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Artificial intelligence

How advanced analytics and smart machines will change the way we work

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Twenty years ago, IBM's Deep Blue defeated Garry Kasparov. Kasparov accused IBM of cheating and requested a rematch. IBM declined and retired Deep Blue.[1] Artificial intelligence (AI) has been a subject of controversy ever since. The late Stephen Hawking believed that intelligent machines pose a threat to the existence of mankind. Elon Musk of Tesla has voiced similar concerns. In contrast, Ray Kurzweil argues that we already live in a hybrid human-machine civilization, and that AI will help make the world a better place, especially in essential areas such as education and healthcare.[2] Mark Zuckerberg of Facebook concurs.[3] So what is it, doom or a new dawn? It is time to sober up and take a step back. In this article, we set out to answer three questions: what is AI? How will it impact the global economy? And what should companies do today to ready themselves for a future in which AI will be part of the new normal?[4]

WHAT IS AI?

The idea of computer-based artificial intelligence dates back to 1950, when Alan Turing proposed an experiment that is now commonly referred to as the Turing test: "A computer would deserve to be called intelligent if it could deceive a human into believing that it was human." One of the key design principles of later generations of smart machines was already present in the electro-mechanical computer Turing's team had designed to crack the Enigma code in World War II: selectivity, i.e., the maxim to pursue only promising branches of computation, as opposed to brute force. Subsequent milestones of AI development include:[5]

1 www.sciencedirect.com/science/article/pii/S0004370201001291 (retrieved in December 2017)

2 time.com/3641921/dont-fear-artificial-intelligence/ (retrieved in December 2017)

3 www.cnbc.com/2017/07/26/mark-zuckerberg-defends-a-i-again-continuing-debate-with-elon-musk.html (retrieved in December 2017)

4 For further reading, please see Mark Tegmark, Life 3.0: Being Human in the Age of Artificial Intelligence, Allen Lane, 2017

5 McKinsey Global Institute, Artificial Intelligence – The Next Digital Frontier?, June 2017

- The construction of the first artificial neural network, using 300 vacuum tubes and military surplus hardware, by Princeton students in 1950

- The launch of the first AI software, Logic Theorist, at the Carnegie Institute of Technology in 1955

- The establishment of the Artificial Intelligence Laboratory by Marvin Minsky at the Massachusetts Institute of Technology in 1963

- The development of expert systems – software programs that use a database of expert knowledge to assess a problem and offer a solution – in the 1980s

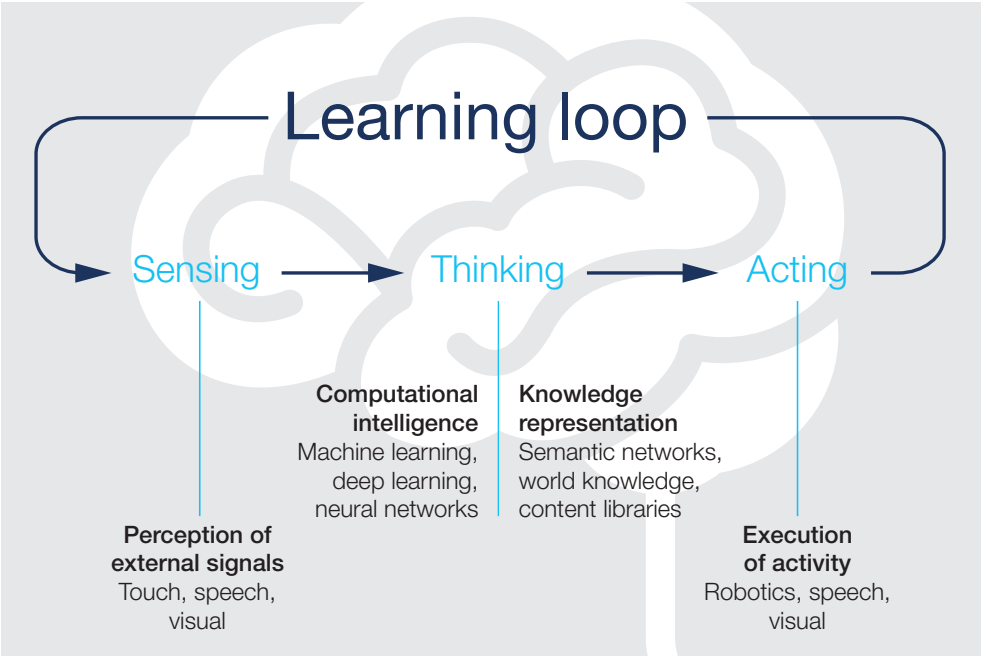
- The 1985 Carnegie Mellon project Chip Test that evolved into Deep Blue, the computer that defeated Garry Kasparov in the controversial 1997 match.

