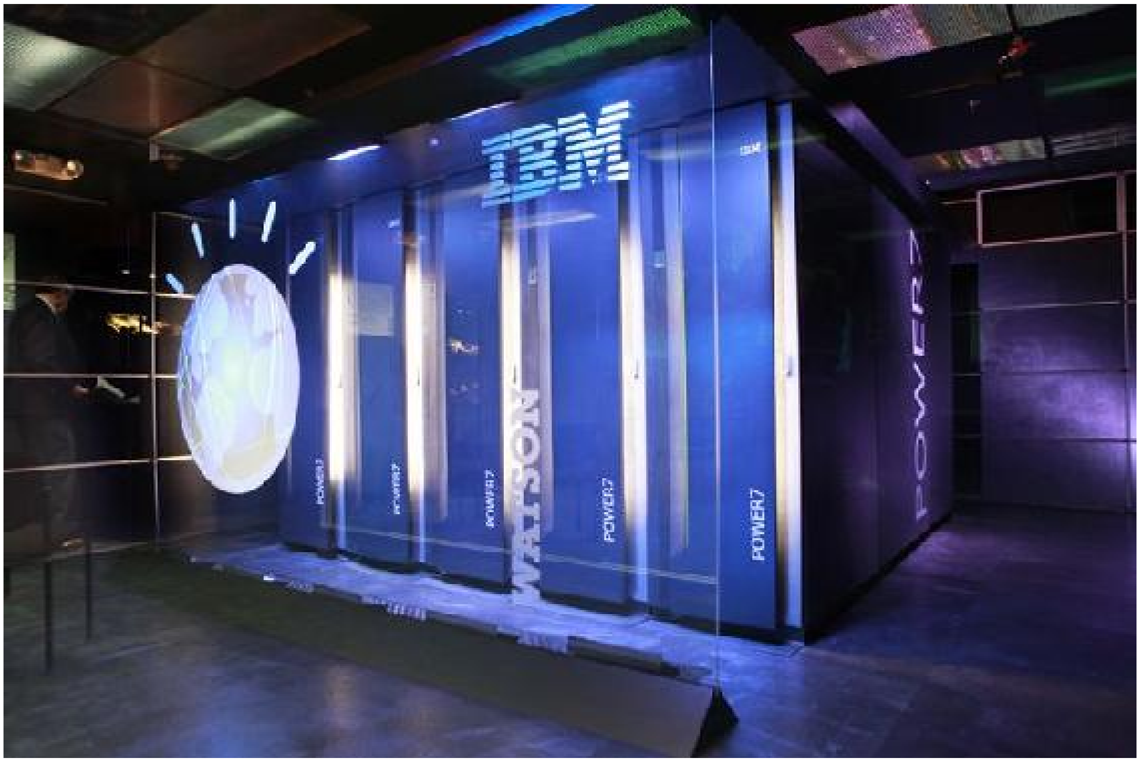

IBM Watson

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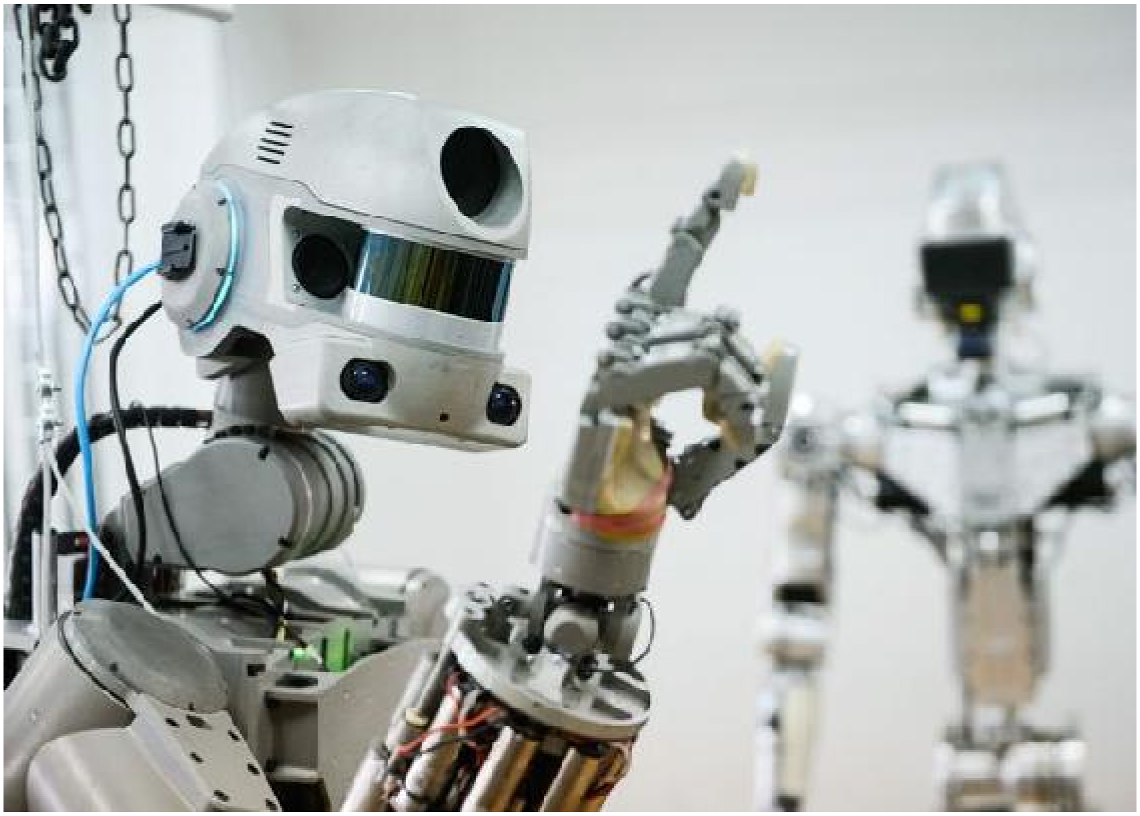
Russian rescue robot FEDOR

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Amazon Echo

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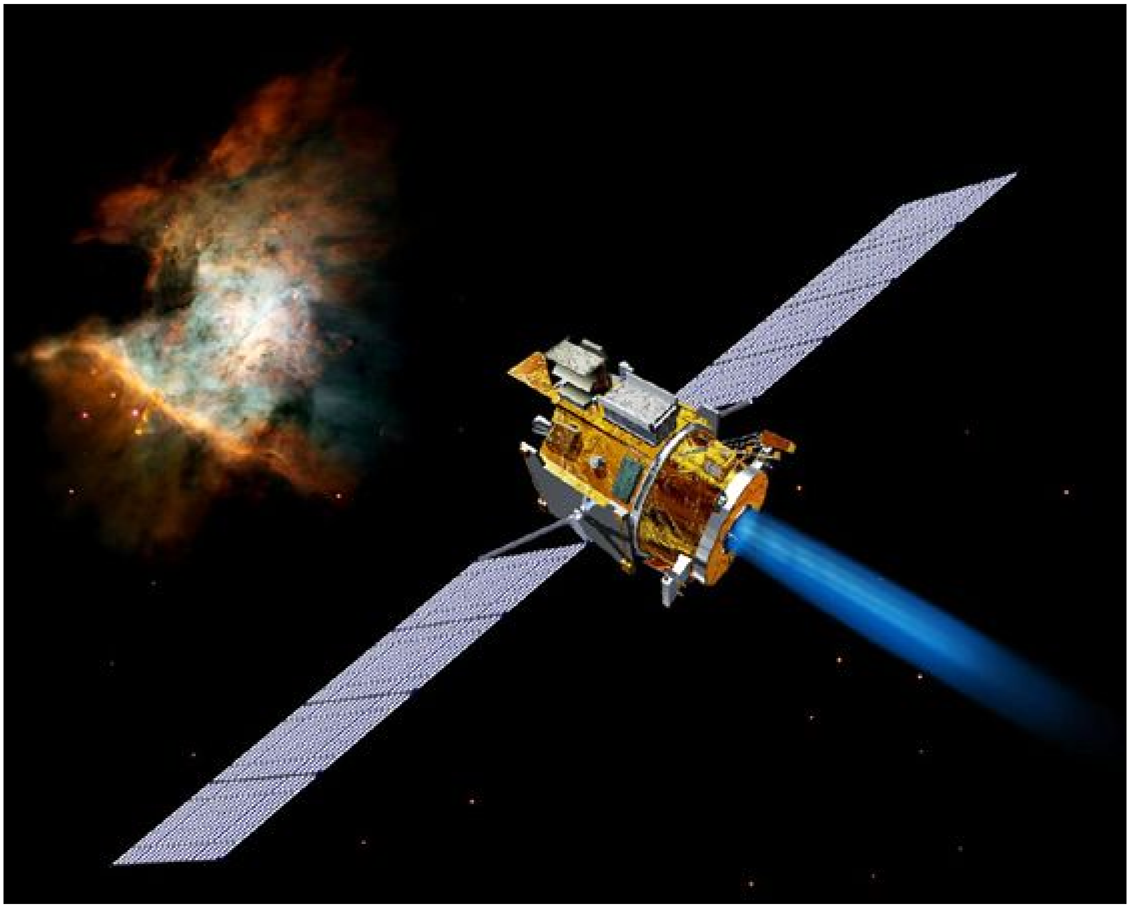
Deep Space 1

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Glossary of A.I. Terms

Artificial Intelligence

A.I. is the broadest term, applying to any technique that enables computers to mimic human intelligence, using logic, if-then rules, decision trees and machine learning.

Machine Learning

The subset of A.I. that includes statistical techniques that enable machines to improve at tasks with experience.

Deep Learning

The subset of machine learning composed of algorithms that permit software to train itself to perform tasks, like speech and image recognition, by exposing multilayered neural networks to vast amounts of data.

Neural Networks or Neural Nets

Software constructions modeled after the way adaptable networks of neurons in the brain are understood to work, rather than through rigid instructions predetermined by humans.

Big Data

Extremely large data sets that are used for computational analysis, many for neural nets to reveal patterns or trends.

Singularity

The hypothesized time/state at which superintelligent machines begin improving themselves without human involvement.

Natural-Language Processing

The computer processing that takes place in speech-recognition technology, in which software is able to recognize spoken sentences and is able to re-create spoken language into text.

Quantum Computing

A computing form that combines digital computing with quantum physics. Quantum computers abide by principles such as superposition and utilize qubits, or quantum bits. Quantum computers operate about 100 million

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times as fast as personal computers and, crucially, can perform simultaneous calculations at rates that increase exponentially.

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The Age of Intelligence

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- Machines in the Military
- Cosmic Intelligence
- The Computer Will See You Now
- Caution: Robots Working
- Q&A: Assessing the Future

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The Deep-Learning Revolution

Why decades-old discoveries are suddenly changing your life and electrifying the computing industry, and why they'll soon transform corporate America

By Roger Parloff

A conception of how deep learning might be used to identify a face

Over the past four years, readers have doubtless noticed quantum leaps in the quality of a wide range of everyday technologies. Most obviously, the speech-recognition function on our smartphones works much better than it used to. When we use a voice command to call our spouses, we reach them now. We aren't connected to Amtrak or an angry ex.

Machine translation and other forms of language processing have become far more convincing, with Google, Microsoft, Facebook and Baidu unveiling new tricks every month. Google Translate now renders spoken sentences in one language into spoken sentences in another for 32 pairs of

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languages, while offering text translations for 103 tongues, including Cebuano, Igbo and Zulu. Google's Inbox app offers three ready-made replies for many incoming emails.

Then there are the advances in image recognition. These same four companies all have features that let you search or automatically organize collections of photos with no identifying tags. You can ask to be shown, say, all the ones that have dogs in them, or snow, or even something fairly abstract like hugs. The companies all have prototypes in the works that generate sentence-long descriptions for the photos in seconds.

Think about that. To gather up dog pictures, the app must identify anything from a Chihuahua to a German shepherd and not be tripped up if the pup is upside down or partially obscured, at the right of the frame or the left, in fog or snow, sun or shade. At the same time, it needs to exclude wolves and cats. Using pixels alone. How is that possible?

The advances in image recognition extend far beyond cool social apps. Medical startups claim they will soon be able to use computers to read x-rays, MRIs and CT scans more rapidly and accurately than radiologists, to diagnose cancer earlier and less invasively, and to accelerate the search for lifesaving pharmaceuticals. Better image recognition is crucial to unleashing improvements in robotics, autonomous drones and, of course, self-driving cars. Ford, Tesla, Uber, Baidu and Google parent Alphabet are all testing prototypes of self-piloting vehicles on public roads today.

But what most people don't realize is that all these breakthroughs are, in essence, the same breakthrough. They've all been made possible by a family of artificial-intelligence techniques popularly known as deep learning, though most scientists still prefer to call them by their original academic designation: deep neural networks, or nets.

The most remarkable thing about neural nets is that no human being has programmed a computer to perform any of the stunts described above. In fact, no human could. Programmers have, rather, fed the computer a learning algorithm, exposed it to terabytes of data—hundreds of thousands of images or years' worth of speech samples—to train it, and have then allowed the computer to figure out for itself how to recognize the desired objects, words or sentences.

In short, such computers can now teach themselves. "You essentially have software writing software," says Jen-Hsun Huang, the CEO of graphics-

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processing leader Nvidia, which began placing a big bet on deep learning about five years ago.

Neural nets aren't new. The concept dates back to the 1950s, and many of the key algorithmic breakthroughs occurred in the 1980s and '90s. What's changed is that today computer scientists have finally harnessed both the vast computational power and the enormous storehouses of data—images, video, audio and text files strewn across the internet—that, it turns out, are essential to making neural nets work well. "This is deep learning's Cambrian explosion," says Frank Chen, a partner at the Andreessen Horowitz venture-capital firm, alluding to the geological era when most higher animal species suddenly burst onto the scene.

That dramatic progress has sparked a burst of activity. In the first quarter of 2016, there were 27 acquisitions or funding rounds of A.I. startups, compared with four in the equivalent quarter in 2011, according to the research firm CB Insights. More than $1 billion in investments were made during that stretch, with $600 million coming in the past 18 months.

Google had two deep-learning projects under way in 2012. Today it is pursuing more than 1,000, according to a spokesperson, in all its major product sectors, including search, Android, Gmail, translation, Maps, YouTube and self-driving cars. IBM's Watson system used A.I., but not deep learning, when it beat two *Jeopardy!* champions in 2011. Now, though, almost all of Watson's 30 component services have been augmented by deep learning, according to Watson chief technology officer Rob High.

Venture capitalists who didn't even know what deep learning was five years ago are now wary of startups that don't have it. "We're now living in an age where it's going to be mandatory for people building sophisticated software applications," Chen observes. People will soon demand, he says, " 'Where's your natural-language-processing version?' 'How do I talk to your app? Because I don't want to have to click through menus.' "

Some companies are already integrating deep learning into their own day-to-day processes. Says Peter Lee, the co-head of Microsoft Research, "Our sales teams are using neural nets to recommend which prospects to contact next or what kinds of product offerings to recommend."

The hardware world is feeling the tremors. The increased computational power that is making all this possible derives not only from Moore's law but also from the realization in the late 2000s that graphics processing units (GPUs) made by Nvidia—the powerful chips that were first designed to

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give gamers rich, 3-D visual experiences—were 20 to 50 times as efficient as conventional central processing units (CPUs) for deep-learning computations. In 2016, Nvidia announced that quarterly revenue for its data-center segment had more than doubled year over year, to $151 million. Its chief financial officer told investors that "the vast majority of the growth comes from deep learning by far." The term "deep learning" came up 81 times during the 83-minute earnings call.

Chip giant Intel isn't standing still. It has purchased Nervana Systems (for more than $400 million) and Movidius (price undisclosed), two startups that make technology tailored for different phases of deep-learning computations.

For its part, Google revealed in 2016 that for more than a year it had been secretly using its own tailor-made chips, called tensor processing units, or TPUs, to implement applications trained by deep learning. (Tensors are arrays of numbers, like matrices, which are often multiplied against one another in deep-learning computations.)

Indeed, corporations just may have reached another inflection point. "In the past," says Andrew Ng, the chief scientist at Baidu Research, "a lot of S&P 500 CEOs wished they had started thinking sooner than they did about their internet strategy. I think five years from now, there will be a number of S&P 500 CEOs that will wish they'd started thinking earlier about their A.I. strategy."

Even the internet metaphor doesn't do justice to what A.I. with deep learning will mean, in Ng's view. "A.I. is the new electricity," he says. "Just as 100 years ago electricity transformed industry after industry, A.I. will now do the same."

Think of deep learning as a subset of a subset. "Artificial intelligence" encompasses a vast range of technologies—like traditional logic- and rules-based systems—that enable computers and robots to solve problems in ways that at least superficially resemble thinking. Within that realm is a smaller category called machine learning, which is the name for a whole toolbox of arcane but important mathematical techniques that enable computers to improve at performing tasks with experience. Finally, within machine learning is the smaller subcategory called deep learning.

One way to think of what deep learning does is as "A to B mappings," says Ng. "You can input an audio clip and output the transcript. That's speech recognition." As long as you have data to train the software, the

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possibilities are endless, he maintains. "You can input email, and the output could be: Is this spam or not?" Input loan applications, he says, and the output might be the likelihood a customer will repay it. Input usage patterns on a fleet of cars, and the output could advise where to send a car next.

Deep learning, in that vision, could transform almost any industry. "There are fundamental changes that will happen now that computer vision really works," says Jeff Dean, who leads the Google Brain project. Or, as he unsettlingly rephrases his own sentence, "now that computers have opened their eyes."

Does that mean it's time to brace for "the singularity"—the hypothesized moment when superintelligent machines start improving themselves without human involvement, triggering a runaway cycle that leaves lowly humans ever further in the dust, with terrifying consequences?

Not just yet. Neural nets are good at recognizing patterns—sometimes as good as or better than we are at it. But they can't reason.

The first sparks of the impending revolution began flickering in 2009. That summer, Microsoft's Lee invited neural-nets pioneer Geoffrey Hinton of the University of Toronto to visit. Impressed with Hinton's research, Lee's group experimented with neural nets for speech recognition. "We were shocked by the results," Lee says. "We were achieving more than 30% improvements in accuracy with the very first prototypes."

In 2011, Microsoft introduced deep-learning technology into its commercial speech-recognition products, according to Lee. Google followed suit in August 2012.

But the real turning point came in October 2012. At a workshop in Florence, Italy, Fei-Fei Li, the head of the Stanford AI Lab and founder of the prominent annual ImageNet computer-vision contest, announced that two of Hinton's students had invented software that identified objects with almost twice the accuracy of the nearest competitor. "It was a spectacular result," recounts Hinton, "and convinced lots and lots of people who had been very skeptical before." (In 2015's contest a deep-learning entrant surpassed human performance.)

Cracking image recognition was the starting gun, and it kicked off a hiring race. Google landed Hinton and the two students who had won that contest. Facebook signed up French deep-learning innovator Yann LeCun, who in the 1980s and '90s pioneered the type of algorithm that won the ImageNet contest. And Baidu snatched up Ng, a former head of the Stanford AI Lab

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who had helped launch and lead the deep-learning-focused Google Brain project in 2010.

The hiring binge has only intensified since then. Today, says Microsoft's Lee, there's a "bloody war for talent in this space." He says topflight minds command offers "along the lines of NFL football players."

Geoffrey Hinton, 68, first heard of neural networks in 1972 when he started his graduate work in artificial intelligence at the University of Edinburgh. Having studied experimental psychology as an undergraduate at Cambridge, Hinton was enthusiastic about neural nets, which were software constructs that took their inspiration from the way networks of neurons in the brain were thought to work. At the time, neural nets were out of favor. "Everybody thought they were crazy," he recounts. But Hinton soldiered on.

Neural nets offered the prospect of computers learning the way children do —from experience—rather than through laborious instruction by programs tailor-made by humans. "Most of A.I. was inspired by logic back then," he recalls. "But logic is something people do very late in life. Kids of 2 and 3 aren't doing logic. So it seemed to me that neural nets were a much better paradigm for how intelligence would work than logic was."

During the 1950s and '60s, neural networks were in vogue among computer scientists. In 1958, Cornell research psychologist Frank Rosenblatt, in a Navy-backed project, built a prototype neural net, which he called the Perceptron, at a lab in Buffalo. It used a punch-card computer that filled an entire room. After 50 trials, it learned to distinguish between cards marked on the left and cards marked on the right.

The Perceptron, whose software had only one layer of neuron-like nodes, proved limited. But researchers believed that more could be accomplished with multilayer—or deep—neural networks.

Hinton explains the basic idea this way: Suppose a neural net is interpreting photographic images, some of which show birds. "So the input would come in, say, pixels, and then the first layer of units would detect little edges. Dark one side, bright the other side." The next level of neurons, analyzing data sent from the first layer, would learn to detect "things like corners, where two edges join at an angle," he says. One of these neurons might respond strongly to the angle of a bird's beak, for instance.

The next level "might find more complicated configurations, like a bunch of edges arranged in a circle." A neuron at this level might respond to the

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head of the bird. At a still higher level, a neuron might detect the recurring juxtaposition of beaklike angles near headlike circles. “And that’s a pretty good cue that it might be the head of a bird,” says Hinton. The neurons of each higher layer respond to concepts of greater complexity and abstraction, until one at the top level corresponds to our concept of “bird.”

To learn, however, a deep neural net needed to do more than just send messages up through the layers in this fashion. It also needed a way to see if it was getting the right results at the top layer and, if not, send messages back down so that all the lower neuron-like units could retune their activations to improve the results. That’s where the learning would occur.

In the early 1980s, Hinton was working on this problem. So was a French researcher named Yann LeCun, who was just starting his graduate work in Paris. LeCun stumbled upon a 1983 paper by Hinton that talked about multilayer neural nets. “It was not formulated in those terms,” LeCun recalls, “because it was very difficult at that time actually to publish a paper if you mentioned the word ‘neurons’ or ‘neural nets.’ So he wrote this paper in an obfuscated manner so it would pass the reviewers. But I thought the paper was super-interesting.” The two met two years later and hit it off.

In 1986, Hinton and two colleagues wrote a seminal paper offering an algorithmic solution to the error-correction problem. “His paper was basically the foundation of the second wave of neural nets,” says LeCun. It reignited interest in the field.

After a postdoctoral stint with Hinton, LeCun moved to AT&T’s Bell Labs in 1988, where during the next decade he did foundational work that is still being used today for most image-recognition tasks. In the 1990s, NCR, which was then a Bell Labs subsidiary, commercialized a neural-nets-powered device, widely used by banks, which could read handwritten digits on checks, according to LeCun. At the same time, two German researchers —Sepp Hochreiter, now at the University of Linz, and Jürgen Schmidhuber, the co-director of a Swiss A.I. lab in Lugano—were independently pioneering a different type of algorithm that today, more than 20 years later, has become crucial for natural-language processing applications.

Despite all the strides, in the mid-1990s neural nets fell into disfavor again, eclipsed by what were, given the computational power of the times, more-effective machine-learning tools. That situation persisted for almost a decade, until computing power increased another three to four orders of magnitude and researchers discovered GPU acceleration.

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But one piece was still missing: data. Although the internet was awash in it, most data—especially when it came to images—wasn't labeled, and that's what you needed to train neural nets. That's where Fei-Fei Li stepped in. "Our vision was that big data would change the way machine learning works," she explained. "Data drives learning."

In 2007 she launched ImageNet, assembling a free database of more than 14 million labeled images. It went live in 2009, and the next year she set up an annual contest to incentivize and publish computer-vision breakthroughs. In 2012, when two of Hinton's students won that competition, it became clear to all that deep learning had arrived.

By then the general public had also heard about deep learning, though because of a different event. In 2012, Google Brain published the results of a quirky project now known colloquially as the "cat experiment." It struck a comic chord and went viral on social networks.

The project explored an important unsolved problem in deep learning called "unsupervised learning." Almost every deep-learning product in commercial use today uses "supervised learning," meaning that the neural net is trained with labeled data (like the images assembled by ImageNet). With "unsupervised learning," in contrast, a neural net is shown unlabeled data and asked simply to look for recurring patterns. Researchers would love to master unsupervised learning one day, because then machines could teach themselves about the world from vast stores of data that are unusable today—making sense of the world almost totally on their own, like infants.

In the cat experiment, researchers exposed a vast neural net, spread across 1,000 computers, to 10 million unlabeled images randomly taken from YouTube videos and then just let the software do its thing. When the dust cleared, they checked the neurons of the highest layer and found, sure enough, that one of them responded powerfully to images of cats. "We also found a neuron that responded very strongly to human faces," says Ng, who led the project while at Google Brain.

Yet the results were puzzling too. "We did not find a neuron that responded strongly to cars," for instance, and "there were a lot of other neurons we couldn't assign an English word to. So it's difficult."

The experiment created a sensation. But unsupervised learning remains uncracked—a challenge for the future.

Not surprisingly, most of the deep-learning applications that have been commercially deployed so far involve companies like Google, Microsoft,

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Facebook, Baidu and Amazon—those with the vast stores of data needed for deep-learning computations. Many companies are trying to develop more realistic and helpful "chatbots"—automated customer-service representatives.

Companies like IBM and Microsoft are also helping business customers adapt deep-learning-powered applications—like speech-recognition interfaces and translation services—for their own businesses, while cloud services like Amazon Web Services provide cheap, GPU-driven deep-learning computation services for those who want to develop their own software. Plentiful open-source software—like Caffe, Google's TensorFlow and Amazon's DSSTNE—have greased the innovation process, as has an open-publication ethic, whereby many researchers publish their results immediately on one database without awaiting peer-review approval.

The greatest influences of deep learning may well be felt when it is integrated into the whole toolbox of other artificial intelligence techniques in ways that haven't been thought of yet. Google's DeepMind, for instance, has been accomplishing startling things by combining deep learning with a related technique called reinforcement learning. Using the two, it created AlphaGo, the system that, in 2016, defeated the champion player of the ancient Chinese game of Go—widely considered a landmark A.I. achievement. Unlike IBM's Deep Blue, which defeated chess champion Garry Kasparov in 1997, AlphaGo was not programmed with decision trees or equations on how to evaluate board positions or with if-then rules. "AlphaGo learned how to play Go essentially from self-play and from observing big professional games," says Demis Hassabis, DeepMind's CEO. (During training, AlphaGo played a million Go games against itself.)

A game might seem like an artificial setting. But Hassabis thinks the same techniques can be applied to real-world problems. In 2016, in fact, Google reported that, by using approaches similar to those used by AlphaGo, DeepMind was able to increase the energy efficiency of Google's data centers by 15%. "In the data centers, there are maybe 120 different variables," says Hassabis. "You can change the fans, open the windows, alter the computer systems, where the power goes. You've got data from the sensors, the temperature gauges and all that. It's like the Go board. Through trial and error, you learn what the right moves are.

"So it's great," he continues. "You could save, say, tens of millions of dollars a year, and it's also great for the environment. Data centers use a lot

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of power around the world. We’d like to roll it out on a bigger scale now. Even the national grid level.”

Chatbots are all well and good. But that would be a cool app.

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NVIDIA’S DGX-1 was dubbed the “world’s first deep-learning supercomputer” in 2016

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Jen-Hsun Huang, the company's CEO.

