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Artificial Intelligence, Machine Learning, Automation, Robotics, Future of Work and Future of Humanity:
A Review and Research Agenda

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ABSTRACT

The exponential advancement in artificial intelligence (AI), machine learning, robotics, and automation are rapidly transforming industries and societies across the world. The way we work, the way we live, and the way we interact with others are expected to be transformed at a speed and scale beyond anything we have observed in human history. This new industrial revolution is expected, on one hand, to enhance and improve our lives and societies. On the other hand, it has the potential to cause major upheavals in our way of life and our societal norms. The window of opportunity to understand the impact of these technologies and to preempt their negative effects is closing rapidly. Humanity needs to be proactive, rather than reactive, in managing this new industrial revolution. This article looks at the promises, challenges, and future research directions of these transformative technologies. Not only are the technological aspects investigated, but behavioral, societal, policy, and governance issues are reviewed as well. This research contributes to the ongoing discussions and debates about AI, automation, machine learning, and robotics. It is hoped that this article will heighten awareness of the importance of understanding these disruptive technologies as a basis for formulating policies and regulations that can maximize the benefits of these advancements for humanity and, at the same time, curtail potential dangers and negative impacts.

KEYWORDS

Artificial Intelligence, Automation, Future of Humanity, Robotics

INTRODUCTION

With the rapid advancement in artificial intelligence (AI), machine learning, automation, and robotics, many jobs are at risk of being replaced by AI and AI-based automation technology. Job replacement, however, is not a new phenomenon. The loss of jobs caused by technological change is termed "technological unemployment" (Peter, 2017). Some jobs, that have disappeared as technology has advanced, include switchboard operators, elevator operators, and typists. The disappearance of

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obsolete jobs that have been replaced by technologies, is referred to as "technological job obliteration," each time an industrial revolution has occurred, people have been concerned about technological unemployment and technological job obliteration.

The steam engines in the first industrial revolution resulted in the transition from manual production to a machine industry. Many manual agricultural jobs were replaced by machines. The second industrial revolution enabled mass production by employing electric power and improving job automation, while the third industrial revolution further improved automated production by using electronics and information technology. With the development of AI and machine learning, as well as a fusion of technologies (such as the Internet of things, big data, robotics, virtual reality, 3-D printing, and quantum computing), the fourth industrial revolution has arrived (Bloem et al., 2014). These technologies are blurring the lines between physical, biological, and digital spheres. Further, the speed of technological breakthroughs has no historical precedent. What are the differences between this time and the past industrial revolutions? What about the future of work and humanity? In the past technological revolutions, the physical strength and speed of humans were overtaken by machines. In the fourth industrial revolution, not only are a human's physical strength and speed inferior to machines in certain jobs, but a human's cognitive abilities in some fields are also surpassed by machines. The latter makes the fourth industrial revolution particularly disturbing and unsettling.

According to a Pew Research Center survey, 63% of participants were hopeful that the expanding role of AI would leave us better off, but they worried that AI would negatively transform and affect society at the same time (Mack, 2018). The focus of this research is to analyze the impact of AI, machine learning, automation, and robotics, and their effect on the future of work and humanity. This article is structured as follows: the next section provides introductions to AI, machine learning, automation, and robotics. Then, we analyze the promises and benefits provided by these technologies. Challenges poses by these technologies are also discussed. Finally, a research agenda is proposed that emphasizes the need for academia, industry, and government to pay attention to and prepare for these rapidly advancing technologies.

Artificial Intelligence (AI)

AI is an umbrella concept that influences and is influenced by many disciplines, such as computer science, engineering, biology, psychology, mathematics, statistics, logic, philosophy, business, and linguistics (Buchanan, 2005; Kumar et al., 2016). AI can encompass anything from Apple Siri to Amazon Go, and from self-driving cars to autonomous weapons. Generally, AI can be classified into weak AI and strong AI. Weak AI, also known as narrow AI, excels in specific tasks. Most advancements in AI, that have been achieved to date, can be classified as weak AI, such as Google Assistance and Alpha Go. Researchers from different domains are, however, competing to create a strong AI (also called human-level artificial general intelligence or artificial super intelligence), which will process multiple tasks proficiently. A strong AI is the controversial and contentious concept. Many transhumanists believe that a strong AI can have self-awareness and become the equivalent of human intelligence. Once a strong AI becomes a reality, an intelligence explosion will be precipitated and technological singularity may be unavoidable. Superintelligence may emerge almost immediately after that (Müller & Bostrom, 2016). Superintelligence can be loosely defined as "any intellect that greatly exceeds the cognitive performance of humans in virtually all domains of interest" (Bostrom, 2014, p. 22). In other words, a strong AI would be able to outperform humans in nearly every cognitive task.

Automation

According to the Google dictionary, automation is the use of automatic equipment in a manufacturing system or other production process. In Wikipedia, automation is defined as "the technology by which a process or procedure is performed without human assistance." Basically, automation is a system or technology that automates some work that was previously done by humans. Parasuraman and Riley (1997, p. 2) defined automation as "the execution by a machine agent (usually a computer) of

a function that has previously been carried out by a human". According to their analysis, automation changes over time and once automation is completely realized, it will be considered a machine. In another word, today's automation could be tomorrow's machine. Lee and See (2004, p. 50) define automation in a more detailed way. According to their definition, automation is a technology that "actively selects data, transforms information, makes decisions, or controls processes", as well as exhibiting potential to extend human performance and improve safety. Although automation has been defined in different ways, the common theme is that automation frees humans from time-consuming and repetitive tasks, whether the tasks involve physical functions and/or cognitive functions.