In recent years, advances in computing power, big data processing, and deep learning have given AI an unprecedented boost. For the first time in history, there is a broad coalition of researchers, engineers, investors, public servants, and consumers who agree that AI is a worthwhile pursuit.

Constitutive elements of AI

So, what does it take for a machine to pass the Turing test and convince human operators it is one of their kind? There are three constitutive elements of AI: sensing, thinking, and acting. Typically, these elements are connected by an ongoing learning cycle (Exhibit 1). Smart machines absorb data by *sensing* their environment, emulating the way humans see and hear. The input process can take the shape of image, text, or voice recognition, but can also be substituted or amended by readout of digital data. *Thinking* is the core of AI. It consists of two complementary functions: knowledge representation (i.e., keeping track of what the machine has already learned) and computational intelligence, a pro-

Exhibit 1



cess of structured inference that is often referred to as machine learning. Finally, *acting* is what the machine does in response to the input it has received and the inferences it has arrived at through thinking. Like the input, the output can take many forms. Examples include text or images displayed on a screen, computerized speech output, and interaction with physical objects through robotics. The more cycles of sensing, thinking, and acting an intelligent machine goes through, the smarter it becomes. It will learn from its own actions by sensing their impact on its environment and feeding these observations back into the next iteration of thinking. This continuous loop of self-propelled learning sets AI apart from purely statistical machine learning; it is the subject of various current research efforts. Examples of promising approaches include reinforced learning, like the way animals learn from positive and negative feedback, and evolutionary strategies. Evolutionary learning is based on the competition

of large numbers of learning agents for the best solution to a given problem.[6] The success and progress of such research will determine how quickly, and how independently, AI-based systems will be able to learn and adapt to new challenges in the future.

For the practical purposes of this article, we will stay away from the philosophical discussion of weak, or narrow, AI (machines emulating certain aspects of human intelligence) vs. strong AI (machines with conscious minds).[7]

Voice bots and other killer applications

Machines you can talk to are one of the most prominent applications of AI available today. The likes of Amazon's Alexa and Apple's Siri may not yet pass the Turing test, but they are a big step up from the frustrating interactions with the computerized call centers and voice-controlled car navigation systems of a few years ago. Voice bots have gotten very good at understanding human speech, decoding the objective content of a given message, and composing a meaningful reply from prerecorded short language fragments. To bring voice bots closer to passing the Turing test, developers face a twofold challenge:

- The recognition of emotional content, such as anger or irony, as conveyed by tone of voice or implication
- Synthesizing natural speech, i.e., producing voice output that is not patched together from prerecorded snippets.

Google is currently addressing the second challenge with its WaveNet technology, a generative model for raw audio.[8] Most computerized voices, however, still sound

6 medium.com/beyond-intelligence/reinforcement-learning-or-evolutionary-strategies-nature-has-a-solution-both-8bc80db539b3 (retrieved in May 2018)

7 Compare John Searle, Minds, Brains, and Programs, Cambridge University Press 1980.

8 deepmind.com/blog/wavenet-generative-model-raw-audio/ (retrieved in December 2016)

somewhat artificial. In response, Lyrebird, a Canadian start-up, has developed a software that can be trained to imitate any individual human voice. The company promises that it lets you "create a digital copy of your voice with one minute of audio."[9] While critics concede that such technology will undoubtedly improve human-machine interaction, they also warn that it is prone to abuse and may give rise to fraud and identity theft.[10]

Other killer applications of AI include:

- Assisted and autonomous driving (see our upcoming article on AI in advanced industries and driverless cars)
- Automatic pattern recognition in medical diagnostics (see our article on digital healthcare)
- Semi-automatic insurance claims review (see our articles on digital healthcare and the emerging analytics-based insurer)
- Adaptive recommendation engines (see our article on data-driven retail)
- A smart energy grid (see our article on distributing the surplus)
- Predictive maintenance (compare the discussion in the comprehensive MGI publication on the Internet of Things[11]; also see the insert on advanced AI applications below).