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GEOFFREY HINTON, neural-network pioneer

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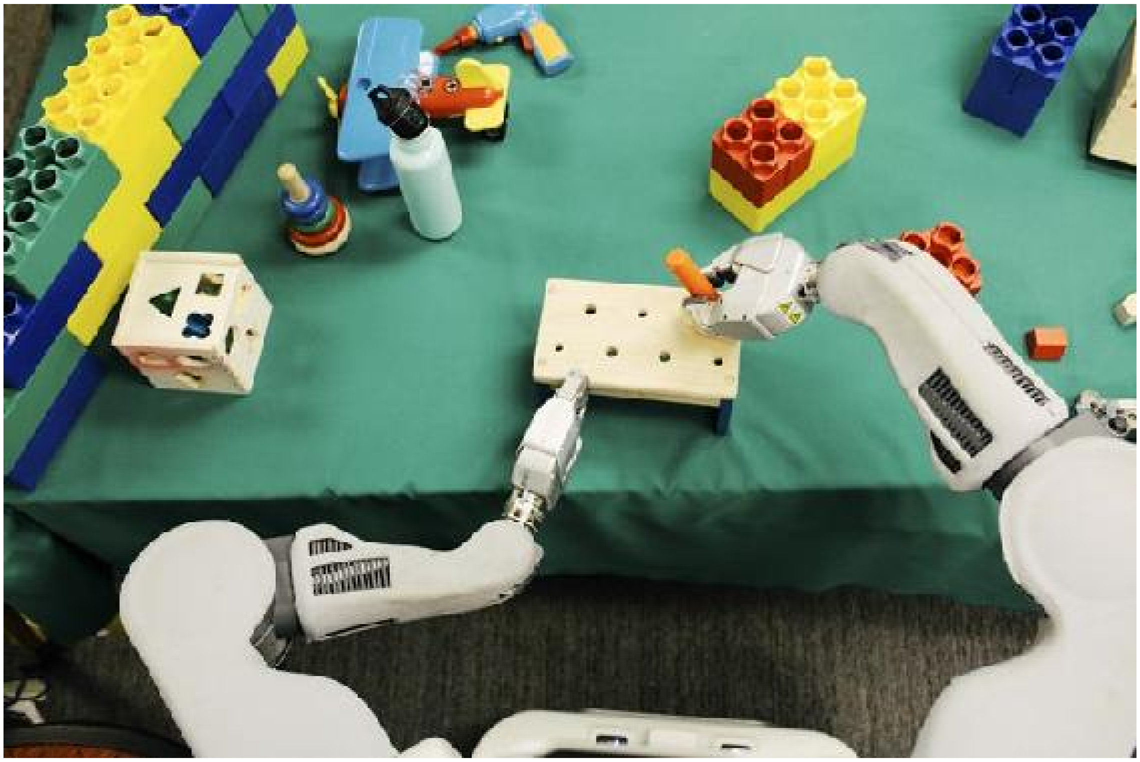

USING DEEP LEARNING, the Berkeley Robot for the Elimination of Tedious Tasks (BRETT) places a peg in a hole at the University of California, Berkeley.

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STANFORD PROFESSOR Fei-Fei Li delivered game-changing news in 2012.

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GOOGLE'S ALPHAGO computer beat world champ Lee Sedol in four out of five Go matches in 2016.

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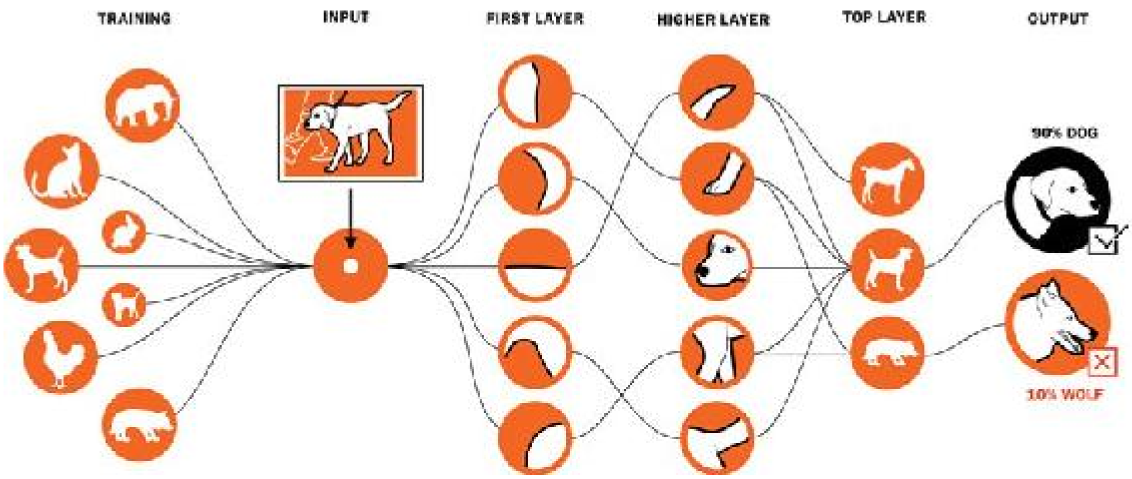
How Neural Networks Recognize a Dog in a Photo



TRAINING
During the training phase, a neural network is fed thousands of labeled images of various animals and learns to classify them.

INPUT
An unlabeled image is shown to the trained network.

FIRST LAYER
The neurons respond to different simple shapes, like edges.

HIGHER LAYER
Neurons respond to more-complex structures.

TOP LAYER
Neurons respond to highly complex, abstract concepts that we would identify as different animals.

OUTPUT
The network predicts what the object most likely is, based on its training.

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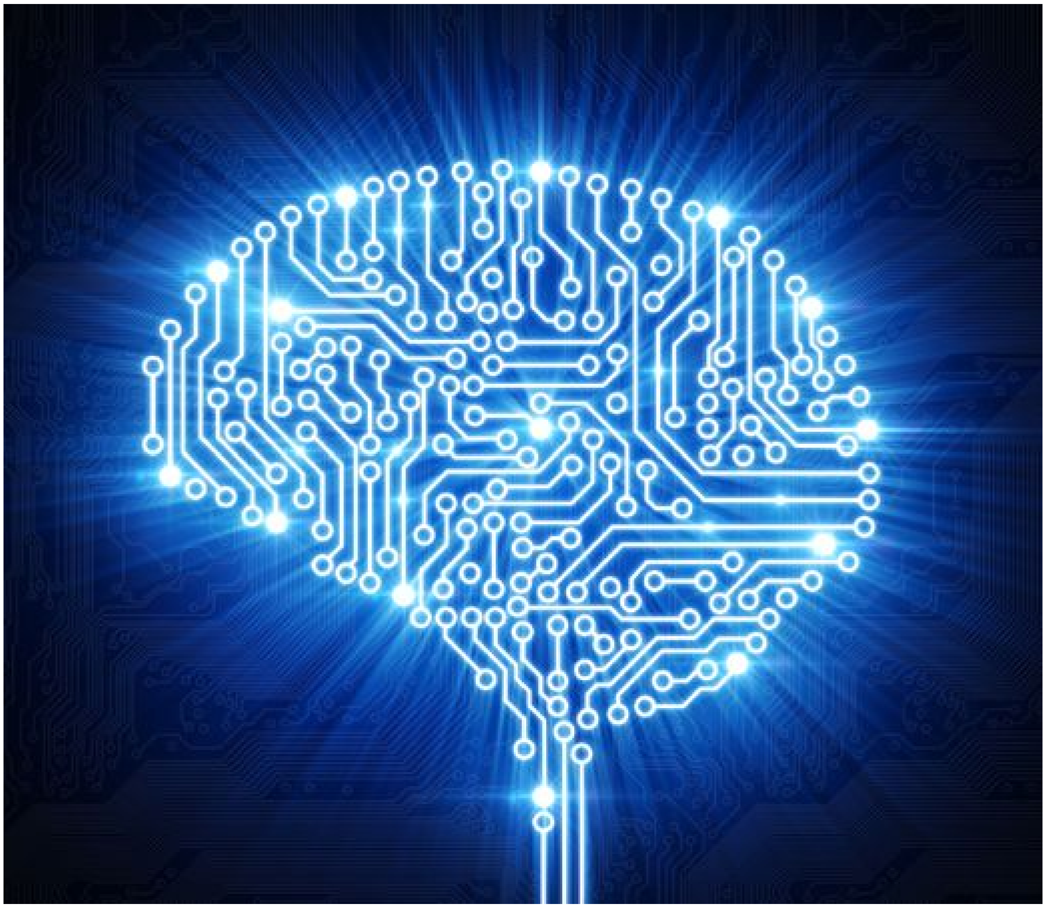
Four Tech Giants Serious About Deep Learning



GOOGLE After launching the deep-learning-focused Google Brain project in 2011, Google introduced neural nets into its speech-recognition products in mid-2012. The company now has more than 1,000 deep-learning projects under way, it says, extending across search, Android, Gmail, photos, Maps, Translate, YouTube and self-driving cars.

MICROSOFT The company introduced deep learning into its commercial speech-recognition products, including Bing voice search and Xbox voice commands, in 2011. Microsoft now uses neural nets for its search rankings, photo search, translation systems and more.

FACEBOOK The social-media titan uses neural nets to translate about 2 billion user posts per day in more than 40 languages and says its translations are seen by 800 million users a day. Facebook also uses neural nets for photo search and photo organization and is working on a feature

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that would generate spoken captions for untagged photos that could be used by the visually impaired.

BAIDU China's leading search and web services site, Baidu uses neural nets for speech recognition, translation, photo search and a self-driving car project, among others. Speech recognition is key in China, a mobile-first society whose main language, Mandarin, is difficult to type into a device.

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A Brief History of Artificial Intelligence

By Courtney Mifsud

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1939

The cigarette-smoking Elektro, Westinghouse Electric's talking robot, appears at the New York World's Fair.

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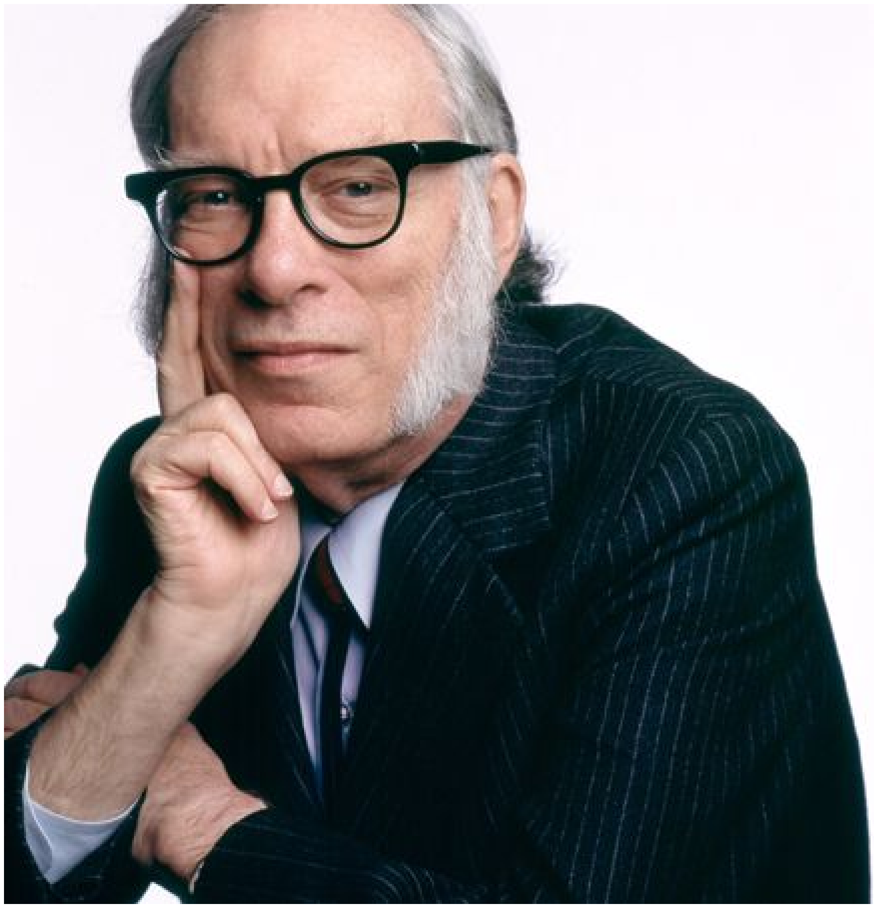
1941



Leading science-fiction writer Isaac Asimov develops the Three Laws of Robotics: (1) A robot may not injure a human being. (2) A robot must obey orders given by humans. (3) A robot must protect its own existence.

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1950

Alan Turing introduces the Turing test, a procedure intended to determine the intelligence of a computer. If a human is unable to distinguish between the computer and a human being, based on a system of equations, the machine passes.

Summer 1956

Dartmouth conference of scientists and mathematicians coins the term **“artificial intelligence,”** marking the birth of the field.

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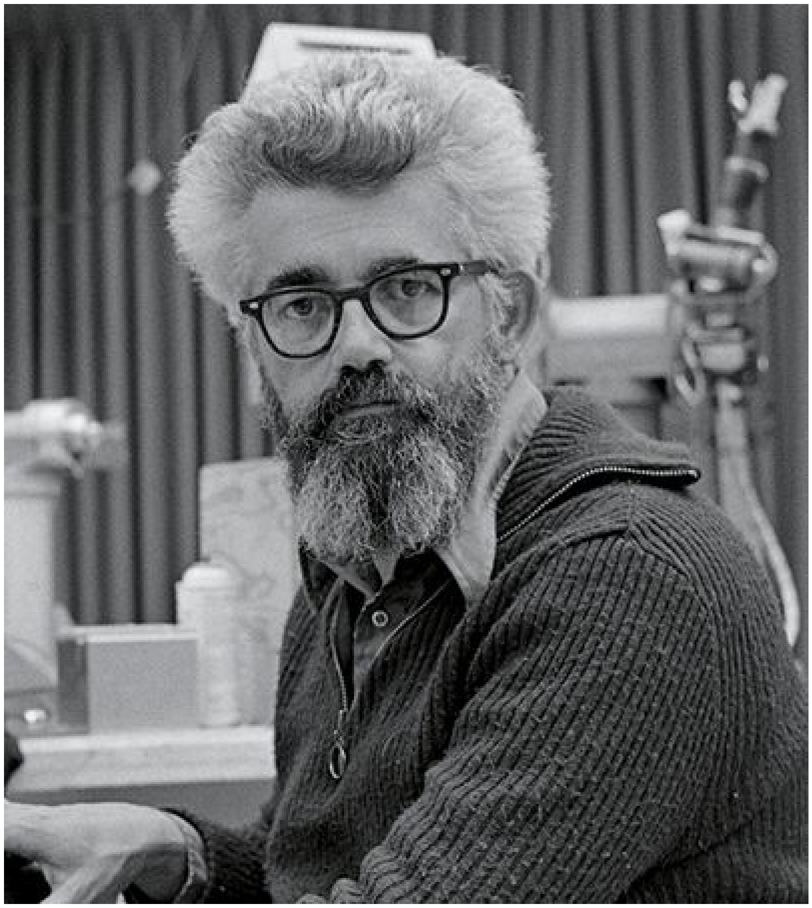
1958



Dartmouth conference organizer and MIT research fellow John McCarthy invents the programming language LISP, the standard for the A.I. community.

1974–early ’80s

After years of buildup and high expectations for A.I. advancements in the ’70s, disappointing progress leads to deep funding cuts for the field. This period of financial setbacks has been dubbed the “A.I. winter.”

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1984

The National Association of Home Builders creates a group called "Smart House," which campaigns for computerized advancements in home design.

1987–93

After the allure of A.I. rose and then fell throughout the '80s, a second wave of financial setbacks strikes the field. The Strategic Computing Initiative leads to deep funding cuts, ushering in the second **A.I. winter**.

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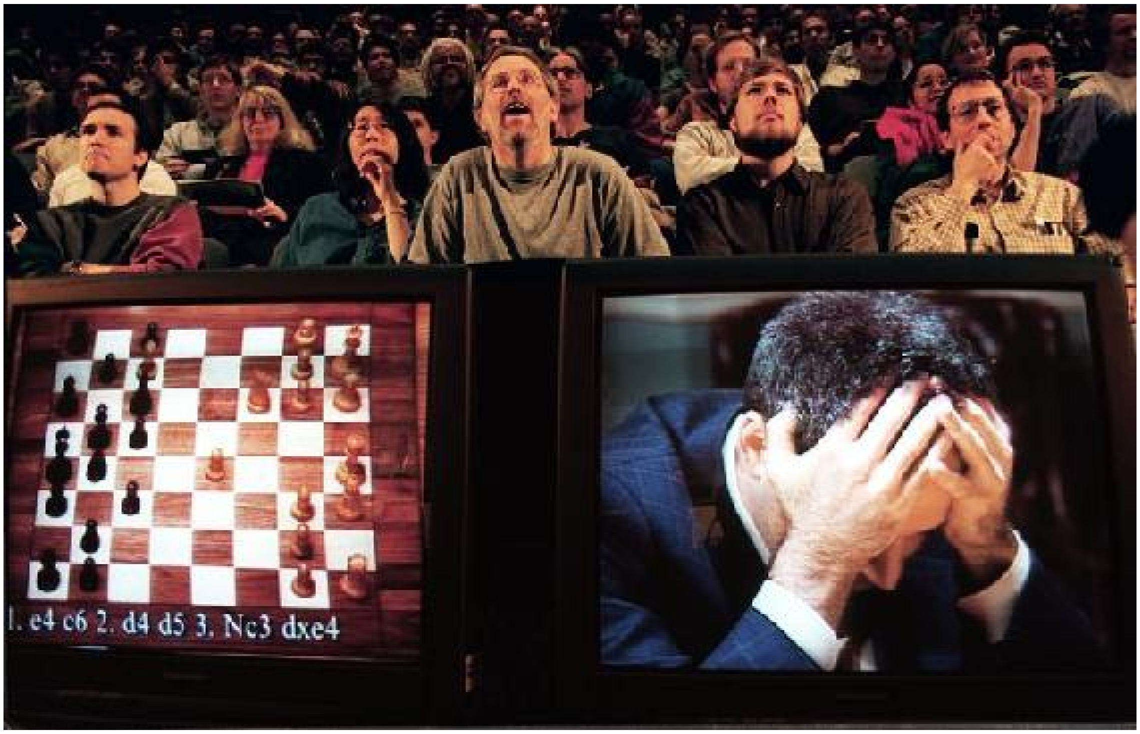
May 11, 1997



IBM's Deep Blue computer beats chess champion Garry Kasparov. The player had beaten Deep Blue a year earlier.

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Oct. 9, 2005

A self-driving vehicle completes the Darpa Grand Challenge, an off-road course for autonomous cars.

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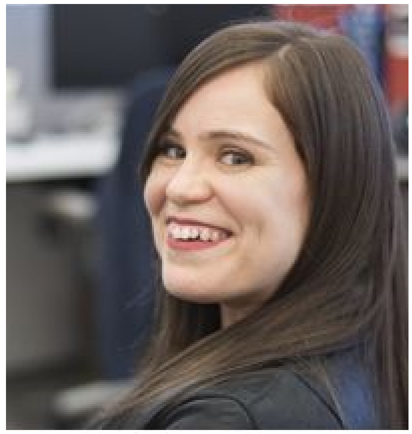
October 2006



Co-founders Hanna Wallach (top) and Jenn Wortman Vaughan

The first **Women in Machine Learning conference** is held. The group creates opportunities for women in the male-dominated field. Its annual workshop facilitates the exchange of ideas among scientists, educators and students.

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2010

iPod designer Tony Fadell starts Nest, the first in a series of streamlined home automation products. Google bought the company in 2014 for $3.2 billion.

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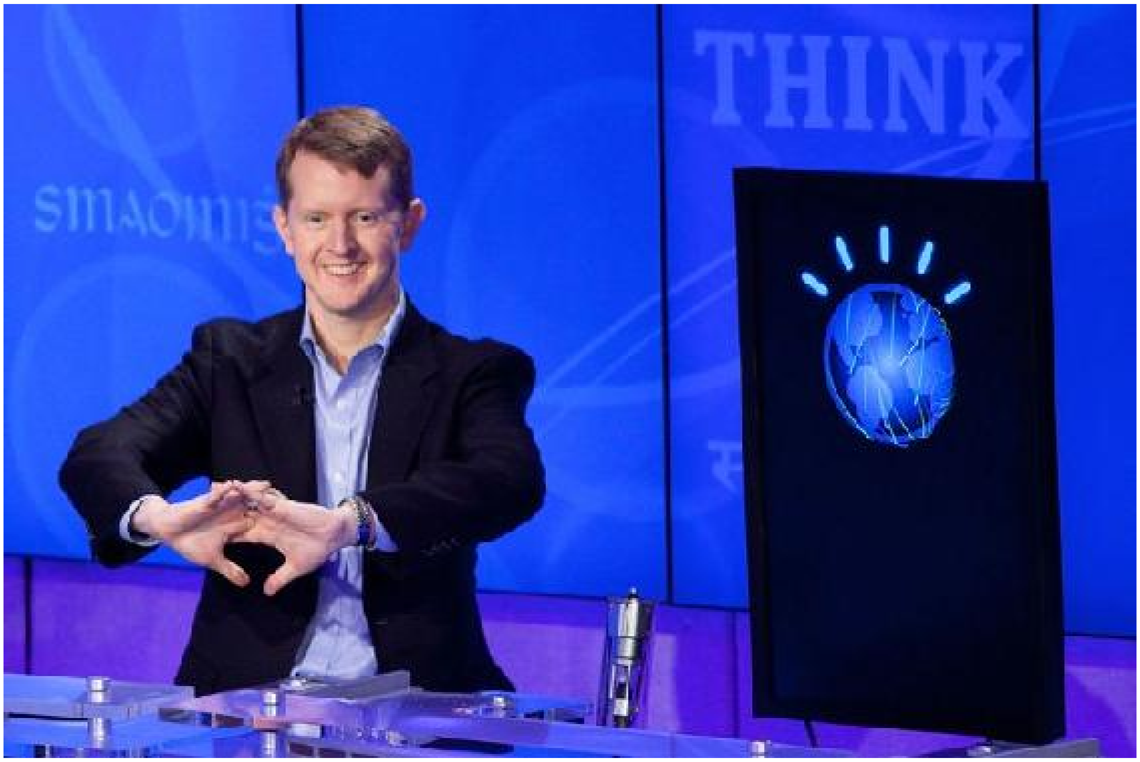
January 2011



Watson, IBM’s room-size question-answering computer, beats long-running *Jeopardy!* champion Ken Jennings, who jokingly writes on his final entry, “I for one welcome our new computer overlords.”

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Oct. 4, 2011

Apple introduces the speech-recognition application **Siri** on the iPhone 4S.

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2012

Andrew Ng and Jeff Dean of the Google Brain Team unveil technology that recognizes cats in YouTube videos.

June 2014

Researchers at Facebook publish their work on DeepFace, a program that uses neural networks to identify faces with better than **97% accuracy**.

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Nov. 6, 2014

The Amazon Echo, with voice-controlled A.I. assistant Alexa, is released to Prime members.

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October 2015

AlphaGo, designed by Google's London-based company DeepMind to play the board game Go, defeats Fan Hui five games to none. The program went on to win 60–0 against world champion Ke Jie in 2017.

January 2017

Libratus, a computer program designed at Carnegie Mellon, beats four of the world’s best players at Texas Hold ’em. Poker, with skills such as bluffing needed for winning consistently, is considered one of the hardest games for computers to beat humans at.

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Machines in the Military

The world's strongest nations are testing ways to bring A.I. to the battlefield

By Justin Worland

THE RUSSIAN GOVERNMENT'S humanoid robot, FEDOR, which can be operated via a remote-control suit or autonomously, is capable of firing a gun and driving a vehicle.

In April 2017, Dmitry Rogozin, the Russian Deputy Prime Minister responsible for defense, traveled from his office in the Kremlin to a remote military facility to see training of the country's newest fighter. Similar in stature to the Russian wrestlers who have brought Russia (and the Soviet Union before it) abundant Olympic medals, FEDOR weighs in at 230 pounds and stands around six feet tall. But instead of relying on instincts built over years on the mat, FEDOR, a Terminator-like humanoid robot, takes its cues from artificial-intelligence software programmed by the Russian government. During his visit, Rogozin watched the robot grasp a

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gun in each hand and fire at a series of circular targets in rapid succession, hitting each of them.

The Russian government developed FEDOR to do things like repair spacecraft and drive vehicles, not to serve as a fighting machine. At least that's what officials have told the public. When activated, however, FEDOR will have a clear application for more violent uses. FEDOR has been firing guns as a type of training. "Shooting exercises is a method of teaching the robot to set priorities and make instant decisions," Rogozin wrote on Twitter. "We are creating AI, not Terminator."

American military officials cite threats like FEDOR—as well as similar A.I. advances in China—to explain the U.S.'s rapid investment in military A.I. The multibillion-dollar funding forms a key part of the Department of Defense's Third Offset Strategy, which uses technology to act as a deterrent against rivals' advantages. (The first offset focused on the development of a nuclear deterrent, and the second emphasized improved reconnaissance technology and precision weapons.) "The competitors that can use A.I. and autonomy in a smart way are going to be the competitors that have a very big operational advantage in the future," said then–U.S. deputy secretary of defense Robert Work in a 2016 speech, using "autonomy" to refer to the delegation of some decision making to A.I.

Indeed, an arms race of sorts has begun pitting major world powers against one another as they rush to adapt A.I. to military functions. This battle centers on developing technology and figuring out how to apply it. Similar to the 20th-century nuclear-arms race, the race to develop A.I. creates a series of ethical questions about how the technology should be deployed: What decisions should a robot be allowed to make? Who takes responsibility for a robot's actions? And, perhaps most important, should robots be able to take a human life?

"Up to now, we've had in place a principle that an agent is responsible and potentially culpable for any bad action that a technology causes," says Wendell Wallach, a scholar at Yale University's Interdisciplinary Center for Bioethics. "Artificial intelligence threatens to undermine that."

Like transformative virtual reality or driverless cars, artificial intelligence is a technology that for some time has seemed just a few years away from transforming our world. Yet its deployment remains elusive. The concept of A.I. first appeared in fiction, like Isaac Asimov's short-story

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series *I, Robot*, in which humans have robots built to serve them but the robots eventually revolt despite being programmed otherwise.

The dystopian depiction of violent robots was not enough to stop the government from getting in the game. Real military investment in A.I. began as the U.S. poured money into Cold War programs aimed at besting the Soviet Union in everything from missile defense to the space race. The military's focus on A.I. centered on the Defense Advanced Research Projects Agency (Darpa). In the first decade following its founding in 1958, Darpa spent millions trying to teach machines to think as they translated Russian to English, among other things.

When that A.I. program eventually failed to produce quick results, it lost its funding, as did many others deemed unfeasible. Funding returned with the development of high-speed computing in the 1980s and '90s. At that point, machines could process information much faster than ever and engage in rapid-fire analysis of vast amounts of information that had been unimaginable a few decades before. The commitment to research in the '80s and '90s laid the groundwork for the central role A.I. has come to play in military strategy. Today, A.I. has reemerged as a top priority for Darpa and the U.S. military, with the Department of Defense spending more than $1.5 billion on such efforts in 2016. That's but a tiny fraction of the DOD's overall budget, but it's a significant figure for the research and development of new technology.

The U.S. government has begun thinking about the seemingly endless potential applications of A.I. across the military's vast operations. Unmanned submarines might hunt for enemy vessels without human guidance. Missiles can detect and target enemy combatants. Robots can survey large swaths of fraught territory before humans endanger themselves on foot. And those are just the applications disclosed to the public.

Once machine learning technology is fully operational, it can be applied to nearly any system, from smart automated hacking to nuclear weapons. But senior U.S. officials say the world need not fear a nuclear war or any war launched by robots—at least not one coming from the U.S. When it comes to weapons that can physically injure or kill humans, officials say, America is pursuing a "centaur model," named after the mythological creature that is half human and half beast. U.S. defense systems employing A.I. would require a human being to sign off on actions that put human life in jeopardy, restricting machines to processing data and doing analytical tasks that they

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can carry out more quickly than humans. “When there’s artificial intelligence or autonomous systems, you get this idea that they’re going to be weapons of war out there that nobody’s controlling,” said former defense secretary Ash Carter in 2016. “That’s not the way we do things. We will always have a human being in the loop.”

Even U.S. defense officials acknowledge that this position has one large caveat: an automated response to opponents using A.I. with less discretion. Officials say the U.S. needs to be able to rely on A.I. to make quick decisions, if only as a deterrent, in the event the country is attacked unexpectedly. Such an event, called a “flash war,” could kill millions in a matter of seconds as computers respond to each other with increasing aggression. Similar rapid-response systems have already triggered swift stock-market declines, and analysts expect that similar events could occur with war robots if there are not efforts to preempt it.