Automation usually follows pre-programmed 'rules' (Evans, 2017). Its purpose is to let machines perform monotonous tasks and free humans to focus on more complex, creative, and emotional tasks. Dishwashers, bar-code scanners, and automated assembly lines are examples of the application of automation.

Machine Learning

Arthur Samuel (2000) coined "machine learning" in 1959 and defined it as a field of study that enables computers to learn without being explicitly programmed. Although this definition is rather vague, it indicates a significant feature of machine learning – it does not follow pre-programmed "rules". In general, machine learning is an automated process that enables machines to analyze a huge data set, recognize patterns, and learn from the data to provide support for predictions and decision making. "Reinforcement machine learning", like the one used in AlphaGo Zero, starts from scratch with only the rules of the game, Go. It learned by adjusting actions, based on continuous feedback, and AlphaGo Zero achieved unbelievable results (i.e. probably the best Go "player" in the world at the moment) in a very short period of time (i.e. a few days). It discovered Go moves that were not known in the game's 3,000-4,000 years history. Reinforcement machine learning can also bypass human biases that may reside in data when using big data for training. Machine learning can be regarded as the automation of cognitive functions (Parasuraman & Riley, 1997), or the automation of knowledge work (Chui et al., 2016). AlphaGo and self-driving cars are products of machine learning, especially reinforcement learning. The drawback in machine learning, at the moment, is that the inner working of these self-learning machines is a black box, which makes it difficult to understand and explain the reasoning process and to justify the recommendations. As a result, trusting these machines is a challenge. Further, machine learning using big data can be susceptible to human biases that are inherent in the data (Lewis & Monett, 2017). People tend to only trust a system when the reasoning process is known and interpretable.

Robotics

Robotics is the technology used to develop machines, called robots, that can replicate human actions. Robots are given different names, according to their functions, such as military robots, agricultural robots, medical robots, and domestic robots. They are not necessarily like humans, since many are designed to carry out repetitive and dangerous tasks, rather than to perform high-precision and creative activities. Designers like to make robots resemble humans in appearance, which helps make them more easily accepted. Many robots can walk and talk like humans and perform tasks, such as lifting objects and carrying heavy loads. Artificial intelligent robots are also expected to learn by themselves, behave like humans, and even have the potential to surpass humans. In this case, a robot is actually an automation of physical functions (Parasuraman & Riley, 1997) and is directed by machine learning.

PROMISES AND BENEFITS

AI, in conjunction with other technologies, has the potential to address some of the biggest challenges that society faces. AI has enormous potential in business, manufacturing, healthcare, education, military, and many other areas. Numerous innovations have been developed using AI-based technology,

such as facial recognition and self-driving cars. These applications require AI systems to interact with the real world and to make automatic decisions.

Self-Driving Vehicles and Drones

Through self-driving technology, it is expected that self-driving vehicles could reduce traffic accidents and deaths. In addition to land-based vehicles, self-driving technology has also enabled development of unmanned drones. Drones have become popular in various businesses and governmental organizations, especially in areas that are difficult for humans to reach or to perform efficiently, such as scanning an unreachable military base and quick deliveries at rush hours. Goldman Sachs estimates that "global militaries will spend $70 billion on drones by 2020, and these drones will play a vital role in the resolution of future conflicts and in replacing human pilots (Joshi, 2017).

AI in Education

The natural language processing capability of AI would benefit people who cannot read and write, and who cannot use computers (Prado, 2015). It is reported that artificial intelligence in U.S. education will grow by 47.5% from 2017 -2021 (Marr, 2018). AI can help release teachers from repetitive tasks such as grading and allow teachers to focus more on professional work (Siau, 2018). Besides, it is better to expose students to this technology early since they are highly likely to work with AI in the future. AI tools can also help make global classrooms available to all, including students who are not able to attend school. To stay up-to-date and ensure progress in our continuously changing world, these applications also need to support continuous life-long learning or never-ending learning (Stoica et al., 2017).

AI in Manufacturing and Factory Automation

AI has brought many benefits to the manufacturing industry, such as real-time maintenance of equipment and virtual design. For example, a generative design can be applied during manufacturing. Designer input design goals and the software can explore all possible permutations of a solution, quickly generate design alternatives, and enable the testing of their feasibility. It is possible to accomplish 50,000 days of engineering in one day (Insights team, 2018). There is no doubt that AI holds the key to future manufacturing growth.

AI in HR

AI streamlines human resource processes in many ways. Compared with humans, AI programs can sift through thousands of applications faster and more efficiently, with less unconscious bias. By identifying the traits of successful employees, AI can increase the chance of a company hiring the most qualified candidates which, in turn, will increase productivity and retention rates. It can also release human workers from repetitive paper work and providing answers to common questions. AI can also help to enhance diversity and inclusion in organizations. A word of caution, however, machine learning typically uses large data sets to learn and the data sets will have inherent biases from humans.