9 lyrebird.ai/blog/create-your-voice-avatar (retrieved in December 2017)

10 www.washingtonpost.com/news/innovations/wp/2017/05/03/this-audio-clip-of-trump-as-a-robot-may-prelude-a-future-of-fake-human-voices/?utm_term=.cee7793719ab (retrieved in December 2017)

11 McKinsey Global Institute, The Internet of Things: Mapping the Value Beyond the Hype, June 2015; pp. 70-73

As AI evolves from a spectacular novelty to a part of daily life, the relationship between energy and cognitive performance becomes more important. While the human brain runs on less than 20 watts, IBM's Watson computer cluster that beat the Jeopardy champion in 2011 had a power intake in the magnitude of 100,000 watts.[12] So from an energy perspective, Watson would have had to compete against the collective wit of 5,000 humans to get to a fair comparison. Currently, substantial research resources are invested in the development of more energy-efficient hardware to enable AI implementation at scale. Says Vivienne Sze, an associate professor of electrical engineering and computer science at MIT: "It's one thing to design algorithms, but to deploy them in the real world you have to consider speed and energy consumption."[13]

12 "A typical adult human brain runs on around 12 watts – a fifth of the power required by a standard 60 watt lightbulb. Compared with most other organs, the brain is greedy; pitted against man-made electronics, it is astoundingly efficient. IBM's Watson, the supercomputer that defeated Jeopardy! champions, depends on ninety IBM Power 750 servers, each of which requires around one thousand watts." See Ferris Jabr, Does Thinking Really Hard Burn More Calories?, Scientific American, July 18, 2012 (www.scientificamerican.com/article/thinking-hard-calories/; retrieved in May 2018). Also see Gareth Cook, Watson, the Computer Jeopardy! Champion, and the Future of Artificial Intelligence, Scientific American, March 1, 2011 (scientificamerican.com/article/watson-the-computer-jeopa/; retrieved in May 2018)

13 news.mit.edu/2017/building-hardware-next-generation-artificial-intelligence-1201 (retrieved in May 2018)

HOW WILL AI IMPACT THE ECONOMY?

AI will change the way we live and work. In the past, only a chosen few had chauffeurs and personal assistants. In the future, self-driving cars and computerized assistants will become ubiquitous. Not only will AI give rise to entirely new products and services, it will also drive the automation of nontrivial tasks. In recent years, computers and robots have demonstrated their ability to perform a range of routine activities more cheaply and often more proficiently than humans. Thanks to AI, machines will soon be able to perform jobs that require advanced cognitive abilities and that have long been considered too difficult to automate successfully.[14] In many industries, advanced AI presents unprecedented opportunities for efficiency gains and new revenue generation.[15]

AI itself is not new, but the pace of recent breakthroughs is. Four factors are driving this acceleration:[16]

- First, machine-learning algorithms have progressed in recent years, especially through the development of deep learning and reinforcement of learning techniques based on neural networks

- Second, exponentially increasing computing capacity has become available to train larger and more complex AI models much faster

- Third, machine-learning models can be trained using the growing amount of data generated every day (e.g., images, click streams, voice and video, mobile locations, and data gathered by sensors embedded in the Internet of Things)

14 McKinsey Global Institute, Artificial Intelligence – The Next Digital Frontier?, June 2017

15 McKinsey Global Institute, Notes from the AI frontier: Insights from hundreds of use cases, April 2018

16 McKinsey Global Institute, What's Now and Next in Analytics, AI, and Automation, Briefing Note, May 2017

- Fourth, improved processors and calculation systems allow for new AI applications, such as advanced machine learning algorithms. Quantum computing is one of the technologies that drive these applications.

A range of automation technologies is already creating real value. Rio Tinto, the mining company, for example, has deployed automated haul trucks and drilling machines at its mines in Australia, and says it is seeing an increase in utilization by up to 20 percent. Google has applied AI to its own data centers, cutting the amount of energy they use by 40 percent. In financial services, automation in the form of digitized end-to-end workflows ("straight-through processing") can increase transaction throughput by 80 percent, while concurrently reducing errors by half.[17]