And that’s just one devastating outcome. The relatively low cost of building A.I. compared with nuclear weapons and other highly destructive devices means that they are more likely to enter mass production and might easily wind up in the hands of terrorists and rogue states, leading to destructive decisions devoid of humanity.

Those potential scenarios have led experts in the field to call for a ban on certain military applications of A.I. In 2016 a group of more than 1,000 scientists and thinkers—including physicist Stephen Hawking and entrepreneur Elon Musk—signed a letter calling for a ban on lethal autonomous weapons. “The key question for humanity today is whether to start a global AI arms race or to prevent it from starting,” the letter says. “If any major military power pushes ahead with AI weapon development, a global arms race is virtually inevitable.”

Such an arms race may have already begun. Russia has FEDOR and is using A.I. to help its foreign hacking and propaganda machine. An Obama-era White House report acknowledged that Chinese academics were producing more research on A.I. than their U.S. counterparts, research that has been applied in areas like the development of smart cruise missiles that the military can “fire and forget” as they locate their target. In the U.S., President Donald Trump retained the Defense Department leaders managing A.I. programs and pushed for an increase in Darpa funding for fiscal year 2018, even as he proposed slashing other research and development programs.

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Given this momentum, the proposed ban on military A.I. currently before the United Nations' Convention on Conventional Weapons might not fully address the problem. But for those concerned, the move would be a good start. The clock is ticking. "Once these weapons exist," said Steve Goose, the director of Human Rights Watch's arms division, in a statement, "there will be no stopping them. The time to act on a preemptive ban is now."

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THE U.S. DEPARTMENT OF DEFENSE is developing an unmanned vessel that can travel the seas for months on end, tracking submarines and detecting mines.

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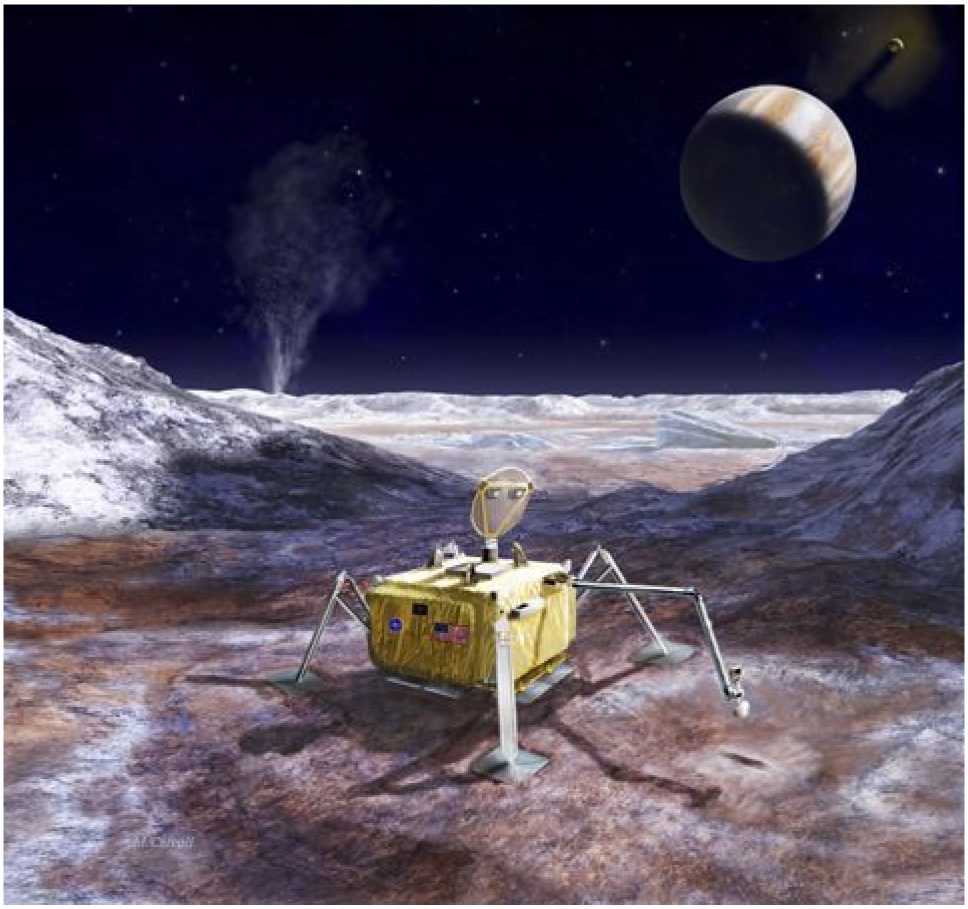
Cosmic Intelligence

Scientists are using A.I. programs to solve some of space's toughest problems

By Courtney Mifsud



AN ARTIST'S RENDERING of a lander concept for a mission planned to Jupiter's icy moon Europa in the 2020s

If you're hoping to find life in space, Mars might be the first place you look. Both Earth and Mars fall into the habitable zone away from the sun where liquid water can exist—a prerequisite for organic molecules. But our planetary neighbor isn't the only nearby world with the potential for life. Europa, Jupiter's small, icy moon, 483 million miles from Earth, is one of 11 worlds in our solar system believed to have oceans. Potential subsurface water beneath its frozen surface makes Europa a major contender for housing biologic life. With an unmanned mission planned for Europa sometime in the 2020s, and with its ongoing research on Mars, NASA is

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looking to artificial intelligence to solve some significant hurdles in the search for extraterrestrial life.

NASA began incorporating A.I. into space exploration two decades ago with the spacecraft Deep Space 1. The comet probe housed Remote Agent software, an A.I. system that aided in planning activities and diagnosing onboard failures. Deep Space 1 was part of the larger New Millennium Program, which brought about technology like the Earth Observing-1 satellite that flew over the planet for 17 years. Powered off in March 2017, the satellite included similar autonomy software. If the satellite was directed to take an image of an erupting volcano, A.I. programs allowed for EO-1 to make its own decisions regarding whether to take follow-up images at a later date.

Before astronauts can go to Mars, NASA is working on making the technology that's already on the ground there think a little more like a human. Since the earliest years of the rover missions, NASA has been implementing a planning system called MAPGEN (Mixed-initiative Activity Plan GENerator), which upgraded the scheduling of day-to-day missions.

Traditionally, planning operations required manual participation from humans back on Earth, sometimes with a 20-minute time delay. This autonomous software used reasoning techniques to alter and adjust the schedule as needed. If the mission finished early, the rover could adapt and do more work, making ground research more efficient.

Efficient mission planning means an increase in data sent back to Earth. More data is a good thing, except that it takes serious manpower for human researchers to weed out the anomalies from the mundane. Thanks to onboard systems, the rovers "triage the data so the human can look at the most interesting cases," says Steve Chien, a supervisor at NASA's artificial-intelligence group.

Since May 2016, the Curiosity rover has been using the Autonomous Exploration for Gathering Increased Science (AEGIS) system for controlling its onboard laser system, ChemCam. AEGIS allows for the rover to analyze the surrounding environment using its cameras and identify the best bedrock to zap with a laser, which releases gases to be studied. This automation led to an increase in laser usage, from 256 firings per day to 327.

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Before AEGIS, scientists relied on “blind targeting” in telling the rover where to fire its laser. Curiosity would shoot at a specific area but without confirmation of what was actually there. This strategy proved to be 24% accurate in hitting the correct target. Now AEGIS finds the correct rock type 93% of the time. The autonomous software is increasing not just the volume of samples captured by the rover but also the accuracy in the submissions. By understanding the data collected from these rocks, NASA can further understand the environment on Mars, a crucial step before boots hit the red ground.

Beneath Europa’s frozen crust, it is believed, there’s a warm ocean ready to be explored. To prepare for that, NASA’s research team is testing underwater drones in Monterey Bay, Calif. With a communication delay of up to an hour and signals that are easily blocked by saltwater, a subsurface mission on Jupiter’s moon requires more than the usual radio-transmitted drones. Chien, along with his collaborators at Caltech, tested fleets of smart drones out of the waters of Monterey Bay. The drones searched out changes in temperature and water salinity and sensed how the ocean changed throughout the routes. The research team is working on developing A.I. that integrates these data points, which could lead to subsurface drones that can navigate their own course without help from Earth. An underwater probe on Europa would need to adapt to changes in environment or risk mission failure. Not only is this autonomy revolutionary for data collection; it’s necessary for further planetary exploration.

“Our goal is to remove the human effort from the day-to-day piloting of these robots and focus that time on analyzing the data collected,” says Andrew Thompson, an assistant professor of environmental science and engineering at Caltech. “We want to give these submersibles the freedom and ability to collect useful information without putting a hand in to correct them.”

In order to seek out underwater life, researchers will need to find the nutrients in the water that support plankton and, in turn, the fish that survive on plankton. Nutrients are swept around by the current suddenly, and although fish can stay on the trail, an unintelligent drone would struggle. Underwater life shifts in different directions, and varying sizes pose problems. “Phenomena like algal blooms are hundreds of kilometers across,” Chien says, “but small things like dinoflagellate clouds are just dozens of meters across.”

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As we look to the stars in the sky and muse of worlds similar to our own, NASA is working tirelessly to find a way to investigate potential extraterrestrial life within our solar system. Emerging artificial-intelligence programs are setting scientists up for success and allowing them to breach necessary hurdles and plan for missions in the next decade. The search is on.

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Steve Chien of NASA's A.I. group testing underwater drones in Monterey Bay, California

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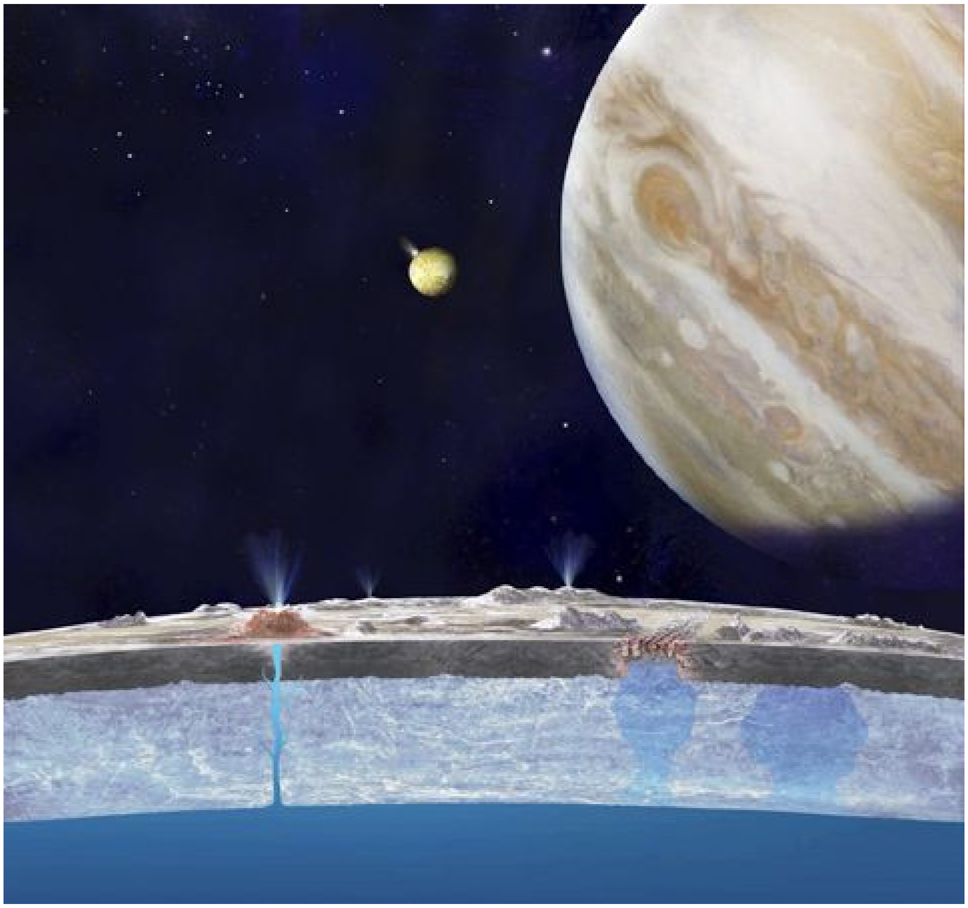

Conceptual art of subsurface oceans on Jupiter's moon Europa

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The shrinking snowcap of Mount Kilimanjaro, taken by the Earth Observing-1 (EO-1) satellite

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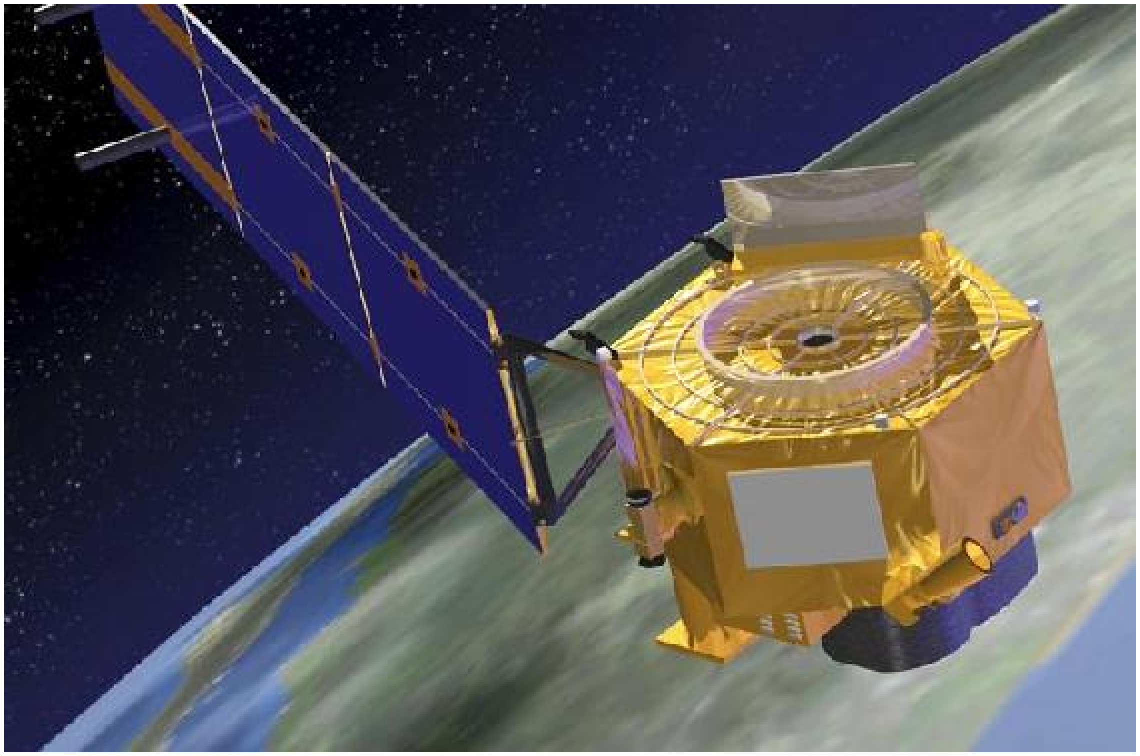
A rendering of EO-1, which was decomissioned in March 2017 but will remain in orbit until 2056

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The Computer Will See You Now

Machine-learning programs are helping doctors and their patients

By Alice Park

Medicine is both art and science. While any doctor will quickly credit her rigorous medical training in the nuts and bolts of how the human body works, she will just as adamantly school you on how virtually all of the decisions she makes—about how to diagnose disease and how best to treat it—are equally the product of some less tangible measures: her experience from previous patients; her cumulative years of watching and learning from patients, colleagues and the human body.

Which is why the idea of introducing machines into medicine seems misguided at the very least, and also foolhardy. How can a robot, no matter how well-trained, take the place of a doctor?

Machine learning, the most basic form of artificial intelligence, is already infiltrating the medical field, and it turns out that machines can play an important role in improving our health—including making diagnoses more accurately and quickly and finding better treatments that save people time and money and prevent exposure to harmful side effects. In fact, with modern medicine increasingly dependent on large numbers of studies and

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drug options and reams of new information, machines may be better able to keep up with and interpret data than the human mind.

The idea behind artificial intelligence in medicine is not so much to replace the doctor (at least not any time in the near future) but to enhance the doctor's medical expertise. A.I. programs take the amassed knowledge that every good physician has—which is the product of everything she learned in medical school and in training as well as her experience in treating patient after patient—and scale it to unprecedented levels.

Why should patients have access to just one particular doctor's expertise when it's now possible to provide them with the brainpower of hundreds of thousands? Why should patients in rural areas who live geographically far from the nation's leading medical centers be deprived of all the up-to-date knowledge housed there? "The way artificial intelligence starts to really impact what's going on in health care is to be able to start cloning all the expert knowledge, so now all of a sudden you get access to all types of care, anywhere," says Steve Harvey, vice president of Watson Health at IBM.

And with the amount of data available to physicians today—from information about disease symptoms to new drugs, interactions between different drugs and how different people treated in the same way can have very different outcomes—the ability to access and digest information is fast becoming a required skill. And it's one that machine learning is uniquely designed to master. "Doctors are realizing that if they want to make sense of massive amounts of data, machine learning is a way of allowing them to learn from that data," says Francesca Dominici, a professor of biostatistics at the Harvard T.H. Chan School of Public Health and co-director of the Data Science Initiative at the university.

Harvard isn't the only academic institution exploring how man and machine can better combine their skills to exploit unprecedented amounts of medical information. At the University of Texas MD Anderson Cancer Center, the APOLLO program is sifting through the genetic data generated by every patient's cancer and directing doctors to the treatments that will give their patients the best chance of surviving longer. At the Boston company Neurala, researchers are busy replicating, in silicon, the neural network of the human brain in all its complexity and sophistication. "Today we can design the brain with the complexity of the mouse, which is incredibly smart," says Massimiliano Versace, Neurala's CEO. "Science and technology are now aligned for the perfect storm to make artificial

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intelligence possible." And in the mental-health field, startups are jumping into machine-learning apps that can help detect when people with conditions such as depression or bipolar disorder are on the verge of a new episode of symptoms in a way that no psychiatrist, however dedicated, ever could.

The key to machine learning in medicine is, well, the machine. And machines from IBM and Google have recently flexed their cognitive muscle by besting the leading *Jeopardy!* champions, chess masters and Go experts —after learning from the knowledge of previous players, which became part of the machines' programming.

Now IBM is bringing that idea to medicine, based on the concept that medical knowledge could be as programmable and amenable as the many possible iterations of chess moves and trivia answers. The company is working with experts at Memorial Sloan Kettering Cancer Center in New York to develop IBM Watson for Oncology, made up of three products that address different types of cancer patients. One level will focus on providing patients with the best available information for treating their cancer with existing therapies; Watson provides access to a database of the collected knowledge of Memorial Sloan Kettering's cancer doctors, as well as the most important cancer studies in the medical literature that these doctors rely on when making their decisions about how to treat patients.

The system incorporates patients' symptoms and other salient information, such as their family history of the disease and the stage of their cancer, before offering up three different levels of treatment options that the physician can consider. These range from current standard therapies that have already been approved for that type of cancer to treatments approved for other cancers that are currently being tested but are not yet approved for the patient's specific cancer, and finally truly experimental treatments that some early studies hint might be effective at treating the disease. The different levels of options give both the doctor and patient a treatment plan —if the standard therapies don't work, then they can move on to the less proven and more experimental ones.

Beyond available treatments, Watson is also helping people with more-advanced cancers who have exhausted the standard therapies. For them, machine learning can call up clinical trials of new therapies that might be effective, including genetic solutions, which are just emerging as a promising area of cancer treatment. The genetic options are based on a

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careful analysis of the patient's specific tumor, the mutations driving the disease and drugs that might be targeted to address those mutations.

For human doctors to digest all this information would be nearly impossible, given the demands on physicians' time to see patients and keep up to date on the latest advances in their field. The potential benefit of having a Watson "doctor" on call at every cancer hospital, no matter how small, can't be overstated. People with rarer cancers that their local physicians haven't treated before won't have to travel great distances to a major hospital that has more experience with that disease, or have to miss the opportunity to get their cancer treated at all. Doctors with less experience with specific cancers can also care for their patients with more confidence, since they now have the institutional knowledge of leading experts in their field at their disposal.

As more information about different cancer patients and their tumors becomes part of Watson, doctors will be able to see patterns that will help them match specific patient profiles to survival rates and better outcomes. They will be able to recognize when people with similar genetic tumors, for example, who took different treatment paths have different health outcomes. That analysis would lead to more refined advice for people about which treatment route is best for them.

The system isn't perfect yet. Some of IBM's partners have found Watson cumbersome when it comes to entering all the relevant information from patients—mimicking, in other words, the way doctors incorporate everything they know about a patient into their treatment recommendations. But physicians support the idea that having a way to collect, collate and categorize the massive amounts of information being generated about each patient will be a big part of improving cancer care in coming years.

Such machine-learning approaches are proving remarkably helpful in another area of medicine that may not seem to be so appropriate for non-human interaction: mental health. For people suffering from depression and bipolar disorder, for example, one of psychiatrists and therapists' most important roles is to help them avoid descending into emotional spirals from which it's difficult to recover. Identifying when people are most vulnerable to depressive or manic episodes could keep them from the most harmful mental symptoms, and it turns out that machines—in this case a smartphone—might be able to do that better than any psychiatrist can.

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That's because, as is well-known, people verging on depressive episodes or succumbing to feelings of sadness and negativity have changes in their speech and behavior. They may speak less and, when they do, adopt a flat, monotonic tone. They may also disengage from friends and loved ones, calling them less or interacting less frequently on social media. Even the best psychiatrist can't possibly keep up with all of his patients to monitor when they start to display such changes in behavior. But smartphones can.

Cogito, a mental-health app built on the idea of machine learning, is now being tested at facilities like Brigham and Women's Hospital in Boston. The app, once installed on a smartphone, monitors activity on social media and phone calls to discern patterns of communication so that when depressive episodes strike, for example, and those patterns change, the app will detect it.

The app also contains a voice analyzer that can search vocal patterns for changes in affect and tone, which may be the first signs of a depressive episode. "The A.I. aspect may be in a better position to gather data over time and give us a better indicator of risk for someone having a mental-health problem and whether they warrant direct intervention with a clinician," says David Ahern, the director of the Program in Behavioral Informatics and eHealth in the Department of Psychiatry at Brigham.

Machine learning could be especially helpful in alerting a physician or a patient's family when things begin to spiral out of control. "Historically, we have been dismally poor at detecting dangerousness or self-harm," says Ahern. "Potentially, with technology like Cogito, we may be able to develop an early-warning system that, for somebody who has a high risk profile because they have a history of depression or suicide attempts, could monitor and see changes in patterns to better determine when the risk gets to the level where intervention is needed to prevent episodes of self-harm or dangerous activity. That's a place where we haven't—with traditional models of care—been very good at. We've been very reactive, and we want to be more proactive."

That's where artificial intelligence can provide the most benefit to people's health. Its ability to predict how aggressive or mild a person's disease might be, and to know which treatments might work well and which might not, may make machine learning an integral, and eventually indispensable, part of medical care. It may be time to realize that it's not man against machine

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but man *and* machine together that can finally create the biggest improvements in human health.

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ONCOLOGIST ABRAHAM SCHWARZBERG reviews treatment recommendations from IBM Watson for Oncology

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Neurala CEO Massimiliano Versace

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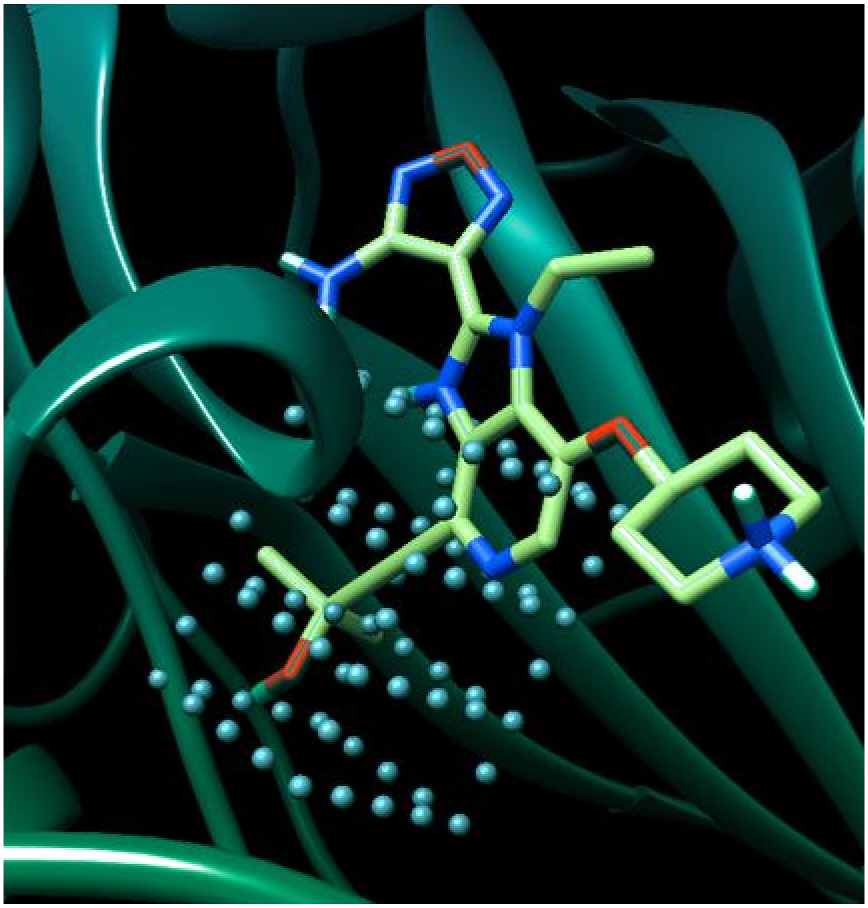
Deep Learning in Medicine



Atomwise uses deep learning to research drugs.

Startup **Enlitic** uses deep learning to analyze radiographs and CT and MRI scans. The company's chief executive, Igor Barani, formerly a professor of radiation oncology at the University of California, says Enlitic's algorithms outperformed four radiologists in detecting and classifying lung nodules as benign or malignant. (The work has not been peer-reviewed, and the technology has not yet obtained FDA approval.)

Merck is trying to use deep learning to accelerate drug discovery, as is San Francisco startup **Atomwise**. Neural networks examine thousands of 3-D images of molecules that might serve as the basis of new drugs and then predict the molecules' suitability for blocking the mechanism of a pathogen. Such companies are using neural nets to try to improve what humans already do; others are trying to do things humans can't do at all. Gabriel Otte started **Freenome**, which aims to diagnose cancer from blood samples. It examines DNA fragments in the bloodstream that are spewed out by cells as they die. Otte asks computers to find correlations between cell-free DNA

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and some cancers. “We’re seeing novel signatures that haven’t even been characterized by cancer biologists yet,” he says.

When Andreessen Horowitz was mulling an investment in **Freenome**, AH general partner Vijay Pande sent Otte five blind samples—two normal and three cancerous. Otte got all five right, says Pande, whose firm decided to invest.

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Prosthetic Progress

BIONIC ADVANCEMENTS include ReWalk (above) and the Luke arm (following).

Some veterans at VA hospitals across the nation may soon be on their feet again, thanks to the latest robotic prosthetics. The Department of Veterans

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Affairs recently purchased more than two dozen exoskeleton systems, which serve as a paralyzed person's legs and spinal cord.

The exoskeleton, made by ReWalk, looks like a robotic skeleton that surrounds a person's torso and legs. It contains sensors at key joints, like the knees and hips, that can detect changes in gravity—such as when a person is leaning forward to take a step—and then move the skeleton, and the person, forward in a walking motion. The systems are part of a research trial in which the exoskeleton is being tested for people to use at home instead of wheelchairs.