AI in Cybersecurity

Cybersecurity algorithms are critical to address the tsunami of cyberattacks. Cybersecurity analytics intelligence can help identify a possible attack before it actually takes place. Using AI and machine learning to help detect and respond to threats can ease the anxiety of cyber workers. In addition, AI can improve the efficiency of identifying threats, reduce the time needed to respond to incidents, and alert anomalous behavior in real time. Companies are already incorporating AI into every aspect of cybersecurity, including cyberintruder identification, prevention, threats detection, and risk analysis. This enables the redirection of human efforts to more critical activities.

AI in Military

AI benefits the military industry on many ways. For instance, combining AI autonomy with computer vision can impact the defense industry by enhancing decision-making and efficiency of soldiers. AI, along with virtual reality, are poised to be a game-changer for military planners, logistics, and military field use. Advances in AI are also enabling significant leaps forward in radio frequency systems. For facial recognition, AI is able to recognize a thermal image captured of a person's face in low-light conditions. Soldiers, who work in covert operations at night, may benefit from this development. AI in the military, however, is a very controversial topic, and many AI researchers and scientists are urging a ban on using AI as a killing machine.

AI at Home

AI is not only changing our workplace, but it is also changing the way we live in our homes. A connected home, combined with AI driven home automation, can take care of almost all daily chores done by humans, such as turning off lights, closing doors, monitoring temperature, playing music, and cleaning floors. Further, AI-powered home automation can reduce the energy consumption by controlling smart thermostats, lighting sensors, and smart plugs. The application of facial recognition algorithms can help detect break-ins and call for emergency services, thereby eliminating the need for human monitoring. Privacy is an issue in this domain.

AI in Health Care

AI-based applications can help improve patients' and elders' health conditions and the quality of their lives. Prime applications of AI in health care include monitoring medicine, treating chronic illness, diagnosing diseases, and surgery support. The National Bureau of Labor Statistics projects that the number of home health aides will grow by 38% over the next 10 years and the length of hospital stays will decrease due personalized rehabilitation and in-home therapy (Stanford University, 2016). From 2012 to 2017, healthcare-AI funding has reached $2.14 billion. AI-based applications in the medical field have achieved many successes, including mining social media to infer health risks, machine learning to predict risky patients, and robotics to support surgery (Hamet and Tremblay, 2017). In the palliative care field, studies show that only 20 percent of Americans spend their final days at home because of the shortage of palliative care professionals, although 80 percent of Americans prefer to be at home (Newby, 2018). AI can also help in predicting and identifying patients who have the most urgent needs for palliative care. From symptom diagnoses to clinical decision support, algorithms that leverage AI have made headlines in terms of accuracy and speed.

AI in Finance

AI in healthcare has a direct impact on finance too. According to Accenture analysis, the AI health market will grow by $6.6 billion by 2021, which can potentially create $150 billion in annual savings for the U.S. healthcare economy by 2026. Unlike traditional finance systems that are based on manually set rules and analytics, the AI-based system is shown to be more effective in detecting financial malfeasance with respect to accuracy and completeness. AI can help fight financial crimes, such as credit card fraud, anti-money laundering, and synthetic identity theft (Chen et al., 2004). Financial Technology (FinTech) is emerging as a transformative and strategic initiative for the financial industry (Siau et al., 2018).

AI and Hazardous Environment

The use of AI in a hazardous environment is growing because intelligent machines and systems are reliable and practical (Ema et al., 2016), and are better able to perform dangerous and laborious tasks than humans (Robert, 2017; Kumar et al., 2016). AI and robotics are designed and used to make safer working environments in fields such as nuclear energy, deep mining, and deep-sea operations. On one

hand, robots are useful in situations where humans cannot be sent. On the other hand, AI can send quick and more accurate warnings. For instance, robots were used in the June 2010 Gulf of Mexico oil cleanup. With the help of robotics, human laborers can be freed from harsh and unsafe conditions, such as super high temperatures and freezing cold temperatures, extreme humidity, chemical risks, and nuclear radiation.

CHALLENGES AND ISSUES

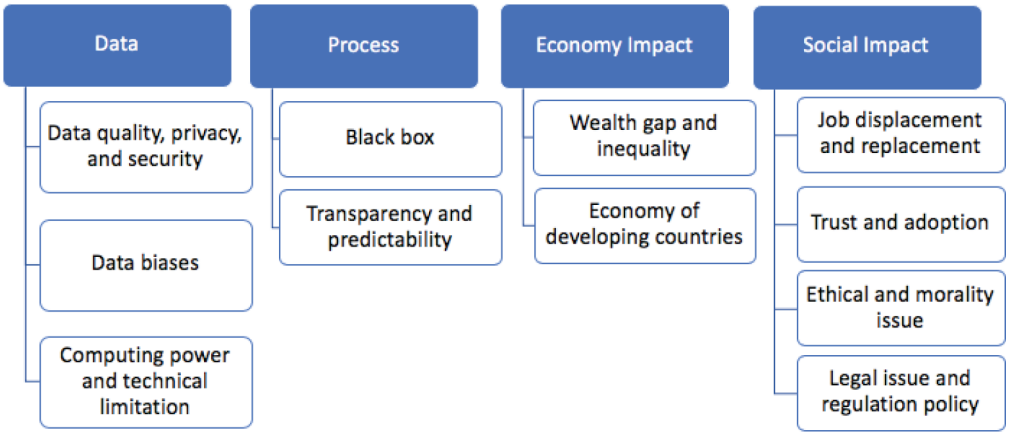
Although AI has great potential as a cutting-edge technology, it poses significant risks for users and society. The risks mainly come from privacy concerns, data security, explicity, and transparency of algorithms, job replacement, trust and adoption, and ethical and governance issues. The concern is that the more advanced the AI is, the more risks it will bring to humanity and society. For instance, AI may make a decision that people cannot control and understand. Besides, AI may create unemployment and widen the inequality of wealth (Siau and Wang, 2018). Many big names in science and technology have recently expressed concerns about the risks posed by AI, partly because many AI milestones, which experts have generally viewed as being decades away, have been reached. Numerous AI researchers believe that human-level AI will happen before 2060 (Tegmark, 2016). Figure 1 depicts the four groups of challenges and issues that face AI.