One in two jobs could soon be done by a machine

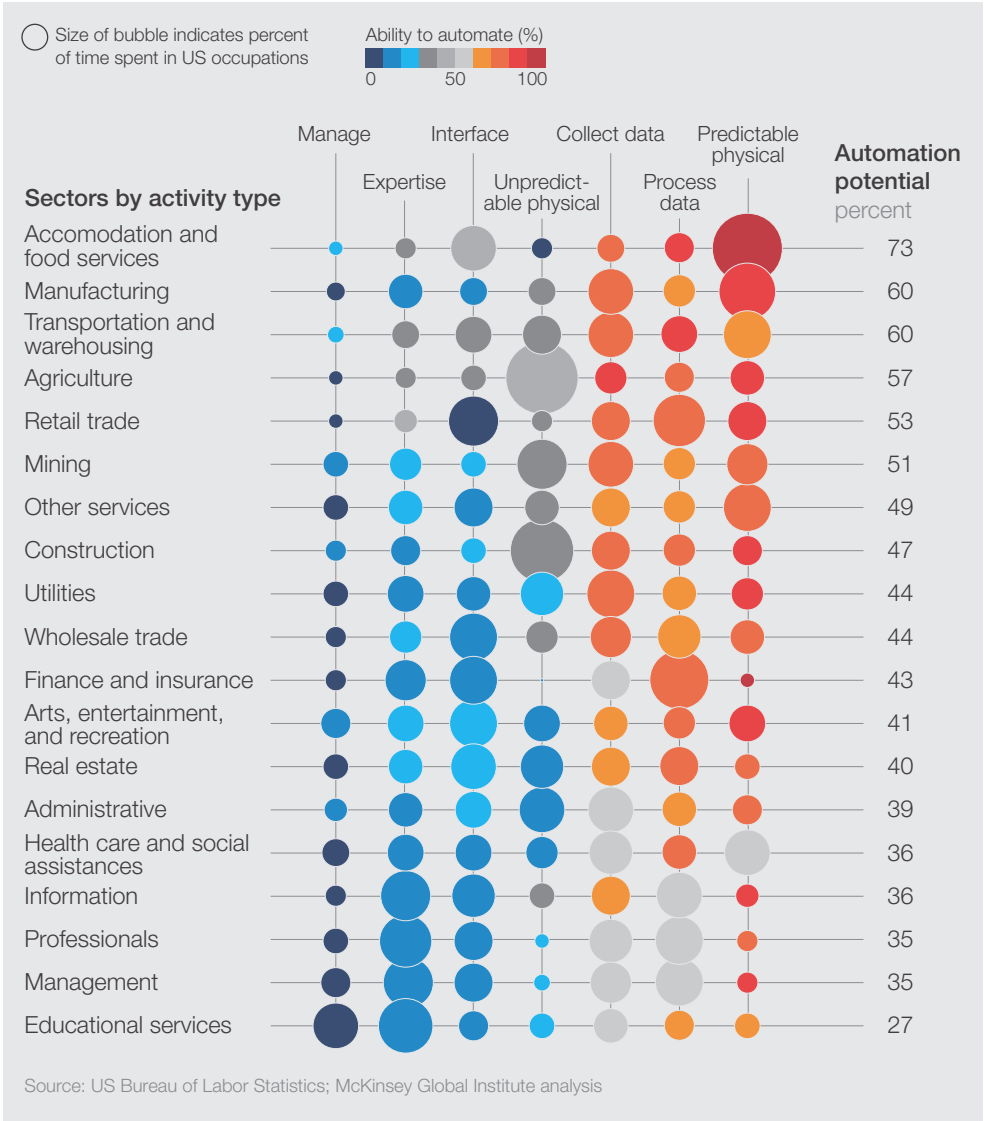
The McKinsey Global Institute (MGI) has carried out a comprehensive study of the automation potential in a wide range of industries. Each of these industries has been examined in terms of the kinds of jobs it entails and the processes that drive value creation. The study is based on technology that is currently available and has been demonstrated to work, although it may have to be adapted to suit the needs of a given industry. Specifically, the MGI used the state of technology in respect to 18 performance capabilities to estimate the technical automation potential of more than 2,000 work activities from more than 800 occupations across the US economy, and then broadened the analysis across the global economy (Exhibit 2).[18]

The size of the circles represents the share of time spent performing a given task in the US. The color represents the estimated automation potential – red stands for the highest potential, blue for the lowest potential. Some processes can be automated more easily than others. Data collection, data processing, and predictable physical activities have the highest

17 McKinsey Global Institute, Artificial Intelligence – The Next Digital Frontier?, June 2017

18 McKinsey Global Institute, A Future that Wworks: Automation, Employment, and Productivity, January 2017

Exhibit 2



Source: US Bureau of Labor Statistics; McKinsey Global Institute analysis

automation potential. Industries in which these activities represent a large share of the total workload are especially susceptible to automation with current technology. The top five industries in terms of automation potential are hospitality, manufacturing, logistics, agriculture, and retail. The average across all industries is 53 percent. In other words: one in two jobs could soon be carried out by a machine. The wages associated with technically automatable activities come to a total of USD 14.6 trillion globally. According to the MGI's projection, the average automation potential will reach 90 percent by 2055.