And the exoskeleton isn't the only smart prosthetic that takes artificial limbs beyond limited manual controls. The Department of Defense funded the development of the LUKE arm (named after *Star Wars*'s Luke Skywalker), which relies on electrical signals sent by the remaining muscles in a user's amputated arm to change its position and grip. It's a more advanced version of prosthetics that mimic how the human arm and hand work, adjusting the amount of force involved depending on the situation. The LUKE arm can, for example, help users pick up an egg without breaking it, as well as grasp a glass cup firmly enough so it doesn't slip. And just like real nerves in a human limb, LUKE sends information to the brain, letting users know how hard they're gripping. The dexterity is life-changing for amputees, and the Food and Drug Administration approved the prosthetic in 2014. *—Alice Park*

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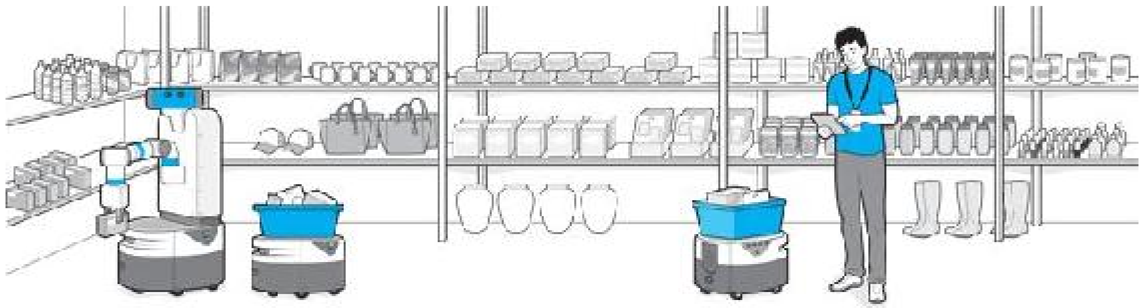
Caution: Robots Working

Beyond tollbooths and ticket counters, will bots one day aid white-collar productivity?

By Alex Fitzpatrick



THE FETCH ROBOT picks items off warehouse shelves, while the Freight robot carries them to human workers for packaging.

There are two schools of thought regarding the coming impact of robots on workers: there are those who warn they will destroy jobs and those who hope new technology will boost the productivity of workers without replacing them.

Melonee Wise is one of the optimists. The 35-year-old CEO of San Jose, Calif.–based Fetch Robotics is working on “collaborative robotics,” using machines to do things humans cannot. “Once we start seeing more service robots like we make, people will be like, ‘These things are really improving my life,’ ” she says.

Fetch, a three-year-old startup, is developing robots for warehouses. One model, called Freight, looks like a muscled version of the floor-sweeping Roomba made by industry leader iRobot. Freight carries a bin and follows human workers, doing the lugging as they pick items off shelves. Another device, nicknamed Fetch, is an advanced robot with an arm that can grab items and work with Freight. Fetch Robotics, which isn’t profitable but has raised $23 million in venture funding, recently announced that its robots have been in use for six continuous months at a California warehouse.

The robotics industry is entering an uncertain chapter. Since 2012, eager investors have poured $3 billion into startups trying to bring robots to manufacturing plants, hospitals and battlefields, according to data firm CB Insights. Much of the potential for a new wave of robots has come from advancements in so-called machine learning, the software that helps give robots contextual intelligence. Some of that enthusiasm has been muted

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recently, however, as the business of selling robots has hit snags. iRobot saw its stock fall nearly 12% one February day after it predicted weaker-than-expected results for the coming year. Google parent company Alphabet sold off Boston Dynamics, maker of a bipedal walking robot that looks vaguely like the Terminator, because the firm's path to profitability is not clear.

Another looming question is robots' role in the workplace. Wise, a Chicago native who holds a master's degree in mechanical engineering from the University of Illinois, argues that Fetch's bots will help warehouse workers avoid injury and strain, making them more productive in the long run. She compares robots to PCs, which caused consternation but ultimately boosted productivity as well as economic and job growth. "Everyone keeps trying to make a distinction between a robot and a computer, but they're basically the same thing," says Wise. "A robot is a computer wrapped in plastic."

Not everybody is convinced. "Technology is going to get to the point where it's going to take over a lot of the routine, predictable-type jobs in the economy," says Martin Ford, author of *Rise of the Robots: Technology and the Threat of a Jobless Future*. That is already happening at checkout lines, tollbooths, parking lots and ticket counters. But Ford and others argue that the combination of robots and artificial intelligence represents a different kind of revolution—one that could eventually come for white-collar professions. "That's a lot of jobs [at stake]," he says.

Still, of the 10 private robotics firms that raised the most venture capital in 2016, most focus on building bots to help with household chores and other non-job-threatening tasks. "Maybe in 30 or 40 years we will have 50% of the jobs disappear," says J.P. Gownder, a vice president and principal analyst at research firm Forrester. "But I don't see it happening in the next 10."

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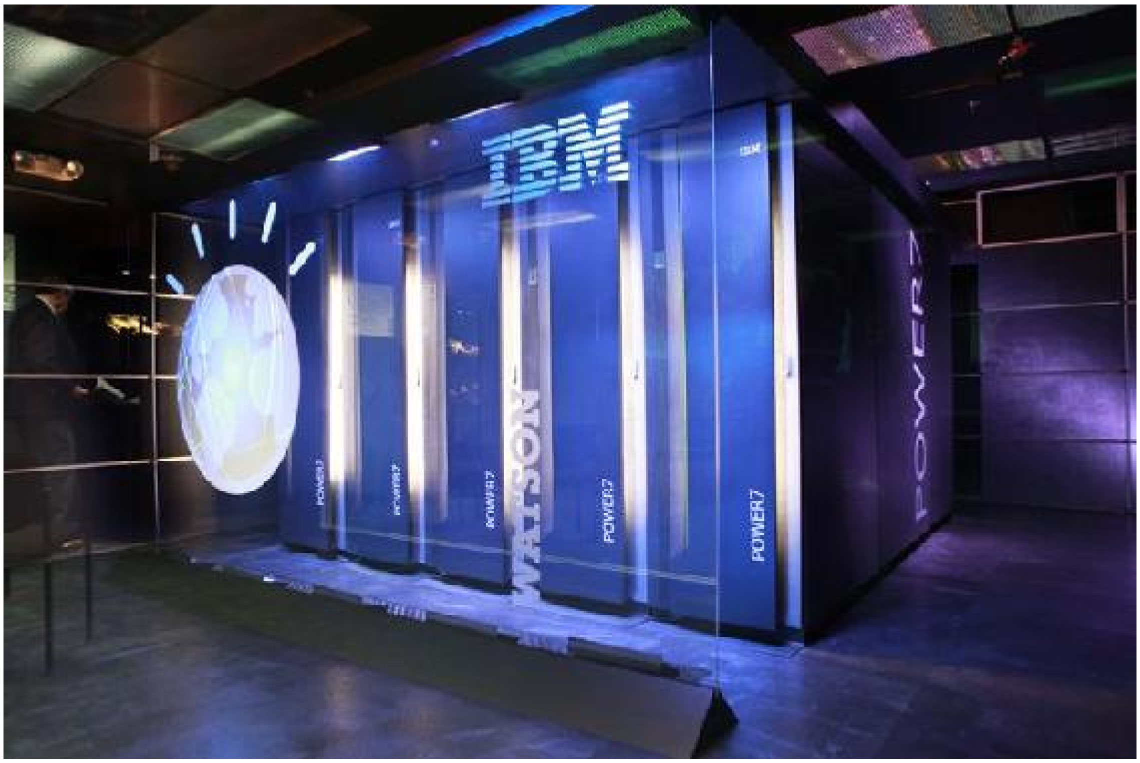
The Expert Q&A

Assessing the Future

IBM senior scientist Murray Campbell breaks down A.I. and the real world. Plus: The fear factor

By Lisa Eadicicco



IN 2001, IBM'S machine-learning system, Watson, defeated *Jeopardy!* champions Ken Jennings and Brad Rutter.

Now that systems can best humans at any game, what's next? The debate over artificial intelligence has divided some of Silicon Valley's brightest minds. Companies like Google, Microsoft and Amazon are embracing A.I., integrating it into their core products. Larry Page, the CEO of Google parent company Alphabet, argued in 2014 that A.I. could bring economic benefits. "When we have computers that can do more and more jobs, it's going to change how we think about work," Page told the *Financial Times*. "There's no way around that."

Other major industry figures warn that artificial intelligence could spin out of control. Elon Musk, the CEO of Tesla Motors and SpaceX, once said A.I. could pose the "biggest existential threat" to mankind. Philanthropist and

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Microsoft co-founder Bill Gates said he's "concerned" about the development of super-intelligent machines.

Yet the technology continues to rapidly advance. In 2016, Google's AlphaGo bot became the first computer system to defeat a professional player of Go, a notoriously difficult game for A.I. to crack. Many experts had considered the feat at least a decade away. Amazon's Alexa virtual assistant is beginning to appear in all sorts of appliances, ranging from desk lamps to cars and washing machines.

Murray Campbell, a research scientist and senior manager with IBM, doesn't think we have reason to worry about artificial intelligence in the near term. Campbell has been studying A.I. for decades, since he was recruited to help develop Deep Blue in 1989, the IBM computer famous for defeating former world chess champion Garry Kasparov. His current work in the company's cognitive-computing division examines artificial-intelligence approaches to reasoning, planning and decision making, and he regularly collaborates with the Watson team.

Watson is famous for prevailing on the television game show *Jeopardy!* in 2011. Today, IBM is hoping third-party developers will use Watson's cognitive system to analyze images, understand speech and crunch huge amounts of data. To pull that off, Campbell says, computers need to learn how to truly participate in conversations rather than just answer questions.

TIME spoke with Campbell to learn what it will be like to have a real conversation with a computer, whether we should fear the idea of robots taking our jobs, and more. Our discussion has been edited for length and clarity.

What is it going to be like to have a real conversation with a computer?
When was the last time somebody walked into your office and posed a perfectly well-formed, unambiguous question that had all of the information in it required to give a perfectly formed, unambiguous answer? It just doesn't happen in the real world. And so what happens is, there's information exchanged. There are some things that are ambiguous or unclear, and people will ask questions to try and clarify, like "What did you mean by that?" or "You didn't mention this," et cetera.

And if you have to script that all out in a dialogue system for a computer to do this, there are just so many ways that a conversation can go, that you can never really do it. So you really have to have a learning approach, where a system learns to do this over time. So that's where we're focusing.

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It will begin to learn what you mean by certain things when you say them. And if it doesn't understand what you mean, it will ask, rather than just blindly doing what you say. So as we think about computers and people working more closely in the coming years, the natural way of interacting is through dialogue.

How does a computer actually comprehend and answer a question?

When you ask the question, there are lots of [natural language processing] techniques and machine-learning techniques that are applied to parse that question into its pieces and then start coming up with hypotheses of what the answer could be by searching through a large corpus. It could be Wikipedia, it could be the *New York Times* archives, it could be anything.

And as these hypotheses start to form, there's evidence that will be found —some in favor of one answer, some in favor of another answer. Some may be showing that a particular answer is bad. So all of this evidence accumulates and is brought together, again using a machine-learning approach to decide which sources to trust the most, which evidence is the most convincing, and then to come up with an answer. Not just an answer, however, but with a level of confidence in that answer. So if it's not certain, you at least know that the answer you're being provided is more or less a guess, whereas if it's certain you can rely on it more.

You've had some thoughts about the computer that beat the expert Go player. How big a milestone for A.I. is this?

I think it is a big milestone. It was the last standing traditional board game that hadn't been conquered by a computer. I think in a sense it's now the end of an era. There won't be as much research on board games going forward.

I think it's more important to move toward messier kinds of problems that have factors like uncertainty involved. There's some information that you don't get to see, unlike in Go or in chess, where everything you need to know is right there in front of you if you can just figure it out.

But in the real world, there's a lot of information that you just don't get to see and you still have to make a decision in spite of that fact. Or there may be some information that you see but isn't reliable, and you have to know how much to trust it. And in the real world you have to deal with language too.

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What's an example of a real-world scenario that you'd like to see A.I. conquer?

Most of the video games that people play provide really great test beds for exploring A.I. technology. They require perception because there's visual input, they often require some kind of language, and there are many possible actions that can be taken. So it's a step toward the real world.

But the real world is the real world. So you can imagine health-care applications where a doctor is meeting with a patient and is trying to decide what the appropriate course of action is. And there's so much information out there in the world that might be relevant for this particular patient, but who has time to look through it all?

So if you had a cognitive assistant that could go out and look through all the information, compare this patient with other patients and look at what course of treatment they had . . . and then provide that information to the physician, who's really the decision maker, they could potentially make better decisions.

Several influential figures in tech, like Elon Musk and Stephen Hawking, have expressed concern about A.I. Do we have a real reason to fear A.I., or is it being overblown?

I definitely think it's overblown. It's worthwhile to think about these research questions around A.I. and ethics, and A.I. and safety. But it's going to be decades before this stuff is really going to be important. The big danger right now, and one of IBM's senior VPs has stated this publicly, is not following up on these technologies. Because the benefits are so huge that if we don't use A.I. technologies, we're going to be losing out on all of these beneficial effects in health care, in self-driving cars, in education.

People have expressed concern about how A.I. will impact the job market one day. IBM's goal with Watson is to make jobs easier, not to eliminate them. Still, won't there be unintended side effects? If a robot is helping answer questions in the hotel lobby, maybe the hotel needs one fewer employee.

There's no doubt that there will be an effect on the job market, more in the mix of jobs and the kinds of jobs that are being done. If we each have our cognitive assistant that can help us be more efficient, then we can get more done and we don't need as many people to do that particular job. But each time we create these cognitive assistants, we create new opportunities. That's the way it's been in the past: new technologies take away some work

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but create new opportunities. These A.I. systems are going to have gaps. They're going to have gaps in their knowledge for many years to come. And the practical way to fill those gaps is to partner them with humans who have a general intelligence and commonsense reasoning so they can work together as a team to complement each other.

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GARRY KASPAROV (left) lost to IBM's Deep Blue, aided by Murray Campbell, in 1997.

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The User-Friendly Vision

- Command Performance
- High-Tech Toys Are Here to Play
- The Future Is Coming Home
- A Lesson in Communication
- Self-Driving Cars Are Safer Than You

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Command Performance

Voice-controlled home assistants, such as those from Amazon and Google, help you in your everyday life

By Lisa Eadiccico

When Stephen Rea wants to turn on the living room lights hanging above his couch, he doesn't reach for a wall-mounted switch or fire up a smartphone app. He simply asks his assistant, Alexa, to do it for him.

Alexa is the voice-activated artificial-intelligence helper that powers Amazon's line of Echo smart speakers. Alexa may sometimes interject uninvited into Rea's conversations, and she's known to misunderstand a request. But overall Rea, an information systems architect for IBM, finds Alexa to be so helpful that he owns four Echo devices: one regular-size model and three miniature Echo Dots. "I'm all about home automation," he says. "[My wife] hates it, but I love it."

So-called smart speakers like the Amazon Echo and Google Home have become overnight hits, able to answer questions, control our smart-home appliances and even call a taxi on our behalf. Analytics firm Voice Labs

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predicts that 24.5 million voice-centric gadgets like the Echo will have shipped by the end of 2017.

The concept of talking to our technology isn't new: Apple's iPhone has had Siri since 2011; Google added voice search to its iPhone app as early as 2008. But the Echo's omnipresent, always-on nature puts it in a better position to function as a true personal assistant, experts say. With such a device, retrieving the answer to a question or setting a timer no longer requires users to be within reach of their phones. "It's created a completely different level of interaction," says Oren Etzioni, the CEO of the Allen Institute for Artificial Intelligence. "It's not in a pocket, it's always on, it's out in the kitchen. And it's breaking more energy into the space."

The Echo's unexpected success has prompted companies to bring voice-activated helpers to all corners of life, from cars to televisions and refrigerators. This was quite evident at the CES technology expo in Las Vegas in January 2017, which served as a sort of coming-out party for Alexa. Automakers, including Ford and Volvo, announced that Alexa would be embedded in new cars, while LG unveiled a high-tech fridge with Alexa and other smarts.

Such phenomena rarely go unnoticed for long in Silicon Valley. Google debuted its Home smart speaker last fall, which houses its Alexa competitor, the Google Assistant. The search giant has been touting its Assistant as a voice-activated helper that can understand context and perform tasks on an owner's behalf. Both Apple and Samsung have ramped up their respective artificial-intelligence efforts over the past few months, too: Apple expanded Siri's capabilities so that it can communicate with third-party apps like Uber and Pinterest; Samsung acquired Viv Labs, a startup led by an entrepreneur who helped create the original version of Siri. Taken together, these efforts suggest that the world may be heading toward a future in which typing and swiping take a backseat to voice interaction.

"Technology crosses a threshold where suddenly it becomes good enough for the general public, and that's happened here," says Etzioni. "[It's like] somebody threw a snowball, and now we're seeing the snowball tumbling down the hill and gather momentum."

Surpassing that threshold wouldn't have been possible without advancements in speech recognition and machine learning, a subfield of A.I. that focuses on teaching computers to learn in the same way humans can. Computers have made significant strides in comprehending spoken

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words over the past several years. Voice-enabled technologies from Google have surpassed 90% word accuracy, as Mary Meeker, a general partner at venture-capital firm Kleiner Perkins Caufield & Byers known for her annual internet trends report, pointed out in 2016.

But simply understanding what people say isn't enough to make a virtual butler like Alexa or the Google Assistant truly intelligent. It's also about inferring what people want when they make a request, says Rishi Chandra, Google's general manager for Home. For example, when a user says, "Crank up the volume," that should trigger the device to make its audio louder, even though that phrase didn't include the terms "raise" or "turn up." "There's a lot of technology that needs to be built to really understand the intent of what the user wants to do," Chandra says.

As virtual assistants become smarter, the technology world is forced to grapple with a fundamental question: How should we navigate the challenges they pose? The most prominent issue has been user privacy. Most technology companies benefit from knowing as much about you as possible, and some worry that the temptation presented by an always-listening microphone may be too much to resist.

Advertisers such as Burger King, meanwhile, have found controversial ways to turn these devices into marketing vehicles, by triggering them through television commercials telling Alexa what to do. In one extreme example, authorities issued a warrant seeking access to the data recorded by a murder suspect's Echo device. And the new camera- and touchscreen-equipped Echo Show, released in June 2017, has already incited a new wave of privacy concerns.

Some experts believe the genie is already out of the bottle. "It's not something we can reverse and decide, 'Oh, we don't want Alexa,' " says Manuela Veloso, head of the machine learning department at Carnegie Mellon's School of Computer Science. "It exists, it's going to be part of our lives . . . What becomes the problem now is how do we make this happen in the right way so that humans and A.I. interact well."

Amazon and Google are well aware of the complications their virtual assistants can cause. Both companies promise to record your voice only when you say the corresponding "hotword." Both make it possible to delete your voice recordings at any time, and both are taking measures to improve the results their virtual assistants offer.

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The key to preventing incidents like the Burger King commercial involves improving the Home's ability to understand who is speaking, says Google's Chandra. Google is already pursuing that strategy by releasing an update for the Home that enables it to distinguish individual voices.

Part of the problem also lies in the fact that these always-listening devices are still new territory for both consumers and the companies making them. Firms such as Amazon and Google are still learning to prepare their gadgets for unexpected scenarios, while app developers are figuring out how to create useful voice interactions. Chandra likens it to when the iPhone launched in 2007. "This notion of touch, it took time for developers to take advantage of it," he says. "I think you'll see, a lot of the [voice] integrations that exist today are fairly primitive."

As voice-enabled assistants improve their conversation skills and appear in more devices, they will be able to help us with much more than just dimming our lights or starting our cars. One day, a more powerful digital aide may take notes for a doctor while he or she interacts with a patient, says Etzioni.

Veloso takes that a step further, positing an A.I. that can sort through vast amounts of research data for a scientist while he or she sleeps. "You wake up the next morning, and this system will tell you all of the things it's found," she says.

Over time, these A.I.-based machines will speak and think more like humans, while learning to crunch massive amounts of data at unprecedented speeds. But there is plenty of work to be done before we get there. "Where this really becomes a game changer is when you can have a dialogue with this virtual assistant," says Etzioni. "This is a marathon, not a sprint, and we're still in the early rounds."

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DEVICES LIKE AMAZON'S ECHO are quickly becoming mainstream as more households rely on A.I. for a growing range of everyday tasks, from setting the thermostat to playing games.

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High-Tech Toys Are Here to Play

Cozmo fits in the palm of your hand, but the wheeled robot wields some serious A.I.

By Lisa Eadicicco

ANKI'S COZMO is a playful robot that users control through an app.

The first thing I learned about Cozmo is that it doesn't like to stay put very long. When the little robot is roused from slumber, its face illuminates, and it begins zooming around the table in front of me. A moment later, it notices I'm watching and turns to greet me, saying my name with a computerized chirp.

Cozmo, which has been available since October 2016, is the latest toy from six-year-old San Francisco startup Anki. It's also an attempt to bring the burgeoning fields of robotics and artificial intelligence to consumers. Anki is betting that toys will give both of those technologies a stronger presence at home. And Gartner, a leading technology and research company, predicts sales of such smart toys will grow globally, from 5

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million units shipped in 2016 to 241 million units by 2020. The growth can be attributed to increasingly cheap components and children's being exposed to smart tech at younger ages.

Toy makers have been cramming circuit boards and wireless chips into their products for years. Mattel and Hasbro, for example, sell high-tech versions of the classics Barbie and Furby. (Barbie can engage in conversations with her owner, and Furby connects through an app to a virtual world.) But toys like Cozmo differ in the way they interact with the people and objects around them, changing their behavior over time as their software "learns." Right out of the box, cameras and sensors allow Cozmo to recognize individuals, avoid falls or bumping into obstacles, and play simple games like keep-away. Cozmo's A.I. enables it to experience a sort of computer-generated mood swing. After winning a game, its confidence might spike, but if it ventures too close to a ledge, its bravery may start to plummet. If it fails to complete a task, like picking up one of its toy cubes, Cozmo may slam its forklift down angrily the way humans bash their hands in frustration. Anki says Cozmo will continue to evolve; the bot has already learned new skills since its launch, such as how to recognize pets and give its owner fist bumps.

"Every input trigger, no matter what happens to him, will influence his future behavior," says Hanns Tappeiner, Anki's president.

Cozmo is first and foremost a toy. But Anki is hoping the bot's sophisticated technology will enable it to serve a dual purpose as an inexpensive and easy-to-use platform for those interested in learning about robotics. The palm-sized rover now has its own coding language that owners can use to program its real-world actions via an app, a development announced in June 2017. "The real reason we are excited is because we can make robotics functionality available to people who aren't normally roboticists," says Tappeiner. The company's three co-founders came up with the idea for Anki in 2008. Their first product—phone-controlled race cars that can avoid crashing into one another—came out in 2013.

But over the past two years, they became convinced that creating a character with personality would bridge the gap between robots and humans. That's when it became evident that the team would have to branch out beyond race cars. "Cars are great for competition and interaction, [but] it's not really the best mechanism to show emotion," notes Anki co-founder and CEO Boris Sofman.

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To do that, the company studied characters from kids' movies and hired animators from Pixar and DreamWorks. It has to prove that Cozmo's charisma will win over parents: the robot costs $180. Disney canceled its line of Infinity smart toys in 2016 after sales flagged. Although there are other robot toys on the market for kids to learn how to code, such as MakeWonder's Dash & Dot bots, Anki's more advanced tech makes the overall experience unique. Many people believe the cuteness factor will go a long way toward popularizing home robots. "Kids in general will be way more accepting," says Gerald Van Hoy, a senior research analyst for Gartner. "It's a huge market—as soon as the right kind of device comes along."

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The Future Is Coming Home

Recent advancements in home automation mean that smart houses are no longer a dream of the future

By Alex Fitzpatrick

Home is where the heart is, of course. But could it also be where the brain is?

That's the dream behind so-called smart-home gadgets, the increasingly prevalent devices that connect to the internet and can be controlled by a smartphone app or, in some cases, by a user's voice. Many get a further boost from artificial intelligence—learning and then predicting users' behavior in seemingly magical fashion. Some smart-home users may have just a couple of internet-connected lightbulbs, or perhaps a smart speaker. Others go all out, turning their homes into technological marvels that would make Tony Stark envious.

Take Rachel Welch, for example. The Austin, Texas–based public relations professional can brew a pot of coffee without ever leaving bed, thanks to her internet-connected drip maker. She can turn on lights in her home with an app, get the latest headlines by asking a device in the kitchen for them, and keep an eye on her home while she's out and about thanks to Wi-Fi-equipped cameras. "I've really come to enjoy the ease and the simplicity of these things," she says.

Welch is far from alone. Smart-home gear, once the domain of techies and tinkerers, is being driven into the mainstream by Silicon Valley's biggest companies, including Amazon, Apple and Google. The smart-home-device market is expected to reach $13.4 billion worldwide in 2017, according to research firm IHS Markit. That's a 35% increase from 2016.

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Smart-home advocates say they're benefiting from better home security, added convenience and a "wow" factor that impresses guests. But there are plenty of challenges. The devices can be difficult to install, for one. Several companies are developing their own competing smart-home ecosystems, so gadgets from one firm may not work well with gizmos from another. And there is vulnerability too: hackers have shown plenty of interest in attacking smart-home devices. Still, it's clear that technology companies see your house as the next great frontier for their products and services.

On board *Star Trek*'s U.S.S. *Enterprise*, crew members interacted with the ship's computer simply by asking it for whatever they needed. Room temperature 71 degrees? No problem. Play Beethoven's Fifth? You've got it. Tea, Earl Grey, hot? Here you go.

That bit of science fiction illustrates the dream of smart-home advocates, who believe their houses should be able to cater to their every whim. We're nowhere close to having food or drinks materialize before our eyes, of course. But the latest smart-home devices are combining artificial intelligence with vocal recognition in a way that Captain Kirk would surely appreciate.

Take the Amazon Echo, for example. Users can ask the smart speaker to read the latest news headlines, order a pizza or even tell them a joke. Met with skepticism at first, the Echo has become an unexpected hit. Amazon does not report its own figures, but Morgan Stanley estimated that the company had sold 11 million of the devices as of December 2016.

The Echo's success has not gone unnoticed in Silicon Valley. Google offers a rival product called the Home, Microsoft is partnering with other firms to put its Cortana digital assistant in speakers, and Apple recently announced that a similar product, the HomePod, would be available in December 2017.

Experts say devices such as the Echo are often a gateway into other smart-home tech. "You get the connected home hub, and then you get bored of asking questions about the weather or the news, so then a lot of people move on to linking up home-monitoring systems and smart-lighting solutions," says Jessica Ekholm, an analyst with research firm Gartner.

Those home-monitoring systems speak to another big trend in smart-home tech: security. Internet-connected cameras can beam video of the inside or outside of homes to owners' smartphones, whether they're across the street or around the world. Thanks to artificial-intelligence software, they're able

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to tell the difference between your house cat and a would-be cat burglar, alerting users when they detect something amiss.

Then there's the money-saving angle. Smart thermostats learn your habits over time, turning down the temperature automatically when you're not home and heating things up when you're headed back. That can help you save big bucks on your energy bill over the long term.

Another draw: the cool factor. Internet-connected LED lightbulbs can change colors on demand through a smartphone app. That may not be particularly useful, but it sure is a neat party trick. (Sports fans can set up a light show triggered by a team's goal, for instance.)

Of course, *Star Trek* is known for painting a particularly rosy picture of gadgetry. A more somber take comes from *Mr. Robot*, a popular show about hackers. In the first episode of the second season, a woman taking a shower is scalded when the water suddenly turns piping hot. She steps out to her hallway to find her smart home's thermostat has been set irreversibly to 53 degrees. Then all hell breaks loose. Her lights go crazy, her alarm starts wailing, and her stereo is blasting Mozart. In a panic, she calls tech support. "Unplug what?" she asks. "Everything is inside the walls." Eventually, she abandons her smart house for her second home in Connecticut. Minutes later, the hackers responsible for the chaos show up and ransack the place.

