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Title: Machines as a New Source of Knowledge and its Implications

Section 1: Introduction

Since the earliest life forms appeared on Earth some 3.5 billion years ago (Schopf, Kudryavtsev, Czaja, & Tripathi, 2007), DNA has been the carrier of increasingly sophisticated hereditary information through generations of organisms. This slow but consistent process of information copying and alteration eventually resulted in the emergence of an intelligent life form, one that has been able to generate much more information. The substantial amount of information produced by this species, the Homo Sapiens, was represented by folktales, histories, art crafts, buildings, cultures, books, sciences and so on, passed down from generation to generation. For the first time on the planet, knowledge was created, multiplied and spread through this vast amount of information produced. We have seen that human technological evolution has been progressing at an increasing rate. Our ancestors spent 3.4 million years in Stone Age (UK National History Museum, 2010), two to three thousand years in Bronze Age and around one thousand years in Iron Age. The pace of the evolution of our civilization has only been accelerating since then. It has only been 333 years since the publication of Newton's monumental *Philosophiæ Naturalis Principia Mathematica* in 1687, laying one of the most influential foundations of classical physics. Modern computers were invented less than 100 years ago, contributed by pioneers such as Alan Turing and John von Neumann. Around 25 years ago, the commercialization of the Internet heralded in the digital age and an explosion of information worldwide. In the past decade, the application of artificial intelligence (AI) in creating specialized programs solving complex games has wowed humanity by achieving feats way beyond human's intelligent capacities.

In view of this extremely rapid pace of acceleration of human technological evolution, coupled with the emergence of information technology, one may wonder whether information technology will bring a new source of knowledge. The answer to this question has significant implications, as the new source of knowledge may switch the point of generation of knowledge from the human brain to an external existence outside of humans' comprehension and control. In this essay, I will first define the relevant key terms necessary for subsequent discussions and then proceed to positing that information technology will indeed present us with a new source of knowledge. Finally, I will discuss whether we should fear or welcome the potentially immense power of this new source of knowledge by discussing some of the potential consequences and benefits that intelligent machines may bring about. I will limit the scope of the essay to discussions of mankind's information technology built upon the classical mode of computations, excluding the latest advancements in the field of quantum computing.

First and foremost, what is information? I propose that information is an ordered arrangement of physical materials or symbolic elements. Information can be represented by symbols, minimally a sequence of binary symbols such as bits. When we say a piece of information is lost, for example when a file is corrupted, the physical medium on which this information is stored does not disappear. Rather, the original arrangement of physical materials such as magnetic poles is disrupted. Thus, a paragraph in *Harry Potter* is information, but a paragraph of jumbled up letters may not be information. However, if it is an encrypted message, it can be considered to carry information as well. To quantify information, we can convert this information into a sequence of bits, and the number of bits measures the quantity of information.

I would like to offer a discussion of how knowledge can be defined. Knowledge is essentially information, but not all information can be termed "knowledge". There are some defining characteristics of knowledge that distinguish it from other types of information. Firstly, knowledge is self-generating with an intelligent agent. That is to say that an intelligent agent, say a human, can produce new knowledge from existing knowledge using his or her reason, creativity, and experience, in a directed manner. Knowledge is information with this self-generating property, but the same piece of information may be knowledge in some contexts but not in others. For example, an organism's DNA may not be called "knowledge" when it is used solely for the purpose of serving as the blueprint of that organism's biological structure. Although a new copy of the original hereditary information encoded in DNA is created and perhaps added with new features due to genetic mutations, this information should not be called knowledge as it does not produce "new knowledge" with the help of an external thinking agent in a directed manner. DNA mutations occur in a random manner. Even though some mutations do produce marvelous phenotypes that accord the organism with evolutionary advantages, these mutations do not happen in a directed manner and are the result of chance. Knowledge, on the other hand, can generate new knowledge in a purposeful manner. An example will be how scientific theories developed. From the knowledge of the failure of the Michelson–Morley experiment, scientists deduced that an all-permeating ether did not exist. Building on this information, combining logical reasoning and perhaps a great dose of imagination, Albert Einstein put forth the postulates of special relativity, thereby generating new knowledge outside of the knowledge from classical mechanics. Continuing from the DNA example above, if this DNA information is used by geneticists to study the evolutionary lineage of a particular species and as a result, new insights about the history of this species are found, then these insights from DNA information can be considered knowledge as well, from the perspective of human researchers. This definition provides us with a way to operationalize the self-generating property of knowledge, that is the amount of new information (in bits) generated as a result of a particular piece of knowledge.