Benefits go beyond labor substitution

Automation will not only render some jobs redundant, it will also yield performance benefits in many industries. Examples include greater throughput, higher quality, reduced variability, a reduction of waste, higher customer satisfaction, and higher safety. The MGI has developed several hypothetical case studies to gain a better understanding of the potential for automation in different settings. The case studies are of a hospital emergency department, aircraft maintenance, oil and gas operations, a grocery store, and mortgage brokering. The results are striking. The value of the potential benefits of automation, calculated as a percentage of operating costs, ranges from between 10 to 15 percent for a hospital emergency department and a grocery store, to 25 percent for aircraft maintenance, and more than 90 percent for mortgage origination. Safety is another area that could benefit from increased automation. In the garment industry, for example, workers are exposed to a wide range of health risks, from lung ailments to lost fingers. In 2015, 1.4 million injuries were recorded in the garment industry worldwide. Automation of dangerous processes, such as leather tanning and fabric cutting, could help bring down this toll dramatically.[19]

19 See p. 3 of globalfashionagenda.com/wp-content/uploads/2017/05/Pulse-of-the-Fashion-Industry_Executive-summary.pdf (retrieved in March 22, 2018)

Advanced AI brings unprecedented opportunities for efficiency gains and new revenue generation across industries

AI technologies are advancing rapidly, and companies in all sectors are looking for ways to derive value from them. But surveys show that many firms are unsure about the applications and potential upside, or are daunted by implementation challenges. The McKinsey Global Institute (MGI) has found that the most advanced forms of AI – deep learning based on neural networks – can play a transformational role in business, with a wide range of practical applications and the potential to capture trillions of dollars in value.[20] Prominent examples include:

- Detecting anomalies to predict component lifetime and trigger replacement or repair ("predictive maintenance"). This application can be used to reduce downtime and operating costs while improving production yield. In a case involving cargo aircraft, AI can extend the life of the plane beyond what is possible using traditional analytic techniques by combining plane model data, maintenance history, anomaly detection on engine vibration data, and images and video of engine condition.

- Optimizing the route for a vehicle, or a fleet of vehicles, to create the best combination of time use and fuel consumption. Specifically, AI can optimize the routing of delivery traffic. One European trucking company has used AI to reduce fuel costs by 15 percent. Based on data from on-board sensors that monitor both vehicle performance and driver behavior, drivers receive real-time coaching, including when to speed up or slow down. This application results in a reduction of both fuel consumption and maintenance costs. Compare the insert on European use cases below.

20 The paper, 'Notes from the AI frontier: Insights from hundreds of use cases', draws on more than 400 specific examples of existing and potential uses of analytics and AI compiled by MGI and McKinsey Analytics, based on practical experience. The cases cover 19 industries, from aerospace and defense to travel and the public sector, and nine business functions ranging from marketing and sales and supply chain management to product development and HR.

- Generating recommendations from customer data. The most common application of this capability is perhaps “next product to buy” modeling in e-commerce (“recommendation engine”). In a given case, a travel company used this approach to offer its customers additional services, such as hotel and car rental reservations, based on a recommendation algorithm trained on product and customer data. This led to a 10 to 15 percent increase in ancillary revenue.

The potential impact of advanced AI techniques could amount to 40 percent of the impact of all analytics. Their effect is largest in cross-cutting areas, primarily supply chain management and manufacturing, where AI can be successfully deployed for predictive maintenance and yield optimization, and marketing and sales, where its ability to customize and personalize product and service offerings can be leveraged. For now, MGI experts size the global opportunity at about USD 3.5 to 5.8 trillion in value annually, and see many new opportunities as the data required for AI and the techniques to deploy it develop in the years to come.

That said, experts at the MGI believe that multiple challenges will have to be overcome to capture the potential impact and the implications for business leaders and policy makers. It is also important to note that, even as there is great economic potential in the use of AI techniques, the use of data must always consider societal concerns, including data security, privacy, and potential issues of bias.