That's an extreme—and fictional—example. But there is a common adage among computer-security pros: If something is connected to the internet, somebody out there is trying to hack it. Need proof? In September 2016, computer security researcher Brian Krebs was the victim of a record-breaking cyberattack, during which hackers used tens of thousands of hijacked smart-home devices to overwhelm and disable his website. Meanwhile, there is more than one publicly accessible search engine through which you can view the feeds of thousands of unsecured internet-connected cameras.

The most vulnerable devices are typically low-end models from no-name brands. Companies such as Amazon and Google have entire departments dedicated to keeping their products secure. But security concerns remain one of the biggest stumbling blocks preventing smart-home technology from becoming a bigger market. "As these devices get more popular, there's no question that there will be people trying to hack your equipment," admits Arjun Sharma, a radiologist and smart-home aficionado. Still, he's confident he won't fall victim to that *Mr. Robot* nightmare. "You've got to

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keep your products updated, obviously," he says, meaning with cutting-edge security. "But I also can't think of what people could do with my house."

If consumers don't fear hackers, they may be skeptical about another group: the very companies making smart-home tech. After all, technology companies tend to make more money if they know more about you, whether through advertising or personalized recommendations. "As you have voice in the home, people are concerned more and more about the device always listening," says Blake Kozak, an analyst at information company IHS.

These fears are not entirely ungrounded. At least two television makers have been criticized for secretly collecting data about viewers' watching habits, raising concerns about internet-connected gadgets in general. While there's no indication that a large tech maker would go so far as to snoop on your kitchen-table talks with your spouse, some people would rather not take the chance. Still, consumers in general have shown time and time again that they're willing to sacrifice some personal privacy in the name of convenience—digital empires from Facebook to Google are built on that very trade-off.

We'll need many more years of advancements in artificial intelligence and voice recognition before we're living with anything like the computer on the *Enterprise*. But it's more likely than ever that the next house you visit will have at least some form of smart technology. That's especially true now that tech companies seem to be focusing on gadgets that are actually useful, rather than, say, an internet-connected juicer.

"It's a really interesting design problem," says Antoine Leblond, the vice president of software at smart-speaker company Sonos. "When you're building things that live in people's homes . . . you have to think hard about how you make the things you build fit within the flow of people's lives." What kind of devices might be next on the horizon? "I like to cook a lot, and I would really love to preheat my oven from somewhere else," says Rachel Welch. And she'd of course be hoping that such a device could remember to turn the oven off too.

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COMFORT, CONVENIENCE, safety and security can now be managed almost entirely through an interconnected system of devices in the home.

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ONE CHALLENGE facing smart-home technology is proving that its benefits outweigh the threats of malicious hackers or invasive commercialism.

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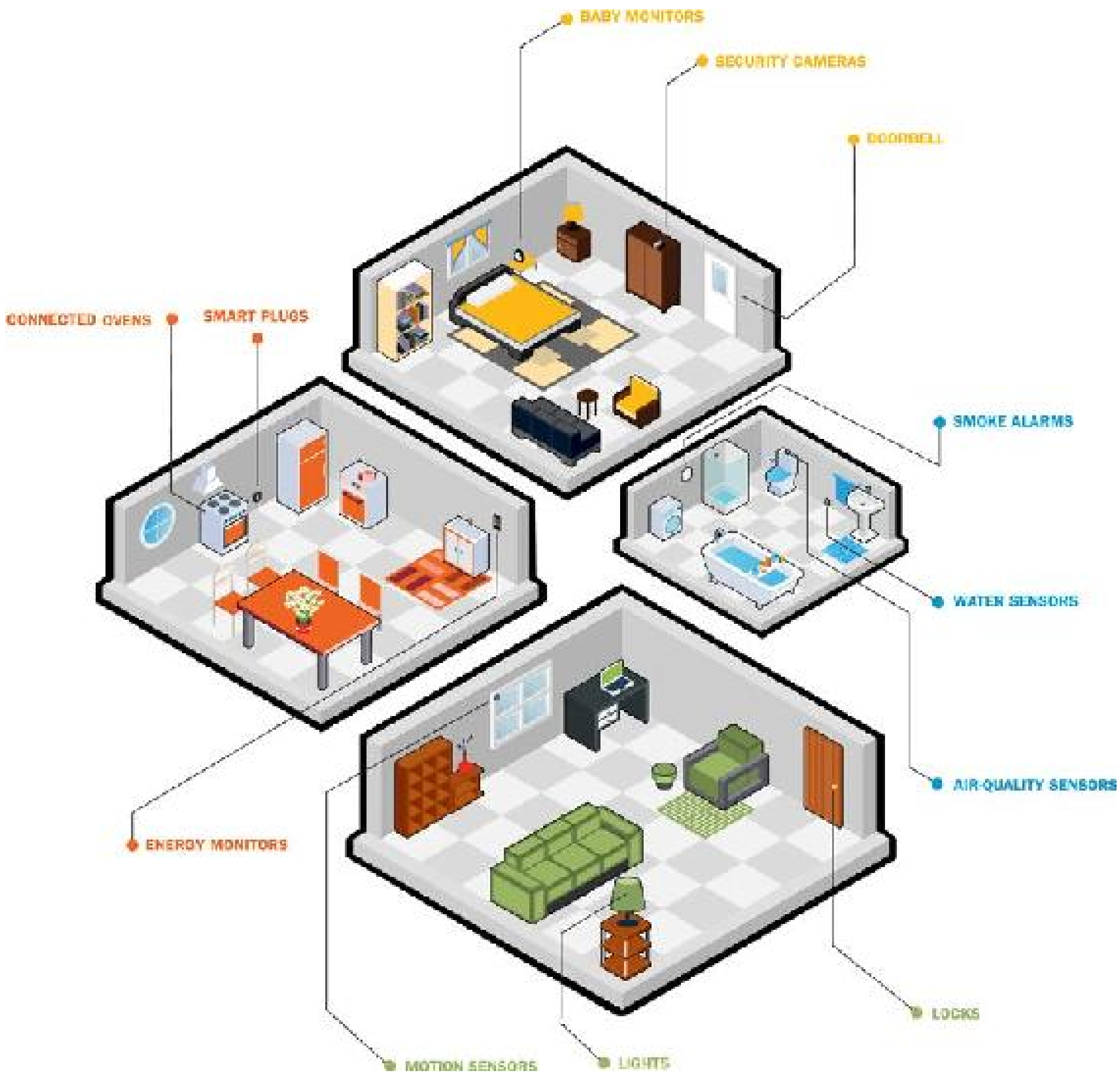
Smart Homes' Top Job: Safety

Gadget makers have a knack for issuing big, long-term promises about the advent of the so-called smart home. But one of the most potent applications is also the most basic: how to make your home safer. Here's a closer look at ways the smart home can do so

By Lisa Eadicicco



Secure Everyday Tasks

CONNECTED OVENS Smart ovens made by GE and Nest's smoke alarm now work together to automatically turn off the oven if, for example, smoke is detected.

ENERGY MONITORS Sensors that plug into your home's electrical system, like the Sense, are meant to lower utility bills. They can also

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alert you if you've accidentally left an appliance running.

SMART PLUGS Wi-Fi-compatible plugs like the Belkin Wemo Switch aim to eliminate panic about leaving the iron plugged in. You can see what's turned on and switch off appliances via its phone app.

Keep Intruders Out

MOTION SENSORS Sensors like those made by Samsung SmartThings connect to a central hub and send alerts to your phone if a door or window is unexpectedly opened.

LIGHTS An update on the hardware-store standby, Philips Hue lights are programmable even from a distance to make it look like you're home when you're not.

LOCKS High-tech door locks, including ones made by Kwikset and August, don't necessarily replace keys, but they can be unlocked via a mobile device.

Monitor Your Home

BABY MONITORS Gadgets like the Infant Optics DXR-8 make it easier to keep an eye on your infant no matter where you are in the house. The camera streams video to a tiny portable screen.

SECURITY CAMERAS Nest and Piper cameras provide a live feed of areas inside or outside the home when you're away. These surveillance devices can send notifications to your phone as well when motion is detected.

DOORBELL Systems like SkyBell monitor what's happening near your front door, allowing you to see visitors via a built-in camera and speak to them whether you're home or not.

Prevent Accidents

SMOKE ALARMS The Nest Protect not only sends alerts to your phone during an emergency but also self-tests its sensors to make sure they're always functional.

WATER SENSORS Sold by D-Link, these sensors ping your phone if moisture or puddles are detected where they shouldn't be, like on the floor near a sink or washing machine.

AIR-QUALITY SENSORS Gadgets like the Foobot can detect potentially harmful agents found in mold, paints and coatings as well as other

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substances in the home. Foobot's app gives your home an air-quality score based on its findings.

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A Lesson in Communication

Does bossing around our smart tech send the wrong message?

By John Patrick Pullen

One of the most unexpected things about having children is how the quest to mold perfect little humans ultimately becomes a project of making yourself a better person. Though hardly revolutionary, this epiphany came to me when I was talking to an inanimate object, Amazon's Echo speaker, in front of my 18-month-old, Jack, in 2016.

"Echo, turn on the lights. Echo, set my thermostat to 72 degrees. Echo, play 'Wheels on the Bus,' " I commanded the gadget, which understands and responds to an ever growing set of orders (including, no surprise, "Echo, buy more diapers"). Every time I said "Echo," Jack's eyes shot up to the cylinder-shaped speaker atop the refrigerator, its glowing blue halo

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indicating it was listening. Then, one day, the inevitable happened: “Uggo!” Jack barked. “Bus!”

After I explained to Jack that it’s not nice to call someone an uggo, I saw myself through my son’s words—and didn’t like how I looked. Sure, Echo doesn’t care how you talk to it. But to Jack, I must have seemed like a tyrant. And by imitation, he became my little dictator. This dilemma is likely only to grow as voice-based artificial intelligence becomes more commonplace. Already, Apple’s iPhones and iPads have Siri; Google-powered devices come with a similar feature, Google Now; and Microsoft has Cortana. Soon we’ll regularly be talking to digital Miss Moneypennys at home, work and everywhere else.

Like most parents, my wife and I hope Jack grows up to be kind. Like most toddlers, he needs some help with this. My exchanges with my technology have clearly been setting a bad example. But how exactly to talk to our technology is far from clear. “The issue of ‘please’ is huge. It’s one of the foundations of etiquette,” says Lizzie Post, the president of the Emily Post Institute and great-great-granddaughter of America’s best-known arbiter of manners. “Kids model the behavior of the parent, and if you want your child to be using the word ‘please’ often, you need to use it often too.”

So now I say “please” as much as I can. I say it to my wife, my son’s teddy bear, Siri, Echo, Cortana, even my dog. But not everybody agrees that speaking to computers the way we’d like to be spoken to is the best way forward. Oren Etzioni, the CEO of the Allen Institute for Artificial Intelligence in Seattle, is one. “I don’t say ‘please’ and ‘thank you’ to my toaster,” he argues. “Why should I say it to [Echo]?”

Etzioni believes that the machines we have now, our smartphones and tablets, are effectively appliances. “It seems to me that we reserve politeness as a social lubricant,” he says. “It has a purpose.” And as a father, Etzioni is concerned that his son will overanthropomorphize smart devices. “I’d be worried that he’d get confused in the same way that we don’t want our kids to think Superman is real and then jump off something,” he says.

If you’ve ever been fooled by an online customer-service chatbot or an automated phone system, you’ll agree that this technology is evolving quickly. Coming generations will find it even harder to differentiate between bots and people, as they encounter even more artificially intelligent assistants backed by machine learning—computers that teach themselves through repeated interactions with human beings.

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At Microsoft, there's a personality team dedicated to helping Cortana get a better grasp of manners and mannerisms. The technology is being infused with cultural cues to make it more likable. For example, Cortana's avatar bows to Japanese users, who prefer formality. "Having a personality designed into the system, knowing some of the nuances of the way humans communicate, how they use different adjectives and how they say 'thank you' and 'please'—we think it's an important part of getting that overall speech and dialogue system right," says Marcus Ash, the group program manager for Cortana.

Meanwhile, Hound, a voice-assistant app available for a broad range of devices, not only processes the magic words (please, thank you, you're welcome, excuse me, sorry) but also softens its responses when users speak them. "When you say 'hello' to Hound, you might hear one type of response, but when you say 'hey' or 'yo,' you will definitely hear a different one," says Keyvan Mohajer, a co-founder and the CEO of SoundHound.

For humans, etiquette is a kind of social algorithm for managing feelings. Computers will get much better at understanding this—but that will likely take decades. Which is more than enough time for me to solve this uggo problem.

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A Language Evolution

TODAY

Voice-driven services like Siri and Hound mostly retrieve and collate information from the web for convenience's sake.

TOMORROW

More adept, humanlike artificial intelligence is on track to supplant translators, teachers and even therapists.

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Self-Driving Cars Are Safer Than You

Autonomous cars are taking over the roads by offering some much-needed upgrades

By Matt Vella

There are three things you should know about self-driving cars:

1. They're here. In late 2015, Tesla Motors pushed a software update to its vehicles around the world. The new code coordinated sensors, cameras, GPS and controls already onboard the cars to allow for so-called autonomous driving—albeit with humans in the driver's seat ready to take over if needed. Within weeks, a crew of rally drivers climbed into a Model S in Los Angeles and sped to New York in just over two days, the car steering itself 96% of the way. Other stoked nondrivers have posted videos of themselves reading books, brushing their teeth and otherwise ignoring

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the road as their cars zoomed along. Tesla founder Elon Musk predicts that his electric cars will be entirely self-driving—even docking themselves at robotic charging stations—by the end of 2020.

Mainline carmakers from General Motors to Mercedes-Benz have also pledged to sell autonomous vehicles in the next few years. Born-again evangelists of self-driving cars include some of the most venerable names in the business, such as William Clay Ford Jr., the executive chairman of the company founded by his Model T–building great-grandfather Henry, and Toyota Motor Corp. president Akio Toyoda, whose great-grandfather was known as the "king of Japanese inventors." (Toyoda, a racing buff, was adamantly opposed to self-drivers before reversing himself in late 2015.) Maryland, Tennessee, Georgia and Illinois have legalized self-driving cars, and at least 13 more states are mulling similar laws.

2. They're superior drivers. These words may grate in the sunburned left ears of car-loving Americans. But the computer is simply a better driver than a human. Better at keeping its eyes on other drivers; better at maintaining a steady cruising speed and thereby maximizing fuel efficiency; better at parsing GPS data, weather data, traffic data—any and all kinds of data, really—and better at making rapid-fire adjustments. The computer doesn't get distracted by a spouse, kids or the jerk who just made an illegal lane change. It doesn't sneak a glimpse at Snapchat or fumble with a leaky burrito or steer with its knees while playing air guitar. The computer couldn't blink even if it wanted to. It never says yes to a fourth chardonnay, never convinces itself that weed improves its driving. Asking directions is a computer's favorite activity, and unless ordered to, the computer never falls asleep.

3. They're going to change everything. The economic and safety effects will be staggering; the moral and legal challenges will be stubborn. There is no "right to drive" enshrined in the U.S. Constitution, but forced to choose, a lot of people would rather take the wheel than the Fifth—no matter how many statistics are marshaled to prove that driving puts others' lives at risk. Self-driving cars will likely join digital surveillance and unmanned drones among the advances and controversies that mark our times. Freedom vs. security, that quintessential quandary of the 21st century, will frame the transition from human drivers to more-skillful computers.

And because the gulf between human and machine is so vast—and growing—the next step after making driverless cars legal will be making

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them mandatory. Today you pay higher insurance premiums to drive a zippy roadster than a dowdy minivan. Tomorrow you could well be paying a steep price for any steering wheel at all. Who will be liable for mistakes? How should computers make life-and-death decisions? Such questions are likely to contort ethicists and lawyers for years to come. But all revolutions involve upheaval, and this one is poised to create far more than it destroys.

In the Throne Room of the American psyche, a driver’s seat occupies center stage. Think Bonnie and Clyde and their fugitive Ford V-8, Jack Kerouac on the road in a ’49 Hudson, James Dean’s fatal Porsche Spyder, Steve McQueen’s Mustang fastback, Greased Lightning, the Love Bug, Thelma and Louise, Nicolas Cage vanishing in 60 seconds. What would the 1920s be without the Tin Lizzie, or the 1950s without the ’Vette, or the 1980s without the DeLorean?

That connection between cars and drivers is nothing like the feeling we had for typewriters or landlines or any of a thousand technologies overthrown by computers and smartphones. That was utility; this is love. Yet America’s long-standing romance with its cars has been deeply troubled, sapping time and treasure while leaving innumerable victims dead or maimed. A world without human drivers will be safer, more livable, more prosperous.

There are about 6 million car accidents—meaning incidents serious enough to be reported to law enforcement—each year in the U.S. About 33,000 Americans die annually as a result, with an additional 2 million or so injured. (Worldwide, there are about 1.3 million traffic fatalities every year, according to the World Health Organization.) Some 94% of road accidents are the fault of drivers, according to the National Highway Traffic Safety Administration (NHTSA), whose collection of statistics reads like a numerical translation of Stephen King’s *Christine*, a chilling account of motorized lethality. The price tag for this mayhem, by one estimate, runs $836 billion.

Other statistics tell of lesser forms of wastage. The average American spends 42 hours per year stuck in traffic, the equivalent of an additional work week. In the country’s most congested areas—Washington, D.C., Los Angeles and New York—that figure climbs as high as 82 hours. Multiplied by the span of a working lifetime, this waste of a precious resource, time, is incalculable.

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Even if you have been spared a serious accident and manage to live in a place where there is little traffic, your life is shaped for the worse by other drivers' flaws. Your car, for one, bears the stamp of human fallibility. Why does it look the way it does? Why is it so heavy? Why does it have more airbags than a Vegas strip club? Why are the bumpers shaped the way they are? The answer: engineering to keep occupants safe as well as legislation intended to keep people from being killed when struck.

To make a real leap forward in safety, the obvious move is to take drivers out of the equation. That is becoming today's reality with shocking speed. Just a decade or so ago, when the U.S. government funded the first international competition for self-piloting vehicles, not one of the challengers finished the 150-mile desert course set out for them. The most successful robocar covered a little more than seven miles before getting itself stuck. (Its wheels also caught fire.) The following year, only five of the 23 vehicles in the competition made it to the finish line, with the fastest one averaging a poky 19 mph. One of the finishers weighed 30,000 pounds—roughly 10 Toyota Priuses—and the rest were so larded with sensors, cameras, computer equipment and antennas that they made Mad Max's Interceptor look chill by comparison.

Today Google's autonomous test cars have logged more than 1.4 million miles on their odometers on public roads, equivalent to about 100 years of driving for the average individual. Total accidents: 17, all caused by human pilots. Ford's test fleet of self-driving cars—now charged with conquering wintry driving, one of the field's most vexing problems—will soon be the country's largest. At the 2016 North American International Auto Show in Detroit, then–U.S. transportation secretary Anthony Foxx announced a 10-year, $4 billion fund to promote self-driving research, along with a plan to dismantle regulatory barriers that might slow the development of autonomous vehicles. In February 2016, the NHTSA said computers controlling a vehicle should be legally defined as drivers rather than human occupants, validating companies like Google developing self-driving cars that have no human-operated mechanisms, like brake pedals or steering wheels.

Even at this early stage in their development, self-driving cars promise huge gains in safety and efficiency. Driverless cars don't have to be perfect to change the world, argues Nidhi Kalra, an information scientist at the

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Rand Corp. They just have to be safer. “Relying on human drivers any longer than we must is too risky,” she says.

According to a 2013 study by the nonprofit Eno Center for Transportation, converting just 10% of the U.S. vehicle fleet to self-driving cars would reduce the number of accidents each year by 211,000 and save 1,100 lives. In this modest scenario, the costs of human clumsiness would be cut by $25.5 billion. If, somewhere down the road, the share of self-driving vehicles rises to 90%, the number of accidents avoided could reach 4.2 million per year, with 21,700 lives saved. Self-driving technology is part of the reason that Volvo has pledged to have zero deaths or serious injuries in its new cars by 2020. In all, the adoption of driverless cars in the U.S. could save $1.3 trillion a year, according to a Morgan Stanley analysis—including $158 billion in fuel costs, productivity increases of $507 billion and $488 billion in accident-related savings. Total worldwide savings: $5.6 trillion.

If you ever tried to bump Dad to the backseat at a rest stop in Montana, no matter how many hours he’d been at the wheel, you have an inkling of the uphill fight that lies ahead for the driverless revolution. They can have our gearshifts when they pry them from our cold dead hands, many will cry. The coming years will no doubt be a seesaw of competing calculations, in which irrefutable data vies with ingrained passion.

Perhaps it helps to understand that autonomous cars don’t just make human driving better. Ideally, they will remake driving in surprising ways. Take intersection etiquette, for instance. To maintain the peace and equality of the social contract, we place stop signs and traffic lights where roads meet. Traffic signs and signals force drivers to take turns. They suppress our inner 5-year-olds, even when the frustrations of driving push us toward a tantrum.

Fully autonomous vehicles have far less need for this wasteful stop-and-start regime. They will be capable of communicating with one another and regulating their speeds to stagger their arrivals at crossroads. They will arrange seamless mergers on and off freeways. Traffic management will become a sort of precision ballet in a fully autonomous world.

Parking, too, will be transformed. Estimates vary, but for every car in the U.S. there are between two and three parking spaces—one at home, one at work and fractions at the mall, airport and stadium. Together, these amount to about 500 million spaces in all, or a total area of more than 3,000 square miles, some 2 million acres. Wildly inefficient. A University of California,

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Los Angeles, study found that 30% of drivers in certain metropolitan business districts are basically driving in circles at any given moment, searching for an open spot. Meanwhile, there may be hundreds, even thousands, of unoccupied spaces in lots on the edge of town.

Automated cars are like tireless parking valets (except that you don't have to tip them). They can drop passengers off at their destination, pick up a signal from an empty parking space and then zip away to await the return trip. When riders are ready to be picked up, a tap on a smartphone will hail the car. Already, Tesla software includes a function called Summon, which fetches the vehicle from nearby parking. In 2018, the firm claims, Summon will be able to retrieve cars from almost any distance.

This feature and others will gradually remake the landscape. Restaurants, big-box stores and offices will no longer be surrounded by asphalt tundra. And "if you have cars that do not crash, you can eventually begin to redesign roads," says Erik Coelingh, who leads Volvo's self-driving-car initiative. "Lanes are 3.5 meters wide. Why? Because people can't drive straight. They need some lateral margin. Bridges, overpasses, underpasses—all could be built much more cheaply" when vehicle movement can be dictated by efficient algorithms.

Subtract human drivers and efficiencies multiply. Steven Shladover, a University of California, Berkeley, engineer, has calculated that even on a freeway at peak capacity, only about 5% of the roadway surface is occupied by cars at any given moment. With computers in control and communicating from car to car, density could safely double, even triple, while the same average speed is maintained. Squeezing more vehicles onto existing roads would relieve pressure to widen highways, let alone build new ones.

There are less tangible effects as well. Autonomous vehicles offer improved mobility for the young, the elderly and the handicapped. According to the U.S. Census Bureau, 88 million Americans will be over 65 by 2050—and nearly 18 million of them over 85. Anguished family conversations over whether to confiscate a parent's car keys would become a forgotten bit of history.

But every Eden has its serpent, the driverless autopia included. At conferences to discuss this future, contrarians often raise a version of the classic "trolley problem." What will happen, they muse, when an algorithmic car must choose between a swerve that would doom a dozen

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bystanders and a crash that would kill the vehicle's lone occupant? Or an easier dilemma: At what age will passengers be allowed to ride alone in an autonomous car—18? 12? 6? Startup chauffeur services already offer rides for children as young as 7. UberFamily allows parents to order up vehicles equipped with car seats and tablets (though it discourages kids younger than 18 from riding unaccompanied). These and plenty of other objections will provide ammunition as America's libertarian id struggles to hold on to the keys.

Not to mention this: the revolution will destroy a lot. The $198 billion auto-insurance industry, the $100 billion parking industry and the $300 billion auto-aftermarket business (including everything from engine parts to mirror dice) are just a few of the industries in line for deep disruption. A survey last summer by the consulting giant KPMG estimated that the auto-insurance industry could shrink to less than 40% its current size over the next 25 years, just because of smarter cars. People will lose jobs. There are about 3 million truck drivers in the U.S., 200,000 cabbies, 170,000 auto-body and glass-repair technicians.

Many in the car business worry that self-driving vehicles are just one tragedy away from the scrap heap—like, say, a robotic car killing a child or running its occupants off a cliff. (Faulty and dangerous technology has doomed certain car models and delayed entire companies, sometimes for decades.) And hacking is a real concern that has yet to be fully grappled with.

How far off is this great reckoning? Estimates vary, but not by much. Tesla founder Musk has pegged the driverless-car transition to begin around 2023. "You can't have a person driving a two-ton death machine," Musk said at a conference in 2015. "It's too dangerous." Ray Kurzweil, another big Silicon Valley brain, who helps run Google's engineering efforts, agrees with Musk: prevalence in the next decade. Industry analysts roughly think 2035 to 2050.

What's certain is that like all technological revolutions, this one will have a self-compounding effect: more and more driverless cars on the road will result in more and more machine-centric street designs. These will in turn make it harder for humans to share the road, which will force more drivers to trade in their wheels. Because computer-controlled cars don't get tickets, cash-starved municipalities may encourage their highway patrols to let a lot fewer human drivers off with a friendly warning. One way or another, you

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will be taxed for driving the old-fashioned way. The cycle could feed on itself until driver's licenses are a rare credential, like Latin professorships or tugboat captaincies.

For the time being, autonomous cars will include a backup role for human drivers. During the cross-country test of the self-driving Tesla, the car—although assured of its own handling skills—had an unsettling tendency to race into curves at breakneck speed. So the steering wheel will probably stay—for a while, says Google co-founder Sergey Brin. In general, however, Brin and other executives in the self-driving arena continually stress that humans are the most dangerous link in the transportation chain. "I think for a large percentage of our day-to-day driving we're going to much prefer for the car to drive itself," Brin told the *Wall Street Journal*. "It'll be safer for both the occupant and the people around you." Manufacturers like Volvo and Mercedes-Benz have ratified that position by promising to assume the liability for any mistakes their smart vehicles make.

I find it strange, in a way, to be so eager for this future. I started my career covering the auto business, and as a kid I delighted in identifying makes and models from small details like the shape of a headlamp or a rear quarter panel. I have gotten misty in the stands of the Indy 500 and on the catwalks above Ford's F-150 truck plant in Dearborn, Mich. I hold road memories dear, especially the long hours in the passenger seat of my dad's convertible on cross-country trips devised to help me "understand America."

That understanding is impossible without an appreciation for our car culture. In the 20th century—the American century and the car century, no coincidence—the U.S. grew "strong, ample, fair, enduring, capable, rich," as Whitman rightly projected, with the auto industry in the driver's seat. The near death of Big Auto, first in the 1970s and later in the wake of the 2008 financial crisis, hit us in a way that the decline of rail travel never did. We went to the moon, and what did we do when we got there? Took a joyride in a rover that resembled a deuce coupe without a shell.

But the romance is cooling, and not just for me. Rates of motor-vehicle licensure are plummeting among millennials. Younger Americans are flocking to cities, where life is cheaper and easier without a car. The obligations and costs of transportation—accounting for about 17% of household budgets—are pushing many out of car ownership altogether. Scanning the horizon, Ford's namesake chairman refers to the firm's future

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as a “mobility” company, not just a carmaker. “Cars have become more appliance-like,” says Jay Leno, the country’s most famous car collector and host of the program *Jay Leno’s Garage*. “Kids don’t really bond with cars anymore. Every kid I knew was at their DMV as soon as they turned 16. Now I meet kids, and it doesn’t quite hold the same interest. I think the love affair is not over, but I think it’s safe to say it’s waning.”