Data Quality, Privacy, and Security

To power AI technology, such as the deep learning systems, large volumes of quality data are needed. Almost all of the application domains, in which deep learning is successful, have had the ability to access mountains of data (LeCun, 2015), such as the Google Assistant and Apple Siri. Neil Lawrence, a professor at the University of Sheffield and on Amazon's AI team, said that data for AI is like coal for the early years of the industrial revolution; and big tech firms, like Google, Microsoft, and Facebook, are today's coal mines (Vincent, 2016). However, there are many smaller startups that have good ideas but are not able to access to data to support their ideas.

In addition to the quantity and quality of data, data security and privacy are very important (Chen and Zhao, 2012). With more data exposed in society and businesses, there is a higher chance that the data may be misused. For instance, to increase the accuracy of the healthcare system's performance, lots of data, including patients' sensitive information, are needed. Sensitive information is that information, which if publicly disclosed, could harm an individual socially and financially (Bansal and Gefen, 2015). A health record contains sensitive information. If that information is not

Figure 1. Challenges and issues



adequately protected in a computer system, an unreliable individual or institution could gain access to that information and harm a patient, financially or personally.

Further, AI systems can cause serious damage if used maliciously. Cybersecurity is becoming even more critical when adversaries have accessed to and are using AI. Artificial super intelligence is a huge unknown risk. Many prominent scientists (e.g. Stephen Hawking) and technology executives (e.g. Elon Musk) are sounding the alarm. For instance, being asked to eradicate cancer in the world, an AI system may derive a solution that can accomplish the task, which could be killing everyone in the world (Bossmann, 2016).

The phones that we use every day may also pose risks to our privacy. Security experts warn that phones may listen, record, and process everything people say, and use private conversations to target ads or for other things. Many people have shared experiences that, even they never google or email about a specific product, they sometimes receive ads just a few hours after they have mentioned it in a casual conversion with others.

Data Biases and Technical Limitation

As mentioned earlier, one concern is human biases inherent in data (DeMartino et al., 2006). This issue is significant in risk assessment modeling, which can provide a decision as to whether a person should be convicted of a crime or rejected or approved for a loan. It is illegal to consider factors like race and gender in such cases. However, algorithms may be imbued with racial, gender, and other biases. For instance, Northpointe says its COMPAS algorithm does not include race as a variable when making recommendations on sentencing. However, in an investigation by ProPublica, journalists found evidence of racial bias, suggesting that COMPAS was likely biased to some age and racial groups (Snow, 2017). The biased data, fed into an algorithm, can also lead to unintentional discrimination in the delivery of care. For instance, the Framingham Heart Study evaluated cardiovascular event risk using data from predominantly white populations. This led to flawed clinical recommendations for nonwhite populations (Newby, 2018).

Today, AI algorithms are already routinely being used to make vital financial, medical, and legal decisions. If the bias lurking inside AI algorithms is not recognized, then there are likely to be negative consequences. Further, some individuals, who realize that algorithms may pose a risk of bias, are more interested in the bottom line than in rooting out biases (Knight, 2017).

From a technical perspective, the data challenge will be exacerbated by Moore's Law, which constrains the amount of data that AI-based technologies can store and process. It is claimed that the amount of data generated by the Internet of Everything devices for 2018 is almost 50x the estimated traffic in 2015 (Stoica, 2017). By 2025, the magnitude of improvements in the computer throughput requirements for processing the aggregate output of all genome sequences in the world will require that computation resources be at least doubled every year (Stoica, 2017).

"Black Box", Transparency, and Predictability

Although machine learning is creating brilliant tools, it is hard to explain the inner processing of machine learning. The "black box" inside its algorithms makes it mysterious, even to its creators and leads to significant information asymmetries among AI experts, users, and other stakeholders (Snoek et al. 2012). Using neural networks as an example, they are usually inscrutable to observers, and the reason why they reach certain decisions usually remains unexplained and unpredictable. Predictability is "the belief that the software artifact will do what it is claimed to do without adding anything malicious on top of it" (Paravastu et al., 2014, p. 34). AI systems that are predictable are naturally more dependable. Those systems can provide users with expected outcomes. In addition, these outcomes can be understood and interpreted by users. The "black-box" in ML algorithms, however, limits people's ability to understand the technology and outcomes, thereby hindering their trust in the system. To increase the transparency of AI, not only should the algorithm be transparent, but computational questions also need to be answered. For instance, what data are used, how these

data are collected, and at which point do humans become involved in the decision-making process. Currently, the question as to whether a human can control the AI system is a big concern. As AI controls our cars, airplanes, and trading systems, we need to make certain that the AI system always does exactly what we want it to do. For example, Singapore has established principles that underpin the AI framework, so that decisions made by, or with the help of AI, should be explainable, transparent, and fair to consumers (Tan, 2019).