AI has already attracted billions of dollars in investment

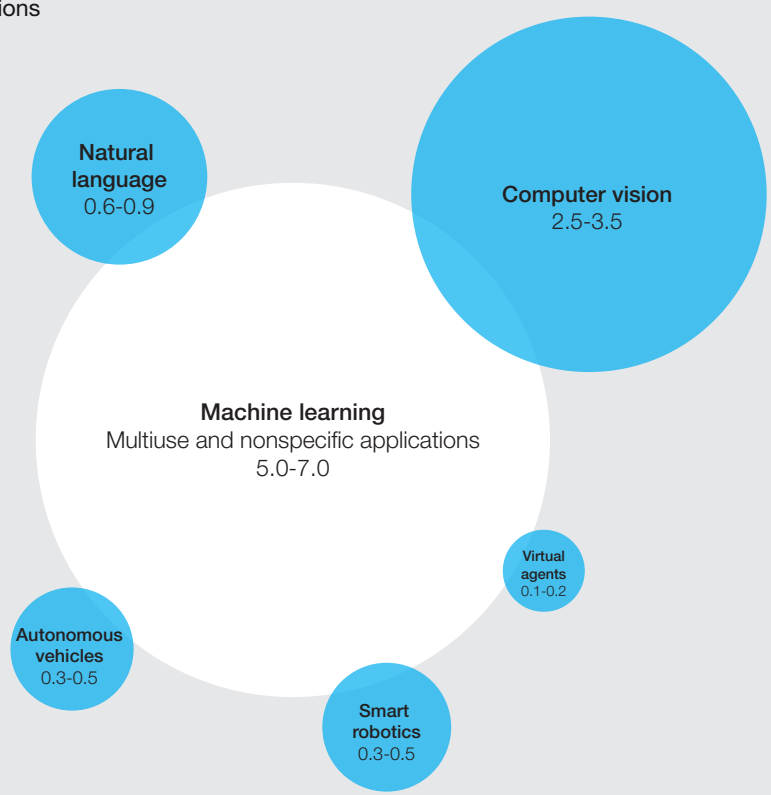
According to McKinsey estimates, major technology companies, such as Google and Baidu, have allocated investments in the magnitude of USD 30 billion to AI in 2016, including M&A activities in the field. Additionally, venture capitalists and private equity players have poured another USD 5 to 8 billion into AI. Another USD 1 billion came from grants and seed capital financing. The resulting total of up to USD 40 billion exceeds the nominal GDP of the national economies like Bahrain (USD 32 billion), Bolivia (USD 35 billion), and Jordan (USD 39 billion).[21]

21 IMF data for 2016

The following technologies have attracted the bulk of direct AI investment (Exhibit 3): *Machine learning* | *Computer vision* | *Natural language* | *Smart robotics* | *Autonomous vehicles* | *Virtual agents.*

Exhibit 3
Machine learning received the most investment, although boundaries between technologies are not clear-cut

External investment in AI-focused companies by technology category, 2016[1]
USD billions



1 Estimates consist of annual VC investment in AI-focused companies, PE investment in AI-related companies, and M&A by corporations. Includes only disclosed data available in databases, and assumes that all registered deals were completed within the year of transaction.

Source: Capital IQ; Pitchbook; Dealogic; McKinsey Global Institute analysis

WHAT SHOULD COMPANIES DO?

The stakes are high, and the pace of change is swift. To benefit from the opportunities AI will bring, companies need to start preparing for the dawning age of smart machines today. Even if the current impact of AI on their business is limited, incumbents cannot afford to sit and wait.[22] This is because innovative companies are already using AI to derive real value from big data and disrupt entire industries. Examples include Uber and Lyft in transportation, Amazon in retail and Netflix in home entertainment. Uber uses PyTorch, an open-source AI framework, to predict ride demand and supply a few hours in advance.[23] Amazon attributes more than one third of its revenue to cross-selling, primarily thanks to the advanced algorithms that drive its recommendation engine.[24] And Netflix saw its subscriber base triple over the course of less than four years, largely because of its ability to develop and deploy new content based on advanced analysis of subscribers' past viewing behavior.[25]

Disrupt or be disrupted

To ready themselves for an age of AI-driven value creation, companies need to think beyond technology. A new IT server, a new software package, or even a new taskforce of tech heads will not solve the problem. To remain relevant in an age of smart machines, CEOs need to start asking some fundamental questions:

22 For further reading, see "Businesses need to act now to realize AI's full potential" (pp. 31 - 41) in McKinsey Global Institute, Artificial Intelligence – The Next Digital Frontier?, June 2017

23 www.cnbc.com/2017/11/03/how-the-uber-ai-lab-works.html (retrieved in December 2017)

24 Charles Gaudet, "What Amazon can teach you about cross-selling," predictableprofits.com (retrieved in 2016)

25 "Number of Netflix streaming subscribers worldwide from 3rd quarter 2011 to 2nd quarter 2016 (in millions)," statista.com (retrieved in 2016). Also see the McKinsey publication "New insights for new growth: What it takes to understand your customers today", by Jonathan Gordon, Volker Grüntges, Vicki Smith, and Yvonne Staack, Marketing & Sales, September 2016

- What is our future business model?
- What are our prospective sources of growth?
- Which capabilities will we need to succeed?