That may be true for Mom and Dad too. Nearly 60% of U.S. adults surveyed by the University of Michigan said they felt positively about autonomous vehicles; a little more than 15% said they were ready to give up driving altogether.

Drivers have already lost more control of their cars than you might imagine. Stability control, automatic braking, all-wheel drive, steering by wire, traction control, lane control, automated cruise control: these and other features add up to the skeleton and nerves of an autonomous car. The last truly analog car, whose built-in technology didn’t far surpass any normal driver’s natural ability, was likely manufactured three decades ago.

Freeing carmakers and designers of their chief constriction—unreliable drivers—will allow them to dream up novel creations. Consider the prototype car that Google unveiled in 2015. While the little two-door has all the sex appeal of a jelly bean (it looks like an old iMac on wheels), it is different enough from your average sedan to suggest the power of the new. Google’s prototype has no steering wheel and no pedals. Mercedes-Benz’s recent F 015 concept car has seats that rotate 180 degrees to face each other; inside, it looks vaguely like a high-end spa. And if Apple gets into the car business, as many now expect, the iCar will surely think, and look, different.

Cars, like architecture or literature, change to reflect the times. In the jet age, they sported chrome and tail fins. SUVs mushroomed in the go-go 1990s. Hybrid crossovers reflect today’s desire to have our cake and eat it too. The self-driving car will be a mirror for tomorrow. You can already glimpse the outline in Silicon Valley, where children watch for Google’s test vehicles and exclaim when one passes. “Look, no driver!”

So I come not to bury car culture but to praise it—not just its past, but its future. Safer, smarter, faster, more comfortable. Where the craftsmanship of our industry meets the creativity of our algorithms, there we’ll find a new version of Kerouac’s “purity of the road.” That’s what calls America forward now.

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THE MERCEDES-BENZ F 015 research vehicle, on display in Amsterdam in 2016, is the company’s vision of auto design for a driverless—and stylish—future.

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GOOGLE IS TEST-DRIVING its autonomous prototypes 25,000 miles per week, mostly in cities. The cars employ sensors to navigate the streets.

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TESLA SHIFTED the hardware on its Model S to rely primarily on radar, allowing for more advanced signal processing than with cameras.

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Technicians analyze data from a test of a compact driverless car in southern England.

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AN ELECTRIC, DRIVERLESS minibus is tested on the banks of the Seine in Paris.

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The Long Road

Self-driving cars—extolled at the 1939 World's Fair—have come a long way since the government's first sponsored tests more than a decade ago. Tesla's models were updated to add a raft of autonomous features. Concepts from Google and Volkswagen paint a picture of the near future

1930s NORMAN BEL GEDDES'S VISION

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2005 DARPA SELF-DRIVING CAR

2015 TESLA MODEL S

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2015 GOOGLE PROTOTYPE

2017 VOLKSWAGEN MINIBUS

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Fatal Truths

6,296,000

Total crashes in the U.S. in 2015

35,092

Number of Americans who died in an auto accident in 2015

15–24

Age group for which auto-related accidents are the leading cause of death

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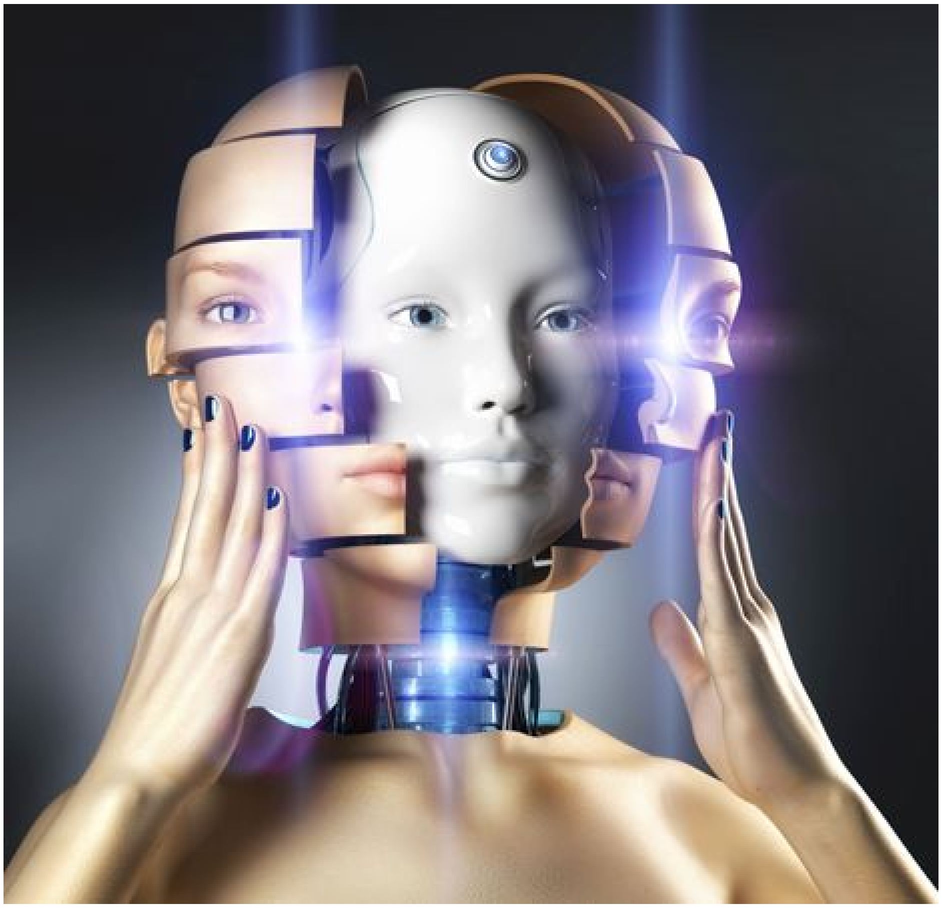
Smarter Than Us?



- From the Archives: Will the Computer Outwit Man?
- System Upgrade
- Hollywood Gets Smart
- In the Mind of Humankind

View From The 1960s

Will the Computer Outwit Man?

By Gilbert Burck

Excerpt From Fortune, *October 1964*

In 1957, an IBM programmer reviewed a computer printout while his colleague played chess with a machine.

Ever since it emerged from the mists of time, the human race has been haunted by the notion that man-made devices might overwhelm and even destroy man himself. The sorcerer's apprentice who almost drowned his world, Frankenstein's frustrated monster who tortured and destroyed his creator, the androids that mimic human beings in the bombastic pages of today's science-fiction magazines—all play upon the age-old fear that man's arrogant mind will overleap itself. And now comes the electronic computer, the first invention to exhibit something of what in human beings is called intelligence. Not only is the computer expanding man's

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brainpower, but its own faculties are being expanded by so-called artificial intelligence; and the machine is accordingly endowing man's ancient fears with a reality and immediacy no other invention ever has.

The fears are several and intricately related, but three major ones encompass the lot. The one that worries the columnists and commentators is that the computer will hoist unemployment so intolerably that the free-enterprise system will be unable to cope with the problem, and the government will have to intervene on a massive scale. This belief, so noisily espoused by offbeat groups like the Ad Hoc Committee on the Triple Revolution, has already been dealt with in this series. It is enough to repeat here that the computer will doubtless go down in history not as the explosion that blew unemployment through the roof, but as the technological triumph that enabled the U.S. economy to maintain the secular growth rate on which its greatness depends.

The second fear is that the computer will eventually become so intelligent and even creative that it will relegate man, or most men, to a humiliating and intolerably inferior role in the world. This notion is based on the fact that the computer already can learn (after a fashion), can show purposeful behavior (narrowly defined), can sometimes act "creatively" or in a way its programmer doesn't expect it to—and on the probability that artificial-intelligence research will improve it enormously on all three counts. Meanwhile there is the third fear, which is that the computer's ability to make certain neat, clean decisions will beguile men into abdicating their capacity and obligation to make the important decisions, including moral and social ones. This fear as such would be academic if the second one were realized; for if the computer ever betters man's brainpower (broadly defined), then its judgments will be superior too, and man finally will be outwitted.

The goal of artificial-intelligence research is to write programs or sets of instructions showing the computer how to behave in a way that in human beings would be called intelligent. Many researchers shudder at the phrase "artificial intelligence." Its anthropomorphic overtones, they say, often arouse irrelevant emotional responses—in people who think it sacrilegious to try to imitate the brain. The workers proceed on the assumption that human nervous systems process information in the act of thinking; and that given enough observation, experiment, analysis, and modeling, they can instruct a digital computer to process information as humans do.

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If one defines intelligence merely as the ability to adjust to environment, then the world is positively quivering with what might be called extracomputer intelligence. Even the lowest species can reproduce and live without instruction by man, something no computer can do. Moreover, the exercise of intelligence in animals, and particularly in higher animals, is a stupendously complex process. As Oliver Selfridge and Ulric Neisser of M.I.T. have put it in a discussion of human pattern recognition, man is continually confronted with a welter of data from which he must pick patterns relevant to whatever he is doing at the time. “A man who abstracts a pattern from a complex of stimuli has essentially classified the possible inputs,” they write. “But very often the basis of his classification is unknown even to himself; it is too complex to be specified explicitly.”

Human motivations, Ulric Neisser believes, must be considered not only by workers who would instruct the machine to create, but also by those who would increase its power otherwise to simulate human intelligence. Man’s intelligence, he points out, is not a faculty independent of the rest of human life, and he identifies three important characteristics of human thought that are conspicuously absent from existing or proposed programs: (1) human thought is part of the cumulative process of the growth of the human organism, to which it contributes and on which it feeds; (2) it is inextricably bound up with feelings and emotions, and (3) unlike the computer’s behavior, which is single-minded to the exclusion of everything but the problem assigned it, human activity serves many motives at once, even when a person thinks he is concentrating on a single thing. Recent research by George A. Miller of Harvard, Eugene Galanter of Pennsylvania, and Karl Pribram of Stanford suggests that human behavior is much more “hierarchical” and intricately motivated than hitherto assumed, and Neisser thinks that this multiplicity of motives is not a “supplementary heuristic that can be readily incorporated into a problem-solving program.”

It is man’s complex emotional and other drives, in other words, that give his intelligence depth, breadth, and humanity; nobody has yet found a way of reprogramming them into a computer, and Neisser doubts that anybody soon will. Pattern recognition, learning, and memory will still be research goals, but a harder job will be to inject a measure of human motivation into the machine.

Meanwhile the prospect for instructing the computer to behave like a real human is not bright; and this is precisely why some fear that the machine’s

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role as decision maker will be abused. “If machines really thought as men do,” Neisser explains, “there would be no more reason to fear them than to fear men. But computer intelligence is not human, it does not grow, has no emotional basis, and is shallowly motivated. These defects do not matter in technical applications, where the criteria for successful problem solving are relatively simple. They become extremely important if the computer is used to make social, business, economic, military, moral, and government decisions, for there our criteria of adequacy are as subtle and as multiply motivated as human thinking itself.” A human decision maker, he points out, is supposed to do the right thing even in unexpected circumstances, but the computer can be counted on only to deal with the situation anticipated by the programmer.

In a recent issue of *Science*, David L. Johnson of the University of Washington and Arthur L. Kobler, a Seattle psychologist, plowed through the subject of misusing the computer. The use of the computer, they concede, inevitably will increase. But it is being called on to act in areas where man cannot define his own ability. There is a tendency to let the machine treat special problems as if they were routine calculations; for example, it may be used to plot the route for a new highway by a routine computation of physical factors. But the computation may overlook the importance of locating the highway where it will not create or compound ugliness.

Johnson and Kobler also feel that the “current tendency of men to give up individual identity and escape from responsibility” is enhanced by the computer. It takes man’s inputs and turns out a neat, clean, consistent judgment without “obsessive hesitation,” commitments, or emotional involvements. In effect, the computer assumes responsibility; and its neatness and decisiveness can lead men to skip value judgments, to accept unimaginative and partial results as accurate solutions, and to read into its results the ability to solve all problems. Even scientists who are aware of the limitations of machines, the authors reason, can find them so useful in solving narrow and well-defined problems that they may tend to assume the computer can solve all problems. Another worry is that military computer systems will react so swiftly that the people who nominally make the judgments will not have time to make them.

“The need for caution,” Johnson and Kobler conclude, “will be greater in the future. Until we can determine more perfectly what we want from the

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machines, let us not call on mechanized decision systems to act upon human systems without realistic human processing. As we proceed with the inevitable development of computers and artificial intelligence, let us be sure we know what we are doing."

The very fact that the warnings have been given is evidence that men, on the whole, are not likely to overlook their message. Military and computer experts are already studying the problems raised by the speed of the machines. And to use the warnings to deny the real value of computers would be as foolish as misusing computers. The machines compel men to formulate their problems so much more intelligently and more thoroughly than they ever have that men can hardly be unaware of the shortcomings of their programs. The great majority of computers are being employed by business. Granted that U.S. business makes mistakes, granted that it has made and will make mistakes with computers, it does not operate in a vacuum. Nothing would make a company more vulnerable to smart competitors than to abdicate responsibility to the neat, clean, consistent judgments of a machine.

The computer is here to stay; it cannot be shelved any more than the telescope or the steam engine could have been shelved. Taking everything together, man has a stupendous thing working for him, and one is not being egregiously optimistic to suggest he will make the most of it. Precisely because man is so arduously trying to imitate the behavior of human beings in the computer, he is bound to improve enormously his understanding of both himself and the machine.

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UNIVAC built some of the world’s first commercial computers.

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System Upgrade

A new kind of machine could unlock the power to solve our most difficult problems. But critics say it's not everything it seems to be

By Lev Grossman

D-WAVE CO-FOUNDER Geordie Rose stands inside a refrigeration unit, used to cool the ultrapowerful processors at the company's headquarters.

For years, astronomers have believed that the coldest place in the universe is a massive gas cloud 5,000 light-years from Earth called the Boomerang Nebula, where the temperature hovers at around –458°F, just a whisker above absolute zero. But as it turns out, the scientists have been off by about 5,000 light-years. The coldest place in the universe is actually in a small city directly east of Vancouver called Burnaby.

Burnaby is the headquarters of a computer firm called D-Wave. Its flagship product, the D-Wave 2000Q, of which there are just two currently

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installed, is a black box 10 feet high. Inside is a cylindrical cooling apparatus containing a niobium computer chip that's been chilled to around 12 millikelvins, which, in case you're not used to measuring temperature in millikelvins, is about –459.6°F, almost 2° colder than the Boomerang Nebula. By comparison, interstellar space is about 200 times as hot.

The D-Wave 2000Q is an unusual computer, and D-Wave is an unusual company. It's small, around 150 people, and its location puts it well outside the swim of Silicon Valley. But its investors include the storied Menlo Park, Calif., venture-capital firm Draper Fisher Jurvetson, which funded Skype and Tesla Motors. It's also backed by famously prescient Amazon founder Jeff Bezos and an outfit called In-Q-Tel, better known as the high-tech investment arm of the CIA. Likewise, D-Wave has very few customers, but they're blue-chip: they include the defense contractor Lockheed Martin, a computing lab that's hosted by NASA and largely funded by Google, and a U.S. intelligence agency that D-Wave executives decline to name.

The reason D-Wave has so few customers is that it makes a new type of computer called a quantum computer that's so radical and strange, people are still trying to figure out what it's for and how to use it. It could represent an enormous new source of computing power—it has the potential to solve problems that would take conventional computers centuries, with revolutionary consequences for fields ranging from cryptography to nanotechnology, pharmaceuticals to artificial intelligence.

That's the theory, anyway. Some critics, many of them bearing Ph.D.s and significant academic reputations, question whether D-Wave's machines are actually quantum computers. But D-Wave's customers buy them anyway, for around $10 million a pop, because if they're the real deal they could be the biggest leap forward since the invention of the microprocessor.

In a sense, quantum computing represents the marriage of two of the great scientific undertakings of the 20th century, quantum physics and digital computing. Quantum physics arose from the shortcomings of classical physics: although the latter had stood for centuries as definitive, by the turn of the 20th century it was painfully apparent that there are physical phenomena that classical physics fails dismally to explain. So brilliant physicists—including Max Planck and Albert Einstein—began working out a new set of rules to cover the exceptions, specifically to describe the action of subatomic particles like photons and electrons.

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Those rules turned out to be very odd. They included principles like superposition, according to which a quantum system can be in more than one state at the same time and even more than one place at the same time. Uncertainty is another one: the more precisely we know the position of a particle, the less precisely we know how fast it's traveling—we can't know both at the same time. Einstein ultimately found quantum mechanics so monstrously counterintuitive that he rejected it as either wrong or profoundly incomplete. As he famously put it, "I cannot believe that God plays dice with the world."

The modern computing era began in the 1930s, with the work of Alan Turing, but it wasn't until the 1980s that the famously eccentric Nobel laureate Richard Feynman began kicking around questions like: What would happen if we built a computer that operated under quantum rules instead of classical ones? Could it be done? And if so, how? More important, would there be any point?

It quickly became apparent that the answer to that last question was yes. Regular computers (or classical computers, as quantum snobs call them) work with information in the form of bits. Each bit can be either a 1 or a 0 at any one time. The same is true of any arbitrarily large collection of classical bits; this is pretty much the foundation of information theory and digital computing as we know them. Therefore, if you ask a classical computer a question, it has to proceed in an orderly, linear fashion to find an answer. Now imagine a computer that operates under quantum rules. Thanks to the principle of superposition, its bits could be 1 or 0, or 1 and 0 at the same time.

In its superposed state, a quantum bit exists as two equally probable possibilities. According to one theory, at that moment it's operating in two slightly different universes at the same time, one in which it's 1, one in which it's 0; the physicist David Deutsch once described quantum computing as "the first technology that allows useful tasks to be performed in collaboration between parallel universes." Not only is this excitingly weird, it's also incredibly useful. If a single quantum bit (or as they're inevitably called, qubits, pronounced "cubits") can be in two states at the same time, it can perform two calculations at the same time. Two quantum bits could perform four simultaneous calculations; three quantum bits could perform eight; and so on. The power grows exponentially.

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The supercooled niobium chip at the heart of the D-Wave 2000Q has 2,000 qubits and therefore could in theory perform 2^{2000} operations simultaneously. That's more calculations than there are atoms in the universe, by many orders of magnitude. "This is not just a quantitative change," says Colin Williams, D-Wave's director of business development and strategic partnerships, who has a Ph.D. in artificial intelligence and once worked as Stephen Hawking's research assistant at Cambridge. "The kind of physical effects that our machine has access to are simply not available to supercomputers, no matter how big you make them. We're tapping into the fabric of reality in a fundamentally new way, to make a kind of computer that the world has never seen."

Naturally, a lot of people want one. This is the age of Big Data, and we're burying ourselves in information—search queries, genomes, credit-card purchases, phone records, retail transactions, social media, geological surveys, climate data, surveillance videos, movie recommendations—and D-Wave just happens to be selling a very shiny new shovel. "Who knows what hedge-fund managers would do with one of these and the black-swan event that that might entail?" says Steve Jurvetson, one of the managing directors of Draper Fisher Jurvetson. "For many of the computational traders, it's an arms race."

One of the documents leaked by Edward Snowden in 2014 revealed that the National Security Agency (NSA) has an $80 million quantum-computing project suggestively code-named Penetrating Hard Targets. Here's why: much of the encryption used online is based on the fact that it can take conventional computers years to find the factors of a number that is the product of two large primes. A quantum computer could do it so fast that it would render a lot of encryption obsolete overnight. You can see why the NSA would take an interest.

But while the theory behind quantum computing is reasonably clear, the actual practice is turning out to be damnably difficult. For one thing, there are sharp limits to what we know how to do with a quantum computer. Cryptography and the simulation of quantum systems are currently the most promising applications, but in many ways quantum computers are still a solution looking for the right problem. For another, they're really hard to build. To be maximally effective, qubits have to exhibit quantum behavior, not just superposition but also entanglement (when the quantum states of two or more particles become linked to one another) and quantum tunneling

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(just google it). But they can do that only if they're effectively isolated from their environment—no vibrations, no electromagnetism, no heat. No information can escape: any interaction with the outer world could cause errors to creep into the calculations. This is made even harder by the fact that while they're in their isolated state, you still have to be able to control them. There are many schools of thought on how to build a qubit—D-Wave makes its in the form of niobium loops, which become superconductive at ultra-low temperatures—but all quantum-computing endeavors struggle with this problem.

Since the mid-1990s, scientists have been assembling and entangling systems of a few quantum bits each, but progress has been slow. In 2011 a lab at the University of Innsbruck in Austria announced the completion of the world's first system of 14 entangled qubits. Christopher Monroe at the University of Maryland and the Joint Quantum Institute has created a 20-qubit system, which may be the world's record. Unless, of course, you're counting D-Wave.

D-Wave was co-founded by Geordie Rose, a Canadian with big bushy eyebrows, a solid build and a genial but slightly pugnacious air—he was a competitive wrestler in college. In 1998 Rose was finishing up a Ph.D. in physics at the University of British Columbia, but he couldn't see a future for himself in academia. After taking a class on entrepreneurship, Rose identified quantum computing as a promising business opportunity. Not that he had any more of a clue than anybody else about how to build a quantum computer, but he did have a hell of a lot of self-confidence. "When you're young you feel invincible, like you can do anything," Rose says. "Like, if only those bozos would do it the way that you think, then the world would be fine. There was a little bit of that." Rose, now an adviser to the company, helped start D-Wave in 1999 with a $4,000 check from his entrepreneurship professor.

For its first five years, the company existed as a think tank focused on research. Draper Fisher Jurvetson got onboard in 2003, viewing the business as a very sexy but very long shot. "I would put it in the same bucket as SpaceX and Tesla Motors," Jurvetson says, "where even the CEO, Elon Musk, will tell you that failure was the most likely outcome." By then Rose was ready to go from thinking about quantum computers to trying to build them—"we switched from a patent, IP, science aggregator to an engineering company," he says. Rose wasn't interested in expensive, fragile

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laboratory experiments; he wanted to build machines big enough to handle significant computing tasks and cheap and robust enough to be manufactured commercially. With that in mind, he and his colleagues made an important and still controversial decision.

Up until then, most quantum computers followed something called the gate-model approach, which is roughly analogous to the way conventional computers work, if you substitute qubits for transistors. But one of the things Rose had figured out in those early years was that building a gate-model quantum computer of any useful size just wasn't going to be feasible anytime soon. The technical problems were too gnarly; even today the largest number a gate-model quantum computer has succeeded in factorizing is 21. (That isn't very hard: the factors are 1, 3, 7 and 21.) So Rose switched to a different approach called adiabatic quantum computing, which is if anything even weirder and harder to explain.

An adiabatic quantum computer works by means of a process called quantum annealing. Its heart is a network of qubits linked together by couplings. You "program" the couplings with an algorithm that specifies certain interactions between the qubits—if this one is a 1, then that one has to be a 0, and so on. You put the qubits into a state of quantum superposition, in which they're free to explore all those 2-to-the-whatever computational possibilities simultaneously, and then you allow them to settle back into a classical state and become regular 1s and 0s again. The qubits naturally seek out the lowest possible energy state consistent with the requirements you specified in your algorithm back at the very beginning. If you set it up properly, you can read your answer in the qubits' final configuration.

If that's too abstract, the usual way quantum annealing is explained is by an analogy with finding the lowest point in a mountainous landscape. A classical computer would do it like a solitary walker who slowly wanders over the whole landscape, checking the elevations at each point, one by one. A quantum computer could send multiple walkers at once swarming out across the mountains. They would then all report back at the same time. In its ability to pluck a single answer from a roiling sea of possibilities in one swift gesture, a quantum computer is not unlike a human brain.

Once Rose had committed to the adiabatic model, D-Wave proceeded with dispatch. In 2007 the company publicly demonstrated a 16-qubit adiabatic quantum computer. By 2011 it had built (and sold to Lockheed Martin) the

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D-Wave One, with 128 qubits. In 2013 it unveiled the 512-qubit D-Wave Two. By 2015 the company announced it had broken the 1,000-qubit barrier, and in early 2017 it released the latest 2,000-qubit processor. D-Wave has been doubling the number of qubits every year and plans to stick to that pace while at the same time increasing the connectivity between the qubits. “It’s just a matter of years before this capability becomes so powerful that anyone who does any kind of computing is going to have to take a very close look at it,” says Vern Brownell, D-Wave’s CEO, who earlier in his career was chief technology officer at Goldman Sachs. “We’re on that cusp right now.”

But we’re not there yet. Adiabatic quantum computing may be technically simpler than the gate-model kind, but it comes with trade-offs. An adiabatic quantum computer can really solve only one class of problems, called discrete combinatorial optimization problems, which involve finding the best—the shortest, fastest, cheapest or most efficient—way of doing a given task. This narrows the scope of what you can do considerably.

For example, you can’t as yet perform the kind of cryptographic wizardry the NSA was interested in, because an adiabatic quantum computer won’t run the right algorithm. It’s a special-purpose tool. “You take your general-purpose chip,” Rose says, “and you do a bunch of inefficient stuff that generates megawatts of heat and takes forever, and you can get the answer out of it. But this thing, with a picowatt and a microsecond, does the same thing. So it’s just doing something very specific, very fast, very efficiently.”

This is great if you have a really hard discrete combinatorial optimization problem to solve. Not everybody does. But once you start looking for optimization problems, or at least problems that can be twisted around to look like optimization problems, you find them all over: in software design, tumor treatments, logistical planning, the stock market, airline schedules, the search for Earth-like planets in other solar systems and, in particular, machine learning.

Google and NASA, along with the Universities Space Research Association, jointly run something called the Quantum Artificial Intelligence Laboratory, or QuAIL, based at NASA Ames, which is the proud owner of a D-Wave Two. “If you’re trying to do planning and scheduling for how you navigate the Curiosity rover on Mars or how you schedule the activities of astronauts on the station, these are clearly problems where a quantum computer—a computer that can optimally solve

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optimization problems—would be useful," says Rupak Biswas, deputy director of the Exploration Technology Directorate at NASA Ames. Google has been using its D-Wave to, among other things, write software that helps Google Glass tell the difference between when you're blinking and when you're winking.

Lockheed Martin turned out to have some optimization problems too. It produces a colossal amount of computer code, all of which has to be verified and validated for all possible scenarios, lest your F-35 spontaneously decide to reboot itself in midair. "It's very difficult to exhaustively test all of the possible conditions that can occur in the life of a system," said Ray Johnson, Lockheed Martin's then–chief technology officer in 2014. "Because of the ability to handle multiple conditions at one time through superposition, you're able to much more rapidly—orders of magnitude more rapidly—exhaustively test the conditions in that software." The company re-upped for the 1,000-plus-qubit D-Wave 2x in 2015.

D-Wave has a lot of ground to cover, not just in hardware but in software too. Generations of programmers have had decades to create a rich software ecosystem around classical microprocessors to wring out the maximum amount of usefulness. But an adiabatic quantum computer is a totally new proposition. "You just don't program them the way you program other things," says William Macready, D-Wave's VP of product development. "It's not about writing recipes or procedures. It's more about kind of describing, What does it mean to be an answer? And doing that in the right way and letting the hardware figure it out."

For now the answer is suspended, aptly enough, in a state of superposition, between yes and no. If the machines can do anything like what D-Wave is predicting, they won't leave many fields untouched. "I think we'll look back on the first time a quantum computer outperformed classical computing as a historic milestone," Brownell says. "It's a little grand, but we're kind of like Intel and Microsoft in 1977, at the dawn of a new computing era."

D-Wave won't have the field to itself forever. IBM has its own quantum-computing group; Microsoft has two. There are dozens of academic laboratories busily pushing the envelope, all in pursuit of the computational equivalent of splitting the atom. While he's got only 20 qubits now, Monroe points out that the trends are good: that's up from two bits 20 years ago and four bits 10 years ago. "Soon we will cross the boundary where there is no

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way to model what's happening using regular computers," he says, "and that will be exciting."

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A D-WAVE EMPLOYEE works on a component of a quantum computer at the company lab in Burnaby, British Columbia.