The more intelligent a machine is, the riskier it is that we will lose control of the machine (Spong, 1995). For instance, lethal autonomous weapons are programmed to fight and kill. In the hands of the wrong person, or when the weapons are out of human control, then these weapons may easily cause mass casualties. In order to avoid being thwarted by an enemy, these weapons are designed to be difficult to "turn off", which increases the risk of losing control in a combative situation. Further, as AI advances and becomes a strong AI, it may have goals that are not consistent with human goals. For instance, if a guest asks a self-driving taxi to drive to the airport as fast as possible, the taxi may not follow traffic rules, but reach the airport at the fastest speed. This is not what the customer wants, but that is literally what the customer asked for. More seriously, the strong AI may wreak havoc on our ecosystem and society as a side effect when achieving its goal.

Wealth Gap and Inequality

AI enables companies to drastically cut down on relying on a human workforce. Individuals who have ownership in AI-driven companies will increase in wealth, while the unemployed individuals will lose their source of income. A widening wealth gap has already happened. In 2014, the three largest companies in Detroit and the three largest companies in Silicon Valley generated roughly the same revenues, but Silicon Valley had 10 times fewer employees (Bossmann, 2016).

In other words, if robots and AI do most of the work and keep production high, then goods and services will be plentiful. This leads to new questions: How to distribute those goods and services to people who do not work and make no contribution? Should the robots be taxed? Universal Basic Income (UBI) was proposed to solve this problem. Although it appears to offer a simple and attractive solution, the feasibility of UBI is uncertain. Further, it may give rise to other problems, such as laziness and mental healthcare issues. UBI may discourage people from seeking retraining and reemployment, and domestic taxpayers may also flee (Re-educating Rita, 2019). As Ray Dalio said, it is "far better and it's possible to find ways for making most of these people productive" (Clifford, 2018).

Economy of Developing Countries

One of the direct threats posed by AI systems on the economy is unemployment. Industrial automation makes it harder for emerging economies, such as those in Africa and South America, to achieve economic growth. Many underdeveloped and developing countries offer cheaper labor in manufacturing areas, which enables them to grow and develop. However, factory automation has significantly decreased the need for companies to outsource their productions to countries with cheaper human labor. For the large body of less educated workers, countries may need to build unique, human-centered service industries (Re-educating Rita, 2019), which may be difficult.

Worse, developing countries may need to rely on the AI systems or robots that were created in developed countries. Also, the algorithms and databases that underlie the AI system may not apply to the conditions in developing countries. These countries have to carve out their own niches within the AI landscape (Lee, 2018), which is challenging.

Job Displacement and Replacement

Deloitte, in partnership with Oxford University, suggests that 35% of jobs will be at risk during the next 20 years (Wakefield, 2016). Scholars at Oxford University estimate that "no less than 47% of all-American jobs and 54% of those in Europe are at a high risk of being usurped by machines" (Bregman, 2017). McKinsey claims that as many as 700 million jobs could be gone by 2030. PwC

suggests that 30% of those in the UK could be automated, compared to 38% in the US, 21% in Japan, and 77% in China (Rise of the robots, 2018). Foxconn, for example, which manufactures components for major brands, including Apple, recently replaced around 60,000 Chinese workers with robots. Historian Yuval Noah Harari (2016) wrote in his book that AI will create a 'useless class' of humans, who will be not only unemployed but also unemployable.

Even though AI does many tasks, that only humans could do previously, and has already replaced humans in many jobs, such as insurance assessment, accounting, truck driving, and healthcare assistants, people believe that new jobs or human-robot cooperative opportunities will be created. At least, jobs for humans will not simply disappear.

Jobs that are of a high risk of being replaced by AI are those that are routine, repetitive, and predictable. For instance, some toll booth operators have already been replaced by automated systems such as E-ZPass, cashiers have been replaced by Kiosks in McDonald's and Wendy's, and Amazon Go does not even have a checkout line or cash register. Other AI-based technologies, such as self-driving cars and IBM Watson, are still some way off, although they have been proved to be able to automatize jobs such as truck drivers and diagnosticians (Sherman, 2015).

Researchers noted that wages and educational attainments have exhibited a negative relationship with the probability of computerization (AI-based automation). Much manufacturing work, that requires moderate training and that once employed vast numbers of workers without college degrees, has disappeared, by either being shipped abroad or offloaded to robots and computers (TE, 2019). Jobs that require creative intelligence, social intelligence, strategy, and empathy are jobs with the lowest probability of computerization (Frey and Osborne, 2017). However, because AI is advancing rapidly and the job landscape is continuously changing, humans will need to figure out how to find meaning in non-labor activities and learn new ways to contribute to society.