Responsibilities may have to be redefined across the entire enterprise. The ways of working will change, as will the modes and styles of customer interaction. Business owners will find themselves working closely with data scientists. The HR department will have to start looking for new kinds of people, and current employees will have to be trained in new ways to keep up with the accelerating pace of change. In our experience, an adaptive way of working is at least as important as technical expertise to take advantage of emerging AI opportunities. For example, companies need to get accustomed to much faster cycles of development, testing, and learning. As Keith Weed of Unilever put it: "Disrupt or be disrupted. We need to become better at experimenting, taking risks, accepting the occasional failure, and learning quickly along the way."[26] See our articles on the principles of agile organizations and the future of work for details.

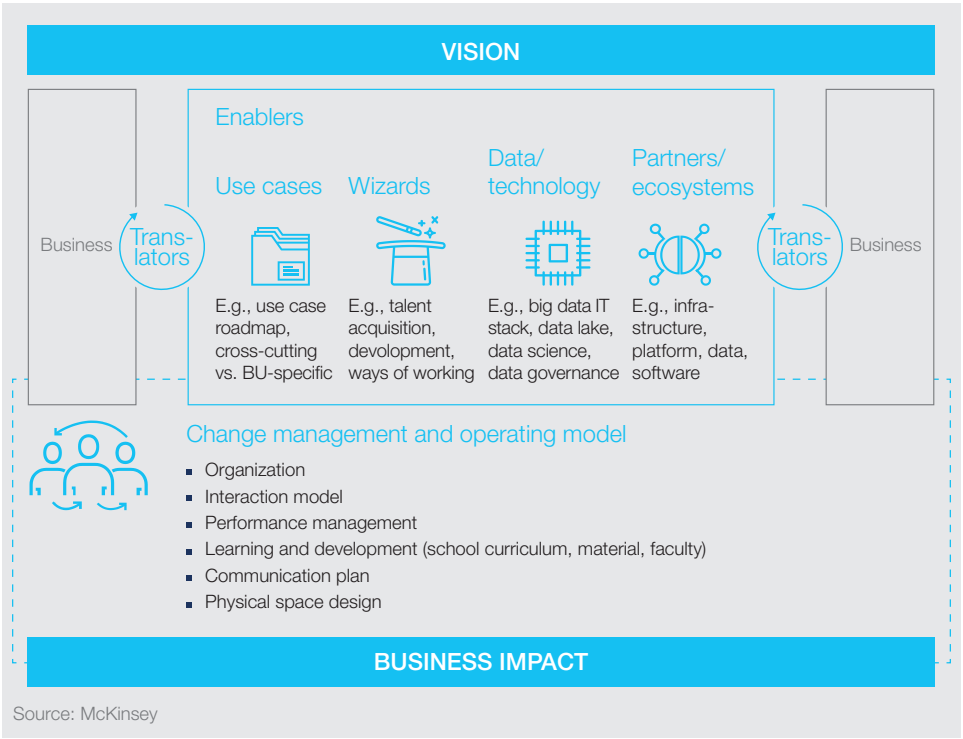
Early adopters of AI are already seeing substantial benefits. For example, a retailer received ten times as many replies to outbound e-mails thanks to automatic personalization, and a government agency was able to cut employee churn in half with the help of a sophisticated segmentation scheme based on machine learning. Also see the case examples in the insert below.

26 www.forbes.com/forbes/welcome/?toURL=https://www.forbes.com/sites/mckinsey/2017/02/15/now-new-next-how-growth-champions-create-new-value/ (retrieved in June 2017)

Four key elements of successful technology-enabled transformations

Unless you are a highly specialized start-up, AI is probably not the only technological topic on your agenda. At the multinational corporations McKinsey serves, AI is part of a bigger journey that also includes value chain digitization, big data management, and the integration of advanced analytics with commercial processes. We have had the privilege to support many such transformations in a wide range of industries over the course of the past few years. Four elements have emerged as common characteristics of successful technology-enabled transformations (Exhibit 4):

Exhibit 4
Approach for tech-enabled transformations



Source: McKinsey

- **Vision.** Successful transformations begin with a clear, inspiring vision that is aligned with a company's business strategy and relevant use cases. A roadmap helps to break down the required changes into manageable increments.