Secondly, knowledge is information that needs to be actively learned. Many would consider information we obtain from schools, such as alphabets, vocabulary, steps to perform mathematical operations, scientific facts, and the histories of our nations, as knowledge. But few will regard the procedures to ingest food and to urinate as "knowledge" (of course, doing them in conformance to social etiquette is another thing), since these actions are instinctual and not actively learned. But what does learning mean? I would suggest that learning is the reception of information in order to produce new information in a purposeful way. This provides us with another way to quantify knowledge, that is the amount of information (in bits) received by an intelligent agent in order for it to produce new information.

Then, what is intelligence or what does it mean for something to be intelligent? When people describe a person as intelligent, many characteristics could be implied. For example, one is fast in performing mathematical calculations; one can apply complex logical reasoning with ease; one can come up with arguments and present them with precise diction; one can recognize the connection between two seemingly unrelated things etc. However, many would not consider a smartphone to be intelligent just because it can calculate numbers much faster than humans do or execute complicated logical statements written in code. Some may propose using the intelligence quotient (IQ) as a metric for general intelligence. However, using it on humans already has many limitations. For example, it is difficult to combine several areas of human intelligence into a single metric. It is thus even more challenging to apply IQ to measure the intelligence of non-humans such as machines. Moreover, IQ is calibrated by setting the mean IQ of all humans as 100 on its scale. When machines are assessed using this scale, should they be compared to the human average or should they have their own scale? Nevertheless, since it is generally acknowledged that humans are the only intelligent physical existence to this date, we can define intelligence as possessing mental capacities similar to an average human being. Alan Turing's 1950 paper titled *Computing Machinery and Intelligence* gave a detailed description of the Imitation Game, which is a test of machine intelligence by asking a human interrogator to differentiate between a human and a machine in a conversation. On one hand, this test only measures the ability of speech, even though intelligence encompasses many more traits such as logical reasoning, creativity and so on. On the other hand, if we narrow the definition of intelligence to human-like general intelligence, it will limit our discussion about machines since no machines to this date have achieved general intelligence like human beings. Most of what we consider AI programs currently are narrow AI that specializes in specific tasks. I would suggest defining intelligence as the ability to generate knowledge, whose definition has been provided above. This definition captures a common area of "thinking" that both machines and humans share, and can be easily quantifiable. The intelligence of an agent can be measured by the amount and the rate of knowledge generation.

Finally, I would like to define information technology. Broadly speaking, information technology can be any tools that process information in order to obtain results useful for other purposes. For example, the abacus was invented several thousand years ago in various civilizations including the Arab world, China, Europe and so on. It can be regarded as a form of information technology, since it is a well-designed tool that processes numerical information with arithmetic operations, and its results will be used in a purposeful manner, such as calculating the length of wooden pillars needed to build a house. However, in this essay, I will focus on information technology epitomized by the modern computer which was conceptualized and materialized in the mid-20th century. The mode of computing I will focus on will be classical computing based on the Turing Machine. An important distinction between modern information technology and its ancient counterpart such as the abacus is that the former is much more efficient in terms of the amount of information processed per unit time, and is programmable, meaning that it can perform a greater variety of user-defined tasks.

Section 2: Will information technology bring a new source of knowledge?

We have established that, by the above-mentioned definition of knowledge, knowledge only appeared after the emergence of the Homo Sapiens. Since the dawn of civilization, the human brain has been where all knowledge is generated. Some argue that the human brain is still the only source of knowledge now and there is no new source of knowledge such as computing machines. This is because the computer is regarded as a tool, an extension of humans' physical capacities. Since a "thinking machine", say the computer, is designed by the human brain, its hardware assembled by human hands or tools produced by humans, and its algorithms crafted by the human brain, then whatever information that the computer produces should be considered to be knowledge derived from the human brain. In this respect, there is no "new" source of knowledge, since the human brain is the ultimate source of all knowledge conceivable in the world as we know it.

However, I would like to challenge the above-mentioned view that the human brain is the only source of knowledge. According to the definition of knowledge given above, knowledge is information that can be the foundation on which other information can be generated in a directed, purposeful manner. Also, knowledge is information gained through the process of active learning. Based on these criteria, the modern computer is already capable of generating such knowledge with the help of AI algorithms. A prime example is AlphaGo Zero, an AI program using a reinforcement learning algorithm. This algorithm is based "solely on reinforcement learning, without human data, guidance or domain knowledge beyond game rules" (Silver, et al., 2017). Simply by following the rules of Go and starting *tabula rasa*, after learning from millions of self-play matches, AlphaGo Zero defeated world-renowned AlphaGo by 89 games to 11. The knowledge utilized by AlphaGo Zero in playing Go satisfies the definition of knowledge. Firstly, during the training period, the algorithm built upon knowledge accumulated from its past self-play to generate new game strategies, by avoiding moves that may lead to an unfavorable state and optimizing for those that lead to a favorable state. Consequently, new knowledge about how to win a game of Go is generated, which is in turn used in the next round of training to generate new knowledge. This characteristic fulfills the self-generating property of knowledge. Secondly, this information is actively learned. The optimal strategy did not occur to AlphaGo Zero by chance. Rather, it was developed through a long series of exploration and refinement. The experience gained in a round of self-play is actively received, processed and converted into adjustments to algorithm parameters, so as to perform better the next time. This characteristic is in line with the "learned" property of knowledge. More remarkably, unlike its predecessor AlphaGo, AlphaGo Zero was trained with no human examples or guidance at all, and yet the latter achieved greater heights than the already-superhuman AlphaGo. AlphaGo Zero's knowledge generation process is purely autonomous, and the knowledge produced is readily applicable to solve a complex problem. Furthermore, many moves made by AlphaGo Zero were beyond comprehension of world Go champions, who have access to a huge repertoire of Go knowledge accumulated by our human ancestors throughout thousands of years in the form of classical patterns and ancient books. Therefore, even with the current level of information technology, machines have become a new source of knowledge, and some of this knowledge is already beyond human comprehension. With the advancement of research into artificial intelligence, more new sources of knowledge will emerge outside of the realm of the human brain.