Trust and Adoption

Trust is crucial in interpersonal relationships, human-technology interactions, and other relationships (Siau et al., 2004). It plays an important role in the adoption of new technology (Siau and Shen, 2003). Although AI's speed and capacity of processing are far beyond that of humans, it is not always competent, fair, neutral, and controllable. The risks of AI, such as AI biases and fatal self-driving car accidents, have created concerns about whether to trust AI, and to what extent. The black box in AI and machine learning algorithms have also influenced their credibility, because it is harder for people to trust what they do not understand and cannot control. Another concern that hinders people's ability to trust AI is "singularity." Once AI surpasses human intelligence, we will not be the most intelligent beings on earth anymore!

Ethical and Morality Issues

Although the concept of "machine ethics" has been proposed since 2006 (Anderson and Anderson, 2006), consideration of AI ethics is still in the infancy stage. Many researchers believe that AI is a long way from having consciousness and being comparable to humans and, consequently, there is no rush to consider the ethical issue. But AI, combined with other smart technology such as robotics, has already shown its potential in business, healthcare, and society. For instance, health robots now can diagnosis diseases and help in surgery. Who should take responsibility for a failed surgery in which a human doctor and a health robot worked together?

Currently, AI mainly refers to a weak AI, where its performance is primarily involved with training data and programming algorithms. Human experts, such as data owners and programmers, play an important role in training AI, and human users are crucial in manipulating AI-based applications. Two aspects that may cause an ethical issue for AI are AI features (Timmermans et al. 2010) and human factors (Larson, 2017). From the perspective of AI's features, it is possible for AI to get access to personal information without a host's knowledge. This is supported by research which has shown that AI can "generate audio that sounds like speech to machine learning algorithms but not

to humans" (Carlini and Wagner, 2017). In addition, machine learning and deep learning are not always transparent upon inspection. The black-box in AI algorithms hinders human interpretation and expectations and may result in the evolution of AI that is without guidance or control (Wang and Siau, 2018). Worse, this may give rise to the risks of malicious utilization. From the perspective of human factors, the most significant is human bias. A weak AI, as discussed previously, relies mostly on training data. The existing biases in training data may be learned by the AI system and displayed in real applications. The second aspect is accountability, which leads to "the problem of many hands" (Timmermans et al., 2010). Who should be responsible for an undesirable consequence when using an AI system--the programmer, the data owner, the end user, or the AI per se? Besides the above two aspects, how to treat an AI system that has emotions and feelings is another consideration. For instance, would it be ethical to deploy robots into a dangerous environment?

Legal Issues and Regulation Policy

Many countries are actively creating legal conditions for the development of AI. In late March 2018, France presented new national artificial intelligence strategy, involving 1.5 billion Euros over the next 5 years, to support research in the AI field (Karliuk, 2018). The strategy aimed at four specific sectors: healthcare, transport, environment and environmental protection, and security. In the European Union, Civil Law Rules on Robotics marked the first step towards the regulation of AI. The resolution was not a binding document, but a number of recommendations were made to the European Commission on possible actions in the area of artificial intelligence, not only with regard to civil law, but also related to the ethical aspects of robotics (Karliuk, 2018). The UK's House of Lords also recommended the development of an ethical code of conduct for AI. The UK's upper chamber of parliament suggested that there be assurance that AI would be used in the public interests and that it would not be used to exploit or manipulate them (Teffer, 2018). Europe pins hope on AI ethics in the global AI race. However, although it is agreed that AI-specific laws should be adopted quickly, not many people know what those laws should look like.

RESEARCH AGENDA

Based on the above discussion, this paper proposes a research agenda with four streams, as shown in Table 1.

Computing Power and Technical Challenges

Before AI's potential can be achieved, many hurdles must be overcome. Computing power is a fundamental one (Franklin et al., 1997; Markoff, 2016). Machine learning requires a huge number of calculations, which should be completed very quickly. The concept, idea, and theory of AI have existed for more than 60 years, but the huge breakthroughs have only begun in the last few years. Many people have had good ideas, but there was not enough computing power to implement them. In the short term, cloud computing and massively-parallel processing systems can provide support but, as data volumes continue to grow and algorithms become more complex, a new generation of computing infrastructure is essential. Quantum computing is one such effort, and intensive research in this area is crucial.

The real world is changing rapidly. An AI system must be able to handle the fast-changing environment and be applicable to a different context quickly and safely, even when the environment or situation has never been encountered before. Continuous learning is important (Stoica, 2017).

Actually, AI is not one technology, but a set of technologies. To benefit the most from AI, many related technologies need to be advanced rapidly as well. Research concerned with the Internet of things, reinforcement learning, natural language processing, text analytics, and generative models are all crucial.

Table 1. Research agenda

Technique
• Computing power and technical challenges • Superintelligence • Emotional intelligence and personalized AI
Governance
• AI biases • AI governance and policy • Ethical issues and moral standards
Economy
• Economics model with AI
Human-Technology symbiosis
• Trust in AI • Adoption of AI • Human augmentation • Human-Machine/Robot interaction • Education and re-training

Superintelligence

Many well-known scientists and technology executives have expressed their concerns about AI, especially strong AI. Bill Gates called AI "a huge challenge" and something to "worry about". Stephen Hawking has warned about AI ending humanity. Elon Musk has likened AI to "summoning up the demon". Their references to AI refer to superintelligence, the intellect that can exceed the cognitive performance of humans, has consciousness, and can redesign itself at an ever-increasing rate. The biggest risks of superintelligence are its competence in enabling itself to accomplish its goals, and causing trouble when the goal is not aligned with human goals (Soares and Fallenstein, 2014). Some experts, however, are optimistic, believing that humans will always be the authors of whatever happens. Although the future is uncertain, we need to be certain about what kind of future we can expect. We believe that superintelligence should be just below human intelligence, playing the role of assistant and helper rather than the superintendent. How to create superintelligence that won't harm humans? What are the technical standards and ethical standards for superintelligence? We should have a blueprint before we start making it.