- Enablers

  — **Wizards.** You need a new breed of people to take advantage of new technology. AI goes beyond classical statistics, such as regression analysis. You will have to bring on board data scientists who are comfortable working with self-learning algorithms and neural networks.

  — **Use cases.** If you want to know people you're funny, don't tell them you're funny. Tell them a joke. There is nothing as powerful as a successful business application to make people see the value of new technology. Look for quick wins to build buy-in and set off a virtuous cycle. We have seen cases in which analytical transformations have funded themselves thanks to this approach.

  — **Data and technology.** Thanks to the growing Internet of Things, there is now more data than most companies know what to do with. To take advantage of big data, you need the right hardware and software to merge multiple data sources and derive the kinds of insights that will drive sustainable growth. Increasingly, these processes will happen automatically and in real time.

  — **Partners/ecosystems.** Cross-sector ecosystems have the potential to create new opportunities for growth, often driven by data. Players like LinkedData.org are using automated algorithms to connect related data from thousands of databases spanning multiple domains. See our lead article about technology-enabled transformations for more information on emerging new ecosystems.

- **Translators.** Additionally, you need people who understand both the business and the technology to act as intermediaries. These translators can be hired externally, but ideally they are people from within the organization who understand the business thoroughly and are specifically trained to fill this role.

- **Change management and operating model.** Data-driven decision making typically requires structural adjustments and new, adaptive business processes. Change management helps ensure that new ways of working are rolled out to the entire organization. In addition, it is essential to set up a dedicated group for digital and analytics learning ("Analytics Academy"). Such a group will help train the wizards and translators, and, eventually, bring the necessary skills to the organization as a whole. Guiding principles include speed, agility, and cross-functional orientation.

Twenty years ago, IBM's Deep Blue defeated Kasparov. Two years ago, Google's AlphaGo beat Korean champion Lee Sedol at Go, a game that had long been considered too complex to be mastered by AI. In recognition of the victory, AlphaGo was awarded an honorary 9-dan ranking, the highest rank for professional players.[27] Two months ago, Saudi Arabia granted citizen rights to an anthropomorphic robot named Sophia.[28] Don't you want to be the first company to put a smart machine on your payroll? The race is on.

27 www.bbc.com/news/technology-35420579 (retrieved in December 2017)

28 www.theregister.co.uk/2017/10/27/robot_granted_saudi_citzenship/ (retrieved in December 2017)

EUROPEAN USE CASE EXAMPLES

Network optimization in express logistics

Online shopping has given a big boost to the logistics sector. Across Europe, parcel delivery is growing at a rate of 7 to 12 percent annually. The rate of customer complaints, however, is also rising rapidly. It has doubled between 2015 and 2016 alone.[29] Increasingly, customers come to expect same-day delivery, a major challenge for even the most sophisticated providers. A national mail order service provider was faced with the challenge to determine the optimal distribution network – of hubs, warehouses, and vehicles – to meet the evolving requirements. To build a fact base for network optimization, a McKinsey team analyzed hundreds of gigabytes of demographic data, enriched with demand forecasts and information about operational costs. McKinsey developed a proprietary scenario simulation tool that is based on advanced analytics. The ultimate objective was to create a blueprint for the optimal network, balancing conflicting requirements such as the lowest possible number of distribution centers and efficient route planning. Because of the effort, the company saved EUR 90 million in operating cost without increasing capital expenditure or compromising service levels.

Shelf space productivity in grocery retail

The number of products and varieties offered by consumer goods companies is growing, but the shelf space in supermarkets is limited or declining, partly thanks to an increase in outlets at downtown locations. A grocery chain was wondering how they should decide what to stock: Basics only? Organic alternatives? What about vegan and gluten-free

29 de.statista.com/infografik/10932/deutsches-und-europaeisches-paketaufkommen. Also see www.cushmanwakefield.de/de-de/news/2017/10/urban-logistics-report/ (retrieved in December 2017)

options? For example, manufacturers launched more than 2,700 new food products with stevia, a natural sweetener, in 2016 alone.[30] The obvious approach – go by ROI and put only the most profitable products on the shelves – proved too simple. If you don't have certain products, some customers will do all their shopping elsewhere.

□□□

30 www.statista.com/statistics/329909/number-of-global-food-and-beverage-product-launches-with-stevia/ (retrieved in December 2017)

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