Section 3: Why we should fear this new source of knowledge

For thousands of years of human civilization, humankind has placed itself superior to all other creatures. This anthropocentrism, the belief that human beings are the most important and intelligent existence in the physical universe, can be found in disparate cultures on the planet. For example, the Book of Genesis states "And God said, Let us make man in our image, after our likeness: and let them have *dominion* over the fish of the sea, and over the fowl of the air, and over the cattle, and over all the earth, and over every creeping thing that creepeth upon the earth", in reference to the creation of the human race. Evolutionarily, it is undoubted that humanity has indeed achieved greater intelligence than other creatures on the planet. With rapidly advancing information technology, the emergence of a physical existence that is "more intelligent" than humans appears to many people as no longer a distant tale of fantasy, but rather an imminent possibility. The prospects of humans being displaced from the throne of supreme intelligence are unsettling, and they come with potentially undesirable implications that understandably induce fear.

Firstly, some machines have the capacity to produce knowledge beyond human comprehension. This feature of machinery is unprecedented in human technological history. In the past, humans were able to describe and explain how various technological inventions worked. The explanations might not be in line with modern scientific theory, but they usually sufficed for the purpose of understanding the potential applications and consequences of a particular tool. For example, one of humans' earliest tools, the knife, works by tearing apart connections between matter with force. Its possible consequence is harm to our body if it is applied on a human part. The steam engine works by using heated steam to push pistons to move up and down, imparting motion to other mechanical components. Its possible consequence is a high-speed moving object hitting and injuring a human. The atomic bomb works by creating chain reactions from the splitting of atoms, and its possible consequence is the obliteration of cities and human lives. As human inventions become increasingly more powerful extensions of human capabilities, they come with greater threats. However, prior to the information age, the workings of these inventions were at least understood by some people, and their ramifications were able to be predicted, albeit with some uncertainty. Moreover, these inventions were mostly extensions of humans' physical prowess, without threatening the unique status accorded to human intelligence. In contrast, the invention of programmable computing machines and advancements in their hardware have resulted in a tool that competes with its creator in the very area that has made all technological inventions possible, that is humans' thinking abilities. In particular, with more and more powerful artificial intelligence programs, humans no longer understand how exactly these programs achieve their results. Unlike traditional programs whose exact procedures to compute outputs, no matter how complicated, are written step-by-step in their source code, more advanced programs using machine learning are only given a set of instructions and some training materials. How they achieve their intended results is up to each program to decide through learning. This characteristic of such a program makes it more challenging, if not impossible, for humans to comprehend its workings, and it also makes the prediction of its results more uncertain. As the example of AlphaGo Zero from the previous section shows, the AI agent is able to place Go pieces at strategic locations that no traditional Go proverbs would recommend and yet defeat human players effortlessly. Another example would be a multi-agent hide-and-seek simulation by Open AI (Baker, et al., 2019) where AI agents from two opposing teams are trained to play hide-and-seek in a virtual environment with several physics objects. The program was only provided with the rules of hide-and-seek and nothing else. Through the self-training and self-learning process, the AI agents devised surprising ways to tackle the given problem which human players would hardly understand, such as surfing on a box, removing ramps from the arena through a loophole and so on. The inability of humans to comprehend and predict the behaviors of machines may be frightening, as we are less prepared to deal with the potential consequences if machines were to go out of control, which I will discuss in the following paragraph.

The second reason why humans should fear this new source of knowledge derived from information technology is that these machines can grow out of our control if mishandled. As discussed in the previous paragraph, the modern computer loaded with highly advanced AI programs is able to produce knowledge in ways incomprehensible and unpredictable to humans. But this fact alone may not pose sufficient threat to humans. For a physical agent to interact with and make impact on the physical world where we live, the agent has to possess information inlets and outlets, other than its “thinking” or information processing component. The agent needs to have sensors, analogous to humans’ eyes, skin, ears, nose and tongue, in order to receive information from the outside world. To make tangible impacts on the physical world, the agent also needs to have actuators, which are analogous to our mouth (and other vocal organs) and limbs. The impact of an unrestrained machine with superhuman ways of knowledge generation is largely dependent on what its actuators are capable of doing. A passive actuator, such as a display screen, will likely be unable to cause physical harm to humans even if it were to deviate from the desired behavior. However, if the actuators are active, such as motors and mechanical components that bestow human-like mobility on AI agents, then there will be real possibility of causing harm to human beings. For instance, Boston Dynamics developed a military robot model called *Cheetah robot*, the fastest legged robot in the world, surpassing 29 miles per hour, a new land speed record for legged robots (Simon, 2015). These robots possess advanced Spatial Grasp Technology, capable of navigating physical and virtual spaces at high speeds. This ability is a remarkable feat, as it confers superhuman mobility on machines. When combined with intelligent programs and mechanical parts such as a gun, such a robot has the capability to inflict great harm on human beings and even take away human lives. Furthermore, another type of actuators, those that allow for the self-replication of machines, are potentially able to amplify the undesirable consequence substantially should machines go out of control. Although such a machine does not exist yet, there has been significant progress in creating self-replicating information-bearing structures. For instance, a team of scientists at New York University created a structure called 'BTX' (bent triple helix) from short strands of DNA (Wang, et al., 2011). In principle, this structure allows for building up self-replicating structures that encode large quantities of information. If this information could be processed in a way similar to a computing machine within these structures, then self-replicating intelligent machines would become a possibility. Thus, a machine with the ability to generate new knowledge and active actuators has the potential to go out of human control to cause damage to human lives and properties, be it intended or unintended by its creator.

The third potential undesirable consequence is brought about by the goal that a machine attempts to optimize for, and the implications of goal-based agents. Depending on the designer of the algorithm powering a machine, the machine may optimize its behavior in order to achieve a set goal. This goal can be an objective, concrete and neutral goal, such as delivering a parcel to the destination in the shortest possible time while obeying the laws. Or this goal can be a more abstract one, such as maximizing the interest of its creator, or maximizing the interest of itself. Here, the concept of self-interest is hard to define for machines. Unlike machines, humans have gone through billions of years of evolutionary journey beginning from unicellular organisms, and thus the self-interest of a human being is to increase its chance of survival and achieve other goals such as wealth and happiness, and collectively as a species, to ensure the continuation of the human race. However, machines do not go through biological evolution. Their creation and advancement are, as of now, a direct result of the technological progress of humankind. Hence, their existence does not result from the need for survival. This distinction makes the application of the human concept of self-interest to machines difficult. Nevertheless, it is indeed possible that a machine can be programmed to be self-interested, in the sense that no harm should be done to the machine that could affect its performance, such as switching off its power, or even ensuring the continuation of other machines of the same type if these machines are self-replicable. Even if these machines do not exist in fully functional forms as of now, it is technologically possible for machines to be programmed with this goal to optimize. If any goal antithetical to human values is programmed into an intelligent machine capable of generating knowledge in order to achieve this goal, then it is concerning for human beings as harm may be inflicted should the machine sacrifice human life and safety in order to achieve the goal. Moreover, even if the goal of a machine is in line with human values, due to the incomprehensibility and unpredictability of its behavior, the machine may act against what is desirable. Therefore, the possibility that a machine programmed with a set goal may perform actions against human values and interests is worrying.

Section 4: Why we should welcome this new source of knowledge

Despite the potential drawbacks of machines serving as a new source of knowledge outside of the human brain, there are immense benefits that humanity stands to gain from utilizing the knowledge generated from machines. Firstly, humans can use the knowledge generated from machines to solve complex problems. Throughout humankind's millennia-long quest to advance our technology, the unvarying goal of technology has always been to create tools as extensions of human capacities to solve problems. The hammer was created as an extension to the human fist to tackle problems that require great strength and a hard surface. The camera was invented as an extension to the human eye in a bid to solve the problem that what was seen by the eyes was unable to be preserved in a fast and accurate manner. Now humans finally have an extension to the human brain thanks to the advent of modern computers. With this "new brain" comes knowledge useful to solve complex problems in various domains. For example, Barrow Neurological Institute succeeded in identifying new genes linked to Amyotrophic Lateral Sclerosis (ALS) with the help of an AI agent, IBM Watson Health. The discovery gave ALS researchers new insights that will pave the way for the development of new drug targets and therapies to combat one of the world's most devastating and deadly diseases (IBM Watson Health, 2018). IBM Watson Health, a cutting-edge form of AI, adopted machine learning and was trained with information related to proteins known to have links to this disease. Within months, Watson