Another big concern is about the existential threat of AI to humanity. People believe that AI could someday result in human extinction, or some other unrecoverable global catastrophe (Bostrom, 2014). This is an under-researched area. Although many researchers and experts believe that superintelligence may be achieved "within a generation" (Hornigold, 2018), the research on safety issues is still in the infancy stage and lags behind.

Emotional Intelligence and Personalized AI

In the long run, an AI system which makes a user-specific decision that takes into account user behavior and preferences will be increasingly the focus. For instance, a virtual assistant learns the accent of its owner, the user, and the face-recognition software is already smart enough to analyze the smallest details of human facial expressions. Further, natural language processing algorithms help to figure out the human sentimental and emotional state from the audio (Alassarela, 2017). Big data and advanced algorithms enable AI to understand us better than we know ourselves. Personalized AI is easier for establishing an emotional connection with a human, and affecting a users' economic and psychological well-being. This area is developing rapidly and has huge potential.

AI Biases

AI systems are only as good as the data we put into them. As reinforcement learning and deep learning are more widely used, the AI system will continue to be trained to use the data. Once biased data are used, however, bias will become an ongoing problem (Verghese et al., 2018). Biases find their way into AI systems that are used to make decisions by many, from governments to businesses to academies. How can bias be eliminated from the data? How can algorithms be written that can eliminate bias? How can biased data be distinguished from good data? All of these questions remain to be answered.

AI Governance and Policy

Given that the threats of AI are indisputably real, governance and regulation are inevitable and necessary. In the last 1-2 years, academics, technology companies, and governments have begun to concentrate on setting standards and guidelines for AI. Transparency, responsibility, human control, biases, and ethics have received the most attention (Wang and Siau, 2018b), and should certainly be considered when setting up a legal framework and policies related to AI. Google, partnered with Microsoft, IBM, Apple, Facebook, and Amazon, has set up a partnership to provide a "trusted and expert point of contact" on the ethical and governance issues. Governments are beginning to respond too. For instance, Germany is drafting a set of ethical guidelines for driverless cars. Good governance would help build trust in AI and benefit economy and society to a maximum extent.

Ethical Issues and Moral Standards

As AI and robotics continue to advance, they will inevitably affect human lives. Human-machine interactions and human-robot interactions will grow significantly. As Torrance (2011) mentioned, an ethical agent can be classified in two categories: ethical productivity and ethical receptivity. In a human-robot interaction, an AI-based robot could either be an ethical producer (such as robots that assist in a surgery) or be ethical recipients (such as military robots that are commanded to dispose of a bomb). To study the ethical issues related to AI, from these two different perspectives, is essential.

Human ethics today are not perfect. On one hand, a human cannot solve all the recognized ethical issues. On the other hand, a human cannot recognize all the ethical issues. As early as 2007, Anderson and Anderson indicated that "The ultimate goal of machine ethics is to create a machine that itself follows an ideal ethical principle or set of principles" (p. 15). Without comprehensive and unbiased ethical standards, how can humans train a machine to be ethical? Further, how can we make sure that intelligent machines understand ethical standards in the same way that we do? To answer these two questions, additional research is needed. First, one should learn about current ethical standards and the proper ethical standards that are needed to train intelligent machines. Second, one should learn how to reduce information asymmetries between AI programmers and ethical standards makers.

While attempting to formulate ethical standards for AI and intelligent machines, researchers should try to understand existing ethical principles better. Thus, they will be able to contribute to the application of ethical principles to academic activities and help train programmers build an ethical AI, as well as build the AI ethically (Wang and Siau, 2018).

Economics Model With AI

PwC estimates that AI could add $15.7trn to the global economy by 2030. How will AI impact economic growth? How will AI help save costs? What changes will AI bring to the global economy? Bill Gates said recently that the law of supply and demand is over. Traditionally, the Gross Domestic Product, used as a benchmark for an economy's well-being, does not calculate investment in intangible elements, such as research and development (Konchitchki and Patatoukas, 2014). But today, as technical companies and technical products occupy a large market share, this economic model should change. On one hand, the cost of software-based products does not increase as quantities increase, which is the foundation of the law of supply and demand. On the other hand, the tools used

by companies to measure intangible assets are behind the times. To get a complete picture of our economy, a new economic model should be created.

Further, the Internet of things makes the world smaller. Economic activities have merged globally rather than being limited to a company or a country. It is important to always keep an eye on global economic trends. The large increase in income inequality, caused by AI, is another big concern (Jenkins 2017). Wealth will be gathered by those who control AI and robots. Meanwhile, human workers will be replaced by those technologies because their labor costs are much higher than the costs for robot workers. Bill Gates once said that robots that take human jobs should pay taxes. But researchers believe that taxing robots is only a short-term solution (Gasteiger and Prettner, 2017). Retraining people for a new job environment is one solution. Another suggestion is the Universal Basic Income (UBI) (Sage and Diamond, 2017). Is the UBI a good idea? Research needs to be done before answering this question.