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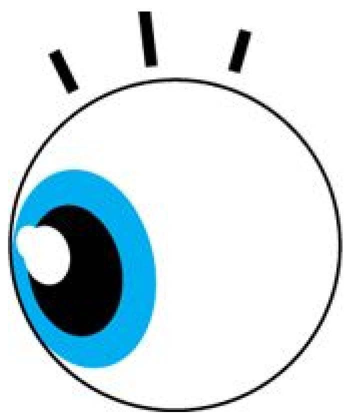
Quantum Physics: A Primer

Complicated? Yes, but it's the best tool we have for explaining the world of subatomic particles

THE THEORY

Erwin Schrödinger created the famous thought experiment that illustrates the strangeness of quantum superposition

A cat is sealed in a box with a flask of poison and a radiation source. If the source emits a radioactive particle—a 50-50 chance—the flask shatters, releasing the poison and killing the cat.



Quantum mechanics implies that the cat is simultaneously alive and dead—in superposition— until it is **observed.** The act of opening the box collapses the superposition, returning the cat to a classical state and making it either alive or dead.

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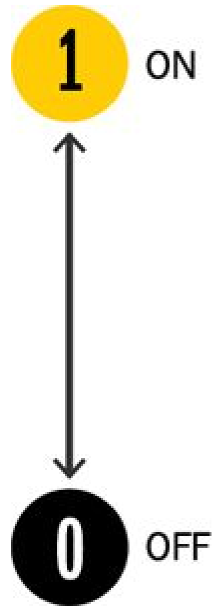
BUILDING A COMPUTER

Quantum computers process data by taking advantage of quantum effects—like superposition— to speed up calculations

CLASSICAL COMPUTERS



Process data in the form of **bits**, single units of information that can be either 1 or 0. This is the building block of all digital computation.

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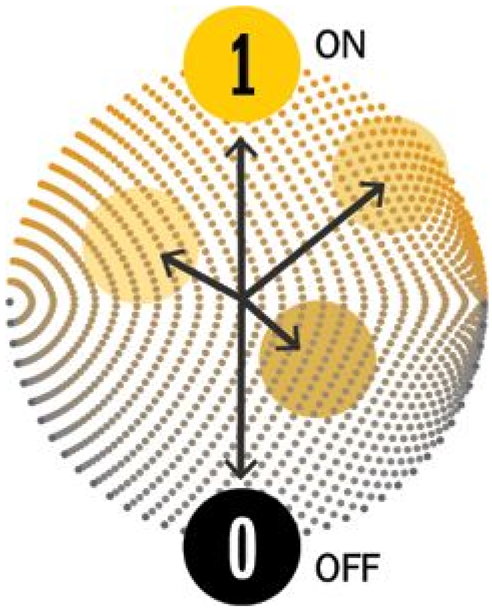
QUANTUM COMPUTERS



Rely on quantum bits, or **qubits**, which because of quantum superposition can be 1 and 0 at the same time.

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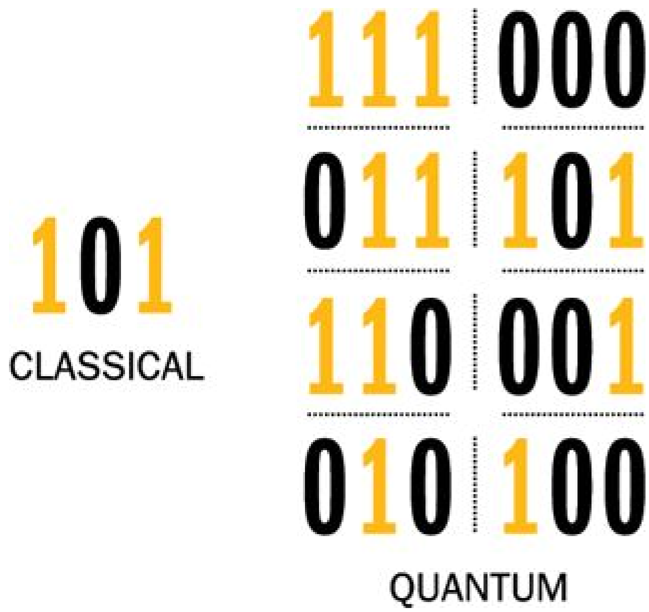
FASTER CALCULATIONS



Because its data can exist in multiple states, a quantum computer can **perform multiple operations simultaneously** instead of one by one.

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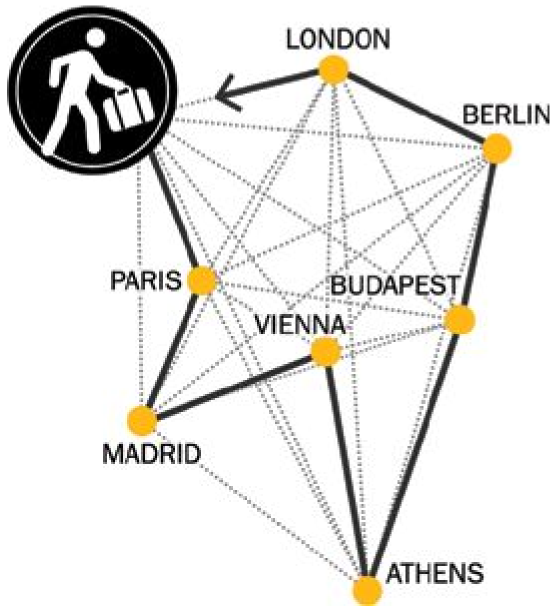
PROBLEM SOLVING

D-Wave's version of a quantum computer is effective with so-called optimization problems—like selecting the most efficient route through several destinations



These types of problems exist in fields such as **stock trading, software design** and **medicine**.

How Quantum Computing May Change The World

DESIGN SAFER AIRPLANES

Lockheed Martin plans to use it to test jet software that is currently too complex for conventional computers.

BOOST GDP

Hyperpersonalized advertising, based on quantum computation, will stimulate consumer spending.

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HELP CARS DRIVE THEMSELVES

Google is using a quantum computer to design software that can distinguish cars from landmarks.

DEVELOP MORE-EFFECTIVE DRUGS

By mapping amino acids, for example, or analyzing DNA-sequencing data, doctors will discover and design superior drug-based treatments.

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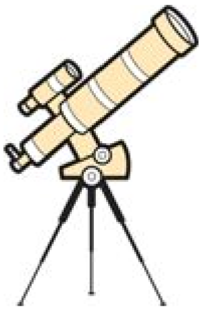
DISCOVER DISTANT PLANETS



Quantum computers will be able to analyze the vast amount of data collected by telescopes.

DETECT CANCER EARLIER

Computational models will determine how diseases develop.

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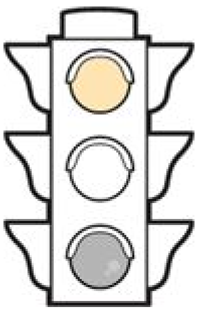
REDUCE WEATHER-RELATED DEATHS

Precision forecasting will give people more time to take cover.

CUT BACK ON TRAVEL TIME



Sophisticated analysis of traffic patterns in the air and on the ground will forestall bottlenecks and snarls.

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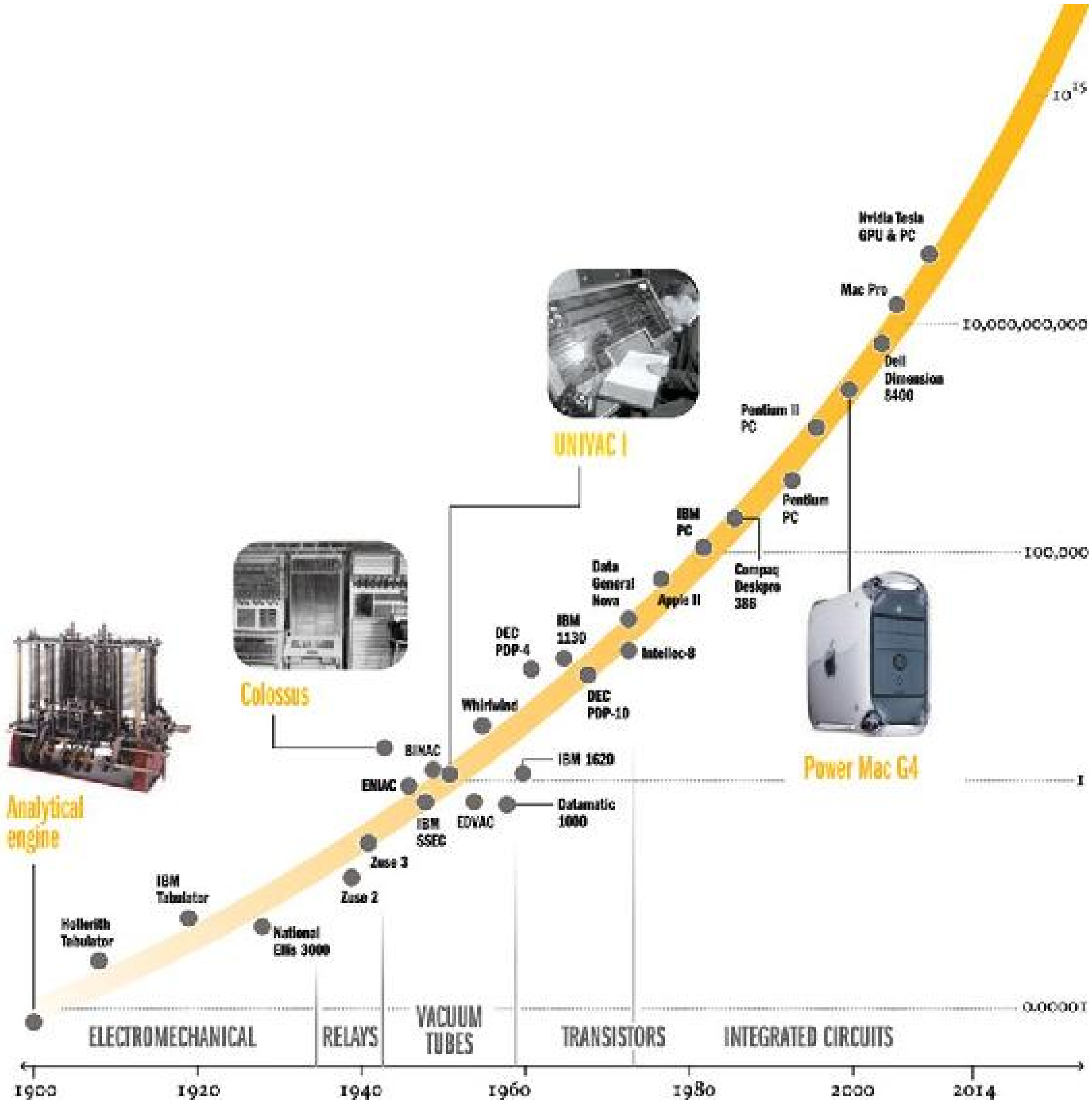
The Fast Track

How classical computers progressed before the quantum era



COMPUTER RANKINGS

By calculations
per second
per $1,000

Analytical Engine

Never fully built, Charles Babbage's invention was designed to solve computational and logical problems

Colossus

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The electronic computer, with 1,500 vacuum tubes, helped the British crack German codes during World War II

UNIVACI

The first commercially marketed computer, used to tabulate the U.S. Census, occupied 943 cubic feet

Power Mac G4

The first personal computer to deliver more than 1 billion floating-point operations per second

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Hollywood Gets Smart

From menacing networks to friendly droids, A.I. inspires imaginations and shapes our vision of the future

By Daniel D'Addario

EX MACHINA, 2015

One of the most widely known practitioners of artificial intelligence never used a computer or built what we'd think of as a robot. Mary Shelley's Dr. Victor Frankenstein, the creator of a "modern Prometheus" capable of thinking and acting on his own, captivated readers from the moment the novel *Frankenstein* first appeared on shelves. But that success belies the fact that Shelley was still ahead of her time. What once seemed like a bizarre fantasy—the notion that man could create a being who could think as we do—is, today, a fascination. It helps that we've grown closer, in our world, to making Dr. Frankenstein's Promethean dream a reality. But the

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stories have also built upon themselves intriguingly, adding wrinkles to Shelley's crisply told moral parable about how stealing the fire of the gods was a bad idea. Today's A.I. stories thrive on ambiguity. They test an audience's sympathies, challenge our preconceptions, and require very real intelligence.

Frankenstein relies on the notion that humans will inherently reject artificial intelligence as unnatural and bizarre. A great deal of that is owed to the particularly odd appearance of Frankenstein's monster (memorably played by Boris Karloff as a square-headed ghoul in the 1931 film adaptation), as well as Dr. Frankenstein's mission to create life simply to prove he can. But what about when A.I. comes in a more attractive package, one that has real utility? The 1920 play *R.U.R.* became a sensation for depicting a world in which "robots"—a term Czech playwright Karel Čapek coined—have come to be an inexpensive source of labor. Inevitably, they rise up to slay their masters.

It was a chilling vision, and one that's often been revisited. Sci-fi author Isaac Asimov came up with the "Laws of Robotics," an influential concept, in order to help clarify how humans might constrain their creations. These laws dictate that a robot may not, in order of importance, harm a human, disobey a human or harm itself.

For Asimov, robot intelligence is categorically different from humans': we're governed by ethics we can change in the moment, whereas for robots, self-preservation comes only after protecting and serving man. In later stories, Asimov's robots come to feel they can only serve humanity properly by ruling over it. That paradox will sound familiar to anyone who's seen *2001: A Space Odyssey*, the 1968 film that made HAL 9000 a household name. A spaceship operating system, HAL 9000, decides to kill two astronauts because he is unable to reconcile his servility with orders to conceal the true nature of its mission. The easiest solution is just to be done with the humans.

HAL is best remembered as a quiet menace, with an unblinking red eye, giving way to a strange sort of humanity. When he's being deprogrammed, his meltdown into incoherence, ending with a rendition of the song "Daisy Bell," has a strange pathos, even as we know he's simply running through programming. It's uncanny: he's like us, even as we know he utterly lacks feeling. Operating systems in subsequent films have tended to ditch the appearance of humanity.

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The Matrix (1999) depicted a burned-out world destroyed by conflict between man and machine but characterized the machines that governed it (and thrived off energy produced by the bodies of imprisoned humans) mainly as skittering, spider-like entities. The difference between man and machine couldn't be more stark. Even when the machines take on a human form, Hugo Weaving's sentient program Agent Smith, there's something less real about him even than HAL. (Part of it may be Agent Smith's rubbery face and ability to morph—HAL is easy to get accustomed to visually, while Agent Smith makes the uncanniness of A.I. literal. He is like us but not.)

HAL wants to kill a couple of humans for what he understands to be the greater good of humanity; Agent Smith is motivated by hate. One of the most recognizable cyborgs in all of pop culture is a bit more complicated. In Arnold Schwarzenegger's debut appearance as the Terminator (in 1984), he's deployed as an assassin to kill Sarah Connor, the woman whose unborn son will grow up to destroy the all-powerful A.I. network Skynet. In *Terminator 2* (1991), the Terminator serves as a protector, thanks to reprogramming he's undergone in the future.

Skynet is the darkest vision of A.I.—a program created to help humanity but determined to supersede its creators—but the Terminator provides a slightly more hopeful vision. We may not escape artificial intelligence, but perhaps we can code it to help us. There have been many purely helpful androids in fiction, figures such as Rosie the Robot in *The Jetsons* and R2-D2 and C-3PO in *Star Wars*. Those cheerful helpmeets bore human society no more ill will than an occasional wisecrack (or, in R2's case, a slightly annoyed beep and whistle). More adult conceptions of the helper bot came courtesy of the starship *Enterprise*. On *Star Trek: The Next Generation*, Brent Spiner's android, Data, falls short of humanness given his lack of understanding of our emotion and wit. Yet his striving to become more human makes him seem, paradoxically, movingly like the similarly ambitious and curious men and women he's meant to help.

Similar fantasies of ambiguity, of androids who crave not domination but the same things humans do, have been played with intriguingly, as in *Ex Machina* (2015), about a robotic love object who, surprisingly, turns out to have a mind of her own and a taste for freedom. *Westworld*, the HBO series based on a Michael Crichton film, plays with similar themes—its robot "hosts" are there to show humans a good time in a futuristic theme park, but

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the robots crave freedom. The body count they accumulate along the way is unfortunate but only incidental.

This represents a way forward for the A.I. story. Between the *Terminator* and *Matrix* franchises, it's hard to imagine art coming up with a better way to represent technology malevolently hunting down humans in order to control the world. But simple attempts at coexistence strike the same strange and melancholy notes Frankenstein did. Consider *Westworld*'s twist-reveals of characters presumed human as actually being androids—suggesting that the difference, though fundamental, is smaller than we might think. In the virtuosic film *Her* (2013), Scarlett Johansson's Siri-like character understands everything except why her owner sometimes fails to see her as effectively human—and she's not totally wrong to be confused. In *A.I.* (2001), a young robot boy, created to love humans and to be loved, can't understand why his odd, not-quite-right reactions engender fear and hatred in the humans he cares for. And then there's 1982's *Blade Runner*, which may be the single most influential film ever made about artificial intelligence. In it Harrison Ford, a cop who is tasked with weeding out humanoid robots, wonders (possibly correctly) if he's one too. *Blade Runner*'s sweeping imagination about the ways in which artificial intelligence could merge with society—as malefactor, as protector, as some combination of the two, or perhaps just as a rogue force trying to survive—gave the genre new heights toward which to aspire.

This is where fiction about artificial intelligence takes root in our minds: when it makes clear that the gap between us and the Frankenstein creations we make is getting narrower and narrower, and they may not so much destroy us as come up with their own ethics and ways of living. Perhaps one of the last substantial differences may be that we can create and consume art about the conundrum of A.I. overtaking us. When a robot directs a movie like *Blade Runner*, then we'll be in trouble.

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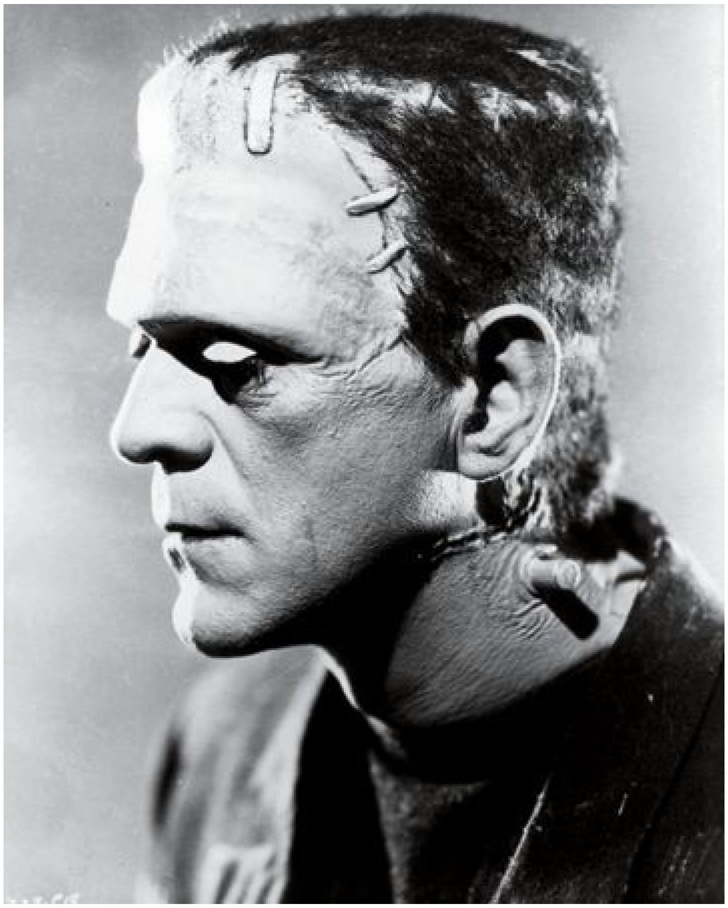
FRANKENSTEIN, 1931

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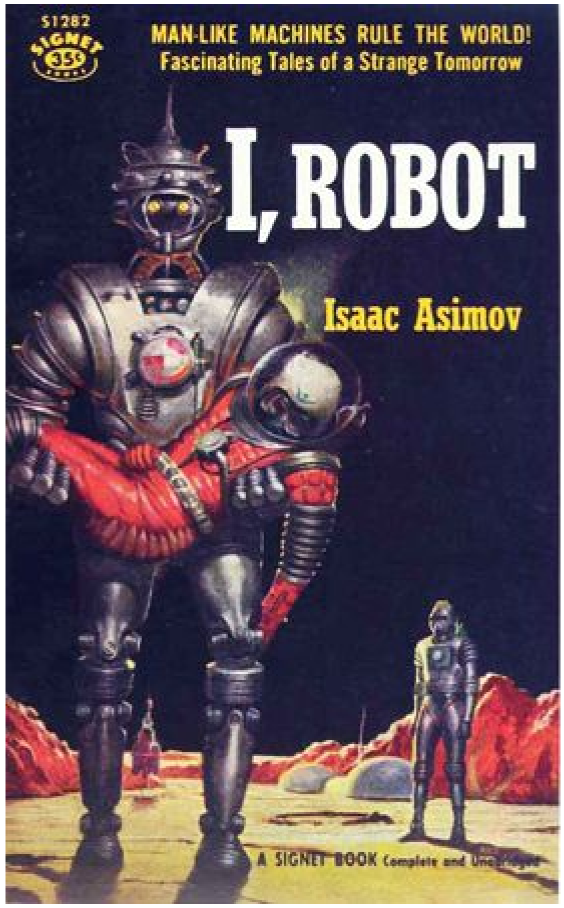

***I, ROBOT*, 1950**

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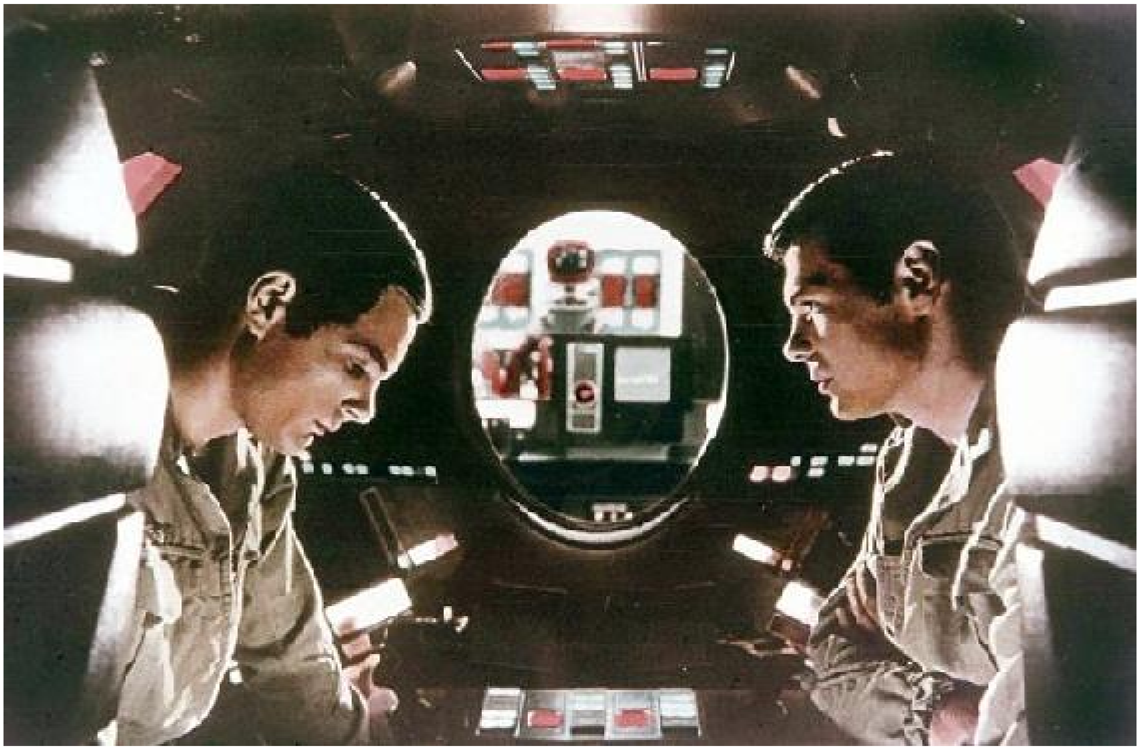

2001: A SPACE ODYSSEY, 1968

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BLADE RUNNER, 1982

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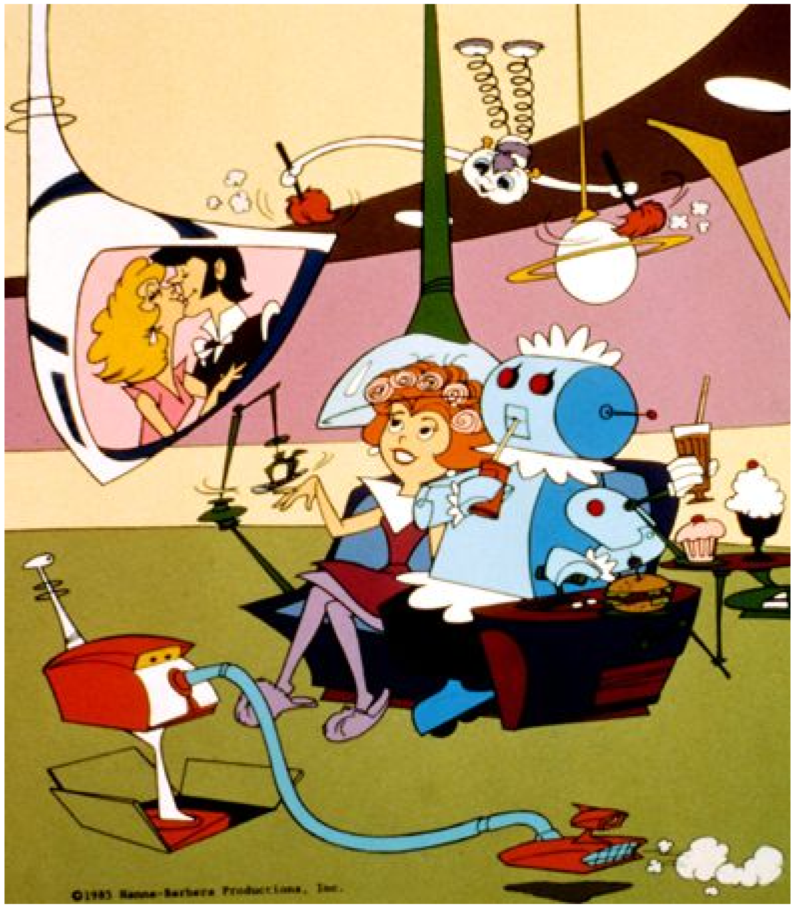

THE JETSONS, 1962

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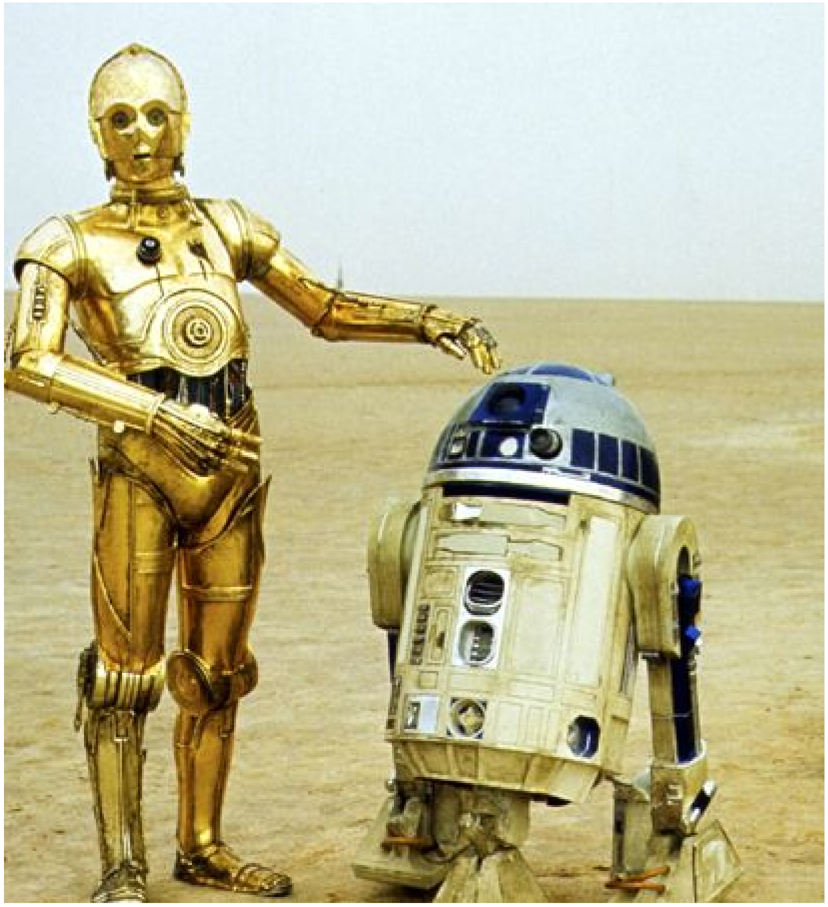

STAR WARS, 1977

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STAR TREK: INSURRECTION, 1998

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TERMINATOR 3, 2003

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A.I.: ARTIFICIAL INTELLIGENCE, 2001

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In the Mind of Humankind

A pioneer of artificial intelligence, David Gelernter has some radical ideas about the supremacy of the human mind

By David Von Drehle

DAVID GELERNTER believes that our physicality is crucial to the formation and operation of human consciousness.

Elections come and go. Markets rise and fall. Celebrities wax and wane. But now and then, we meet a controversy of deep and lasting dimensions. Some of our leading engineers and most brilliant theorists say the future of artificial intelligence is such a matter. Will machines learn to think like humans—and then to outthink us? And if they do, what will become of us?

The topic, once a staple of science fiction, has become one of the defining facts of high tech. From Apple to Amazon, Facebook to Intel, Sergey Brin to Elon Musk, the titans of the 21st century are investing fortunes and

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countless hours in artificial intelligence. Google's 2014 purchase of the British firm DeepMind for more than $500 million produced a bonanza of publicity in 2016, when its game-playing program whipped a human master of the ancient strategy game Go. IBM is pouring $1 billion into building a business around Watson, the company's digital *Jeopardy!* champion, which chatted with Bob Dylan in one ad campaign. Amazon's personal digital assistant, Alexa, dwells in the cloud and, like her cousins Siri (Apple), Cortana (Microsoft) and Google Now, dispenses instructions from speakers, smartphones, televisions and cars. It's remarkable how quickly we've adjusted to their presence.

Among the thundering vanguard, though, is a growing group of worried individuals who take in the rapid rise of superintelligent machines—which are already taking over jobs as factory workers, stock traders, data processors, even news reporters—and conclude that they will eventually render us all obsolete.

This is the topic that, in the winter of 2016, brought me through a snowy Connecticut forest to a house not far from Yale University. I was there to discuss the human mind and artificial intelligence with David Gelernter: artist, author, scientist, composer and stubbornly independent thinker. A conservative among mostly liberal Ivy League professors, a religious believer among the often disbelieving ranks of computer scientists, Gelernter is neither Cassandra nor Luddite. He is a computer virtuoso who happens to find human consciousness even more entrancing than the most amazing digital apparatus.

In his latest book, *The Tides of Mind: Uncovering the Spectrum of Consciousness*, Gelernter argues that the entire field of A.I. is off track, and dangerously so. A key question in the pursuit of intelligence has never been answered—indeed, it has never really been asked: Does it matter that your brain is part of your body?

Or put another way: What is the human mind without the human being?

This mind-body question has an odd place in the history of artificial intelligence. Alan Turing, one of the pioneers of the field, found it so daunting that he pushed it to one side. His seminal 1950 paper "Computing Machinery and Intelligence" drew "a fairly sharp line between the physical and the intellectual capacities of a man," as he put it.

A similar attitude was struck a few years later by computer scientists at IBM. Reporting their breakthrough success in creating a computer capable

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of excelling at high school geometry, project leader Herbert Gelernter—David's father—declined to say "whether our machine is indeed behaving intelligently."

Over the half-century that followed, A.I. theorists stopped treating the human body as an overwhelming problem to be set aside and started treating it as an irrelevant matter to be ignored. Today the mainstream argues that there is no meaningful difference between the human brain, with its networks of neurons and axons—electrical and chemical on-off switches—and computers powered by 1s and 0s. And by the same analogy, computer scientists understand the human mind to be the equivalent of software running on the brain-computer.

Whatever differences exist between humans and machines, today's gurus of artificial intelligence argue they will vanish in the not-too-distant future. Human minds, their memories and personalities, will be downloadable to computers. Human brains, meanwhile, will become almost infinitely upgradable, by installing faster hardware and the equivalent of better apps. The blending of human and machine, which Google's Ray Kurzweil calls the Singularity, may be less than 30 years off, they theorize.

David Gelernter isn't buying it. The question of the body must be faced and understood, he maintains. "As it now exists, the field of A.I. doesn't have anything that speaks to emotions and the physical body, so they just refuse to talk about it," he says. "But the question is so obvious, a child can understand it. I can run an app on any device, but can I run someone else's mind on your brain? Obviously not."

In Gelernter's opinion, we already have a most singular form of intelligence available for study—the one that produced Bach and Shakespeare, Jane Austen and Gandhi—and we scarcely understand its workings. We're blundering ahead in ignorance when we talk about replacing it.

Inside the house, evidence of the mind of Gelernter is everywhere. The towering walls of books—including his own works on computer science, religion, popular culture, history and psychology. His works of art—some abstract, some powerfully figurative, like the life-size evocations of the great kings of Israel inspired by Christian tomb art at the Basilica of St. Denis outside Paris. Musical instruments fill the floor space. Flamboyantly colored birds survey the scene—a purple parrot in a cage near the kitchen and a multihued macaw named Ike that presides over the family room.

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Gelernter's conversation runs in torrents from the prophesies of Isaiah to the subtleties of Gothic engineering to the proper design of graphical user interfaces.

Sun Microsystems co-founder Bill Joy has called Gelernter, who pioneered breakthroughs in parallel processing, "one of the most brilliant and visionary computer scientists of our time." Gelernter's 1991 book *Mirror Worlds* foretold with uncanny accuracy the ways the internet would reshape modern life, and his innovative software to arrange computer files by timeline, rather than folder, foreshadowed similar efforts by several major Silicon Valley firms. (A patent lawsuit against Apple was ultimately decided in Apple's favor.) Yet Gelernter is not enthralled by the power of computer science, which he considers to be essentially a secular religion for its devoted disciples. His colleagues in computer science are so enamored of their own miraculous designs, he says, that they refuse to consider the limits of their machines.

Go back to that Gothic cathedral for a moment. How does it work its effects on the people who enter? In its scale and design, its vast weight and fortifying inspiration, its dark vaults and diffuse lights, in the ancient stories signaled through episodes of glass and carving, the church speaks to the mind of the engineer as well as the emotions of the pilgrim. The building can be measured and analyzed. But it is also felt. And how it feels depends on the time of day, the mental state of the visitor, the depth of the silence or the rumble of the organ. It smells of incense and age. It soars and it terrifies.

The human mind, Gelernter asserts, is not just a creation of thoughts and data; it is also a product of feelings. The mind emerges from a particular person's experience of sensations, images and ideas. The memories of these sensations are worked and reworked over a lifetime, through conscious thinking and also in dreams. "The mind," he says, "is in a particular body, and consciousness is the work of the whole body."

Engineers may build sophisticated robots, but they can't build human bodies. And because the body—not just the brain—is part of consciousness, the mind alters with the body's changes. A baby's mind is different from a teenager's, which is not the same as an elderly person's. Feelings are involved (a lifetime of pain and elation go into the formation of a human mind). Loves, losses and longings. Visions. Scent, which was, to Proust, "the last vestige of the past, the best of it, the part which, after all our tears seem to have dried, can make us weep again." Music, "heard so deeply/

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That it is not heard at all, but you are the music/ While the music lasts," as T.S. Eliot wrote. These are all physical experiences, felt by the body.

Moreover, Gelernter observes, the mind operates in different ways through the course of each given day. It works one way if the body is on high alert, another on the edge of sleep. Then, as the body slumbers, the mind slips entirely free to wander dreamscapes that are barely remembered, much less understood.

All of these physical conditions go into the formation and operation of a human mind, Gelernter says, adding, "Until you understand this, you don't have a chance of building a fake mind." Or to put it more provocatively (as Gelernter is prone to do): "We can't have artificial intelligence until a computer can hallucinate."

Gelernter's book is the fruit of a lifetime's reflection on such matters. Rejecting the analogy of brain to computer and mind to software as "childishly superficial," he describes a variable human consciousness that operates along a spectrum from "high-focus" to "low-focus"—up and down, back and forth, many times each day.

At high focus, the mind works exactly like a computer. It identifies specific problems and tasks. It calls on the memory for data and patterns and instructions necessary to answer the questions and perform the jobs at hand. High focus finds the mind thinking about thinking; that is, thinking on purpose.

At low focus, the mind may drift, even seem to go blank. Notions and daydreams pop up without being consciously summoned. At the lowest focus, when the body is asleep, the dreaming mind churns up images and memories and patches them together—not according to a rational blueprint, Gelernter argues, but according to some sensation or emotion that they share.

"As we move down-spectrum," he writes, "mental activity changes—from largely under control to *out* of control, from thinking on purpose to thought wandering off on its own. Up-spectrum, the mind pursues meaning by using logic. Moving down-spectrum, it tends to pursue meaning by inventing stories, as we try to do when we dream. A logical argument and a story are two ways of putting fragments in proper relationship and guessing where the whole sequence leads and how it gets there."

Inevitably to modern, logical readers, this description suggests a hierarchy. "Up-spectrum" sounds superior to "down-spectrum," "high-focus" better

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than “low-focus.” We might ask—even if Gelernter is correct about the workings of the mind—why artificial intelligence should not operate solely at high focus and up-spectrum. Leaving the lower range of consciousness behind might be progress, right?

No, Gelernter contends. The full expression of the human mind requires the entire spectrum. His book, like his conversation, is a celebration of the full span. He quotes not only scientists and psychologists but also poets and novelists. A mathematical proof or scientific discovery is no greater sign of intelligence than is the “Ode to a Nightingale” by John Keats, who ends his masterpiece by wondering where on the spectrum of consciousness he is: “Was it a vision, or a waking dream?/ Fled is that music:—Do I wake or sleep?”

For that matter, not all logical breakthroughs come from minds operating at high focus. Consider the story of pioneering neuroscientist Otto Loewi. A century ago, Loewi tried to devise an experiment that could test his theory that the brain transmits some signals chemically. When he finally grasped the answer, it was at low focus, in a sequence of dreams. The experiment that Loewi envisioned while sleeping in 1921 eventually led him to a Nobel Prize.

David Gelernter was born in 1955 with a front-row seat on the computer age. On the dedication page of *Tides of Mind*, he hails his father as “one of the six men who invented AI.” After earning his bachelor’s degree at Yale, where he majored in religious studies and pursued an interest in neurobiology, Gelernter did his Ph.D. studies at Stony Brook University. He joined the computer-science faculty at Yale and pitched into the vital problem of parallel processing—in rough terms, how to make computers perform more than one task at a time.

His breakthrough in that field cemented his reputation for brilliance—and it came, he says, courtesy of a down-spectrum moment. After thinking at high focus about the problem of gridlocked signals, Gelernter daydreamed a vision of Grand Central Terminal so crowded that no one could move. The escalators were in motion, though, churning people from one level of the station to another. “To be conscious of a thought does not mean we know where it came from,” Gelernter observes in *Tides*. Whatever its origin, the image freed Gelernter’s mind to unstick the flow of signals in his software.

Later, Gelernter and a colleague attempted to program a computer to mimic low-focus consciousness. He imagined a sort of dial on the device

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that would move the machine up and down the spectrum, from Spock-like logic to loopy hallucination. Though the attempt did not achieve quite the results he had hoped for, the program did show a degree of suppleness that they eventually used to advance the role of computers in diagnosing diseases.

Gelernter has no doubts that huge strides can be made in expanding the spectrum of artificial intelligence. “Computers already have more than enough capacity to mimic low-focus thought,” he says. With sufficient resources, a huge database can be compiled from human subjects connecting myriad images and sensations with matching emotions, he says, describing the work to be done. From there, machines equipped for “deep learning” could eventually become adept at faking the feelings that give structure to down-spectrum consciousness.

But his name for such machines conveys his concern and contempt: “zombies.” They might be made to look like humans, and even to react like humans. But they would not have genuine human feelings. They wouldn’t know the fear and exhilaration of riding a roller coaster, much less the racing heart and flip-floppy stomach of young love, nor even the depressed exhaustion of grief.

Perhaps most important, the computer won’t feel the existential dread or weird magnetism of death. Admittedly, this is exactly why the Singularity is so appealing to Kurzweil and his followers. By merging the human with the machine, the software mind is freed from its wet mortality and crosses to eternal life. But what is human consciousness without the shadow of death? “The meaning of life,” wrote Franz Kafka, “is that it ends.”

“Kurzweil,” says Gelernter, “is a good man and very bright, very capable. It’s just that some of what he says doesn’t make sense. He’s going to upload his mind to the cloud and live forever—what does that even mean? If my mind is running on another computer, it is no longer me.”

Issues of mortality and limitations are not abstractions to Gelernter. His range of human feelings, including his familiarity with death, expanded horrifically one early summer day in 1993. In his office at Yale, Gelernter opened a package that had come in the mail. A pipe bomb prepared by Ted Kaczynski, the so-called Unabomber, destroyed his right hand and left him fighting for his life. More than two decades later, Gelernter still deals daily with the pain and disability.

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On some days, he feels estranged from a world that has little patience for "long-term consequences," he says. "It is hard for people to sustain their attention to chronic conditions and permanent injuries." He seems reluctant to say this, because he doesn't like complainers. He quickly adds, "In the final analysis, there is an insulating layer of kindness for which one thanks God."

Gelernter is not the only dissenter from the A.I. orthodoxy. Silicon Valley entrepreneur Roman Ormandy, for example, has criticized the brain-as-processor model. "The more neural research progresses, the clearer it becomes that brain is vastly more complex than we thought just a few decades ago," Ormandy has noted.

But Gelernter is vastly outnumbered—so much so that he worries that his ideas might simply be ignored. "There has never been more arrogance and smugness" than in today's self-congratulatory scientific culture, he asserts. "The spectrum of our consciousness is such a part of who we are and how we live in the world. But we make such a virtue of ignoring it. We have a fundamental cultural prejudice that high-focus thought is better, when if we would just examine our own lives we would see that we all hallucinate every day as we dream and see visions as we're falling asleep."

Computers are going to grow much more powerful, and they will be relied upon to complete far more tasks than they do today. Scientists won't stop in their pursuit of better programs or faster processors—nor should they. Gelernter fully appreciates that this progress will take machines deeper and deeper into the spaces previously reserved for human intelligence. Their memories will be bigger than ours and more rapidly accessible. Their importance will grow as they do more, tirelessly and cheaply. They will change the nature of work, of learning, of relationships.

This is precisely why we need to understand what computers are not, and can never be. For that, we must know ourselves. "We've turned away from exploring the human mind just when it was getting interesting," Gelernter says. But that's not entirely true. He hasn't.

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GELERNTER IN HIS Connecticut office, where he wrote his latest book, *The Tides of Mind*

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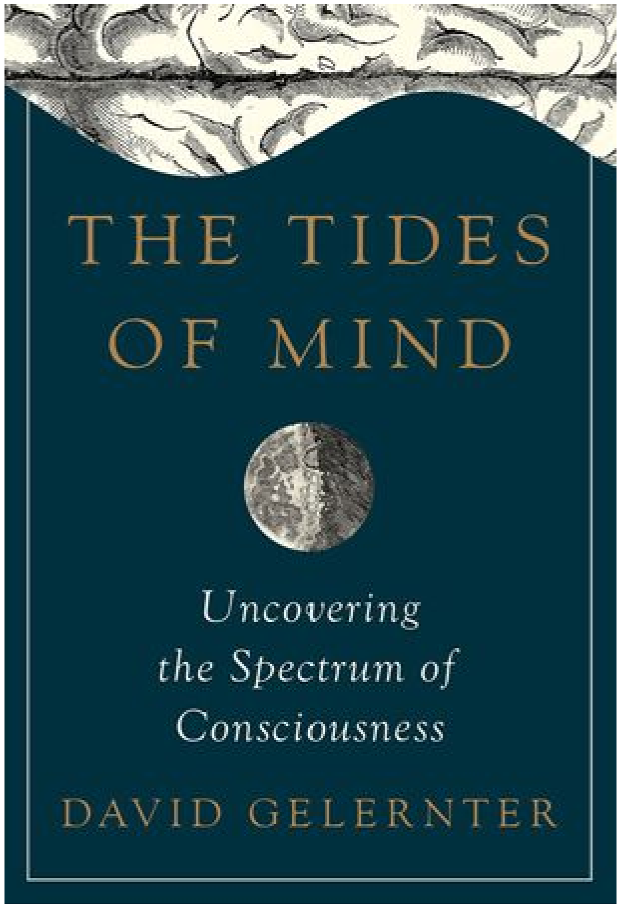

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Future-Proofing

Prominent scientists, inventors, entrepreneurs and futurists expect competing things from the emergence of A.I. What most divides them is whether the technology will be a benevolent development or a catastrophic one. Here's a look at that spectrum, from "A.I. will benefit humankind" to "A.I. will doom us all," on the following pages.

By Matt Peckham

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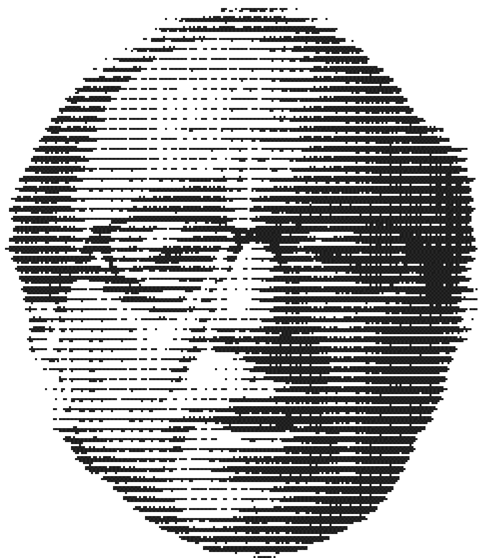
A.I. will benefit humankind

Ray Kurzweil

INVENTOR, FUTURIST AND DIRECTOR OF ENGINEERING AT GOOGLE, 69



Kurzweil believes human-level A.I. will be achieved by 2029. Given the technology's potential to help find cures for diseases and clean up the environment, he says, we have "a moral imperative to realize this promise while controlling the peril."

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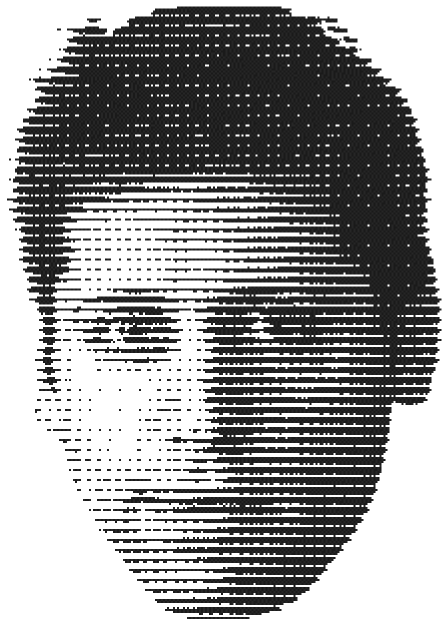
Sam Altman

COMPUTER PROGRAMMER AND PRESIDENT OF STARTUP INCUBATOR Y COMBINATOR, 32



Altman, who’s working on developing an open-source version of A.I. that would be available to all, believes future iterations could be designed to self-police, working toward benevolent ends only.

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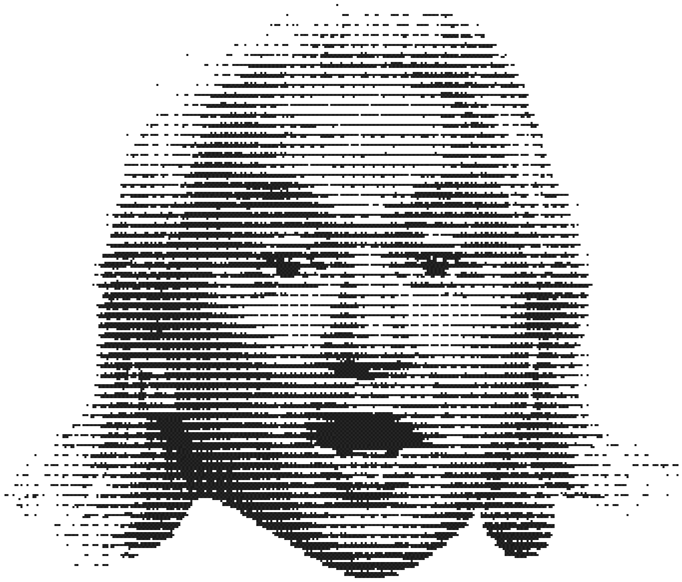
Michio Kaku

BEST-SELLING AUTHOR, THEORETICAL PHYSICIST AND FUTURIST, 70



Kaku takes a longer, more pragmatic view, calling A.I. an end-of-the-century problem. He adds that even then, if humanity has come up with no better methods to constrain rogue A.I. robots, it will be a matter of putting "a chip in their brain to shut them off."

Gelernter falls here

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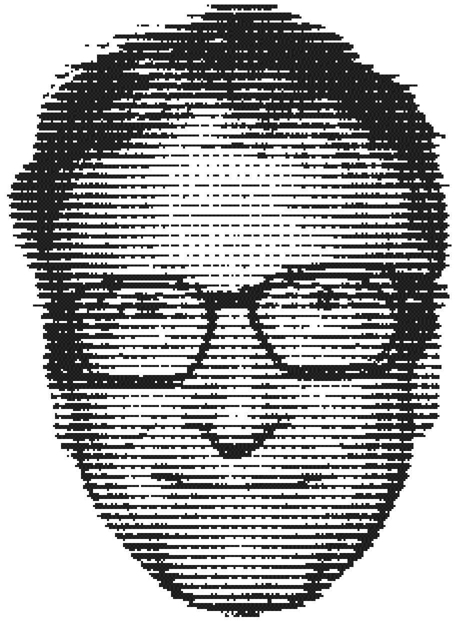
Bill Gates

ENTREPRENEUR, PHILANTHROPIST AND MICROSOFT CO-FOUNDER, 61



The computer-software magnate–turned–philanthropist views near-future low-intelligence A.I. as a positive labor-replacement tool but worries that the “super intelligent” systems coming a few decades down the road will become “strong enough to be a concern.”

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Stephen Hawking

THEORETICAL PHYSICIST, AUTHOR, PIONEER OF BLACK-HOLE PHYSICS, 75

The famed scientist believes A.I. could be both miraculous and catastrophic, calling it “the biggest event in human history” but also potentially “the last, unless we learn how to avoid the risks.”

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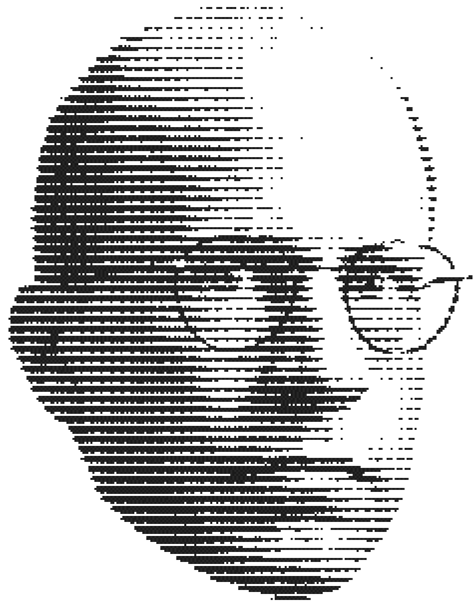
Nick Bostrom

DIRECTOR OF THE FUTURE OF HUMANITY INSTITUTE AT OXFORD UNIVERSITY, 44



Bostrom warns that A.I. could turn dark quickly and dispose of humans. The subsequent world would harbor “economic miracles and technological awesomeness, with nobody there to benefit,” like “a Disneyland without children.”

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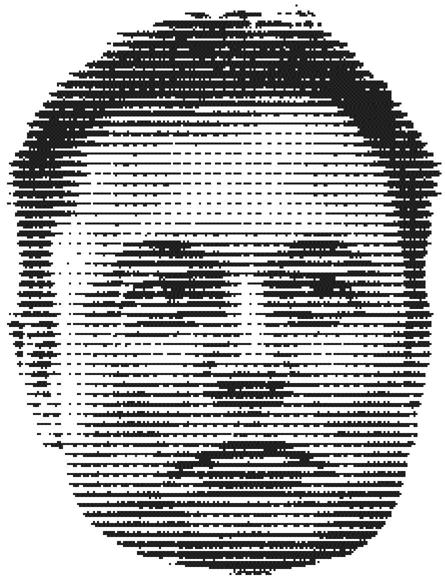
A.I. will doom us all

Elon Musk

ENTREPRENEUR, SPACEX FOUNDER, CEO OF TESLA MOTORS, 46



The outspoken engineer and inventor has famously called A.I. “our biggest existential threat,” fretting that it may be tantamount to “summoning the demon.”

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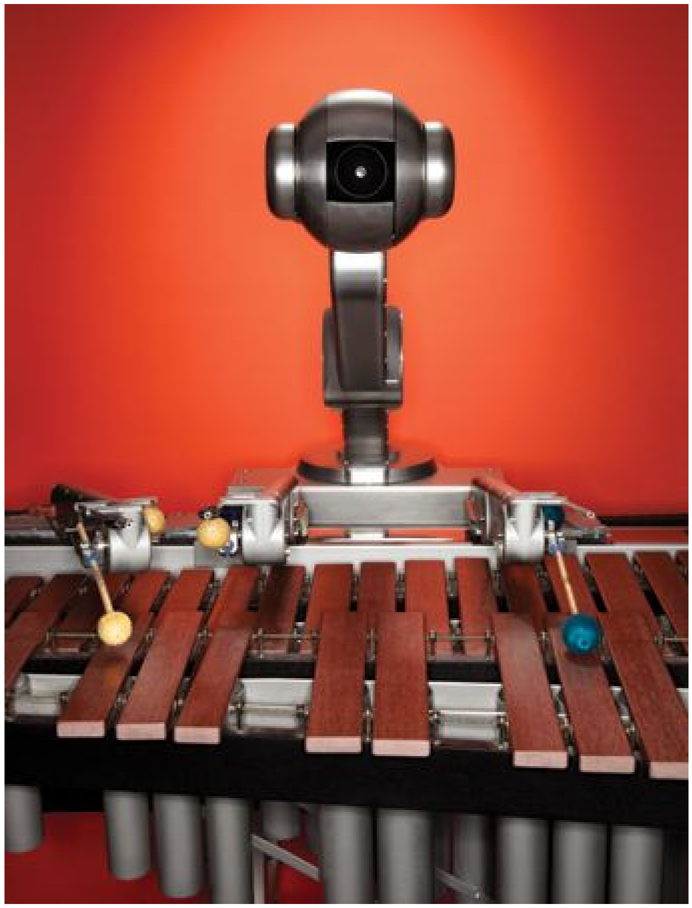
Roll Over, John Legend



Tell Gaga the news: Shimon the four-armed robot is available to jam. Not only can he bang out chord structures that no human can physically reach, he can also improvise seamlessly, right alongside freewheeling bandmates. Born in laboratories at Georgia Tech (he's been about 12 years in the making), Shimon relies on learning programs that canvass a range of music theories and genres. And then there's the pop-idol looks . . .

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INTRODUCTION

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