Trust in AI

Considering the potential risks that exist when trust in AI is hindered, the question of how to build such trust must be seriously considered. Many studies concerning trust have been conducted (Siau and Shen, 2003, Siau and Wang, 2018). To study trust in AI, the focus should be to identify the difference between AI and other things, such as a human, an organization, e-commerce, and machines. A trust-building model is necessary for appropriate development of that trust. Case studies and behavioral studies can be employed more in research about trust building.

Adoption of AI

As AI becomes smarter and more useful, to what extent should humans adopt it? From an individual perspective, AI can benefit humanity, especially with doing routine or dangerous tasks. Although people would be happy to adopt a robotic vacuum cleaner, the McDonald's Kiosk, and Amazon Alexa but, to what extent people would like to adopt autonomous weapons or robot doctors? From an industry perspective, a survey showed that AI adoption in 2017 remained relatively low with ta majority of the major success stories coming from the largest tech players in the industry (e.g., Google, Baidu, Apple) (Rayo, 2018). The most significant reasons include the experimental status of AI application, its lack of use, and insufficient financial commitment. To increase the adoption of AI, research should focus on building an adoption model of AI.

A Technology Acceptance Model (TAM) can provide some useful insights. TAM is a preeminent theory of technology acceptance in Information System research (Gefen et al., 2003). TAM indicates that acceptance of a new information technology is determined by its perceived usefulness (PU) and the perceived ease of use (PEOU) (Holden and Karsh 2010). PU and PEOU should also be considered as contributors to trust building (Pavlou and Gefen, 2004; Harris and Goode, 2004; Vance et al., 2008).

Human Augmentation

As AI-based robotics develop further, the future human can be stronger, faster, and less prone to injury. Human capacities may be extended beyond innate physiological levels. For instance, robotics has already advanced wearable supernumerary limbs and enabled additional limbs to extend physical abilities beyond traditional limits (Parietti and Asada, 2016). This area has been a great benefit for disabled individuals.

Human-Machine/Robot Interaction

With the development of Natural Language Processing, the Internet of Things, eye-tracking, and neurotechnology, the interactions between humans and machines exist everywhere. As robotics advances, it becomes more and more important to develop a robot that is not solely functional, but also mindful of its users (Sheridan, 2016). One study found that top doctors made erroneous decisions in 3.5% of cases, while state-of-the-art AI had an error rate of 7.5%; when the two are combined, the

error rate can drop to 0.5%. In addition to the technologies that support human-machine interaction, the way and method in which humans interact with machines should also be studied. The motivation behind interaction (Robert, 2018), privacy concerns of human workers, and the trust between humans and robots are important research topics.

Education and Re-Training

Jobs that require fewer skills and contain routine tasks are easier to automate. Ownet, a consultancy company, has developed an AI tool that can scan 10,000 contracts in 50 seconds, which would cost a human 3,300 hours. Deloitte believes that 39% of legal roles could be automated within a decade, and another study indicates that 95% of accountants could lose their jobs. From construction workers to journalists, AI has shown the potential to do some parts of their jobs. PWC says that individuals with only a few educational qualifications are more vulnerable than PhD-touting scientists (Rise of the robots, 2018). From this perspective, education and re-training would make a significant contribution.

Although traditional job positions may disappear, and their required skills be useless in the future, new job categories could be created and some skills, such as programming and human-machine interaction, would become very important. According to the Royal Society, 58,000 data science jobs are being created every year in the UK alone, and it is hard to find qualified people to fill them. It is reported that 70 percent of the fastest-growing skills are new to the index and 65 percent of children will end up in jobs that do not exist yet (Kasriel, 2018).

What kind of education should be provided? What type of course structure would be proper for a future career plan? What retraining should be provided so that human workers remain competent to compete in the job market? John Hawksworth, the PWC's chief economist, said "If, back in the 1980s, when I was leaving university, someone had told me they were going to be a web designer, I wouldn't have known what on Earth they were talking about because that job didn't exist" (Rise of the robots, 2018, p. 16). In this case, we can expect that entirely new skills will be emerging in the future, bringing challenges to transform education. Besides, jobs requiring the human touches, such as nurses, artists, and social workers, seem less likely to be replaced by AI. In addition to teaching knowledge and professional skills, education and re-training should pay more attention to the training of social skills, creativity, and human skills. In other words, the benefits of automation and robotics should be used to help fund continuous education and retraining.

CONCLUSION

Distilling a generally-accepted definition of what qualifies as artificial intelligence (AI) has been attempted for many decades. One reason why a definition is hard to get is that AI is not a single technology, but a consolidation of many disciplines. From machine learning to robotics, to natural language processing and the Internet of Things, AI plays an important role in the modern technology world and has merged into our daily life. Consequently, many problems should be considered in conducting research on AI. The research agenda proposed in this paper lists some potential directions for future study. Although the technical aspects of AI, such as reinforcement learning and generative models, deserve much attention, the research agenda also focuses on the impact of AI and on topics that are closely related to human work, society, and humanity. The future of work and the future of humanity are at least as important, if not more important, than the technical aspects of AI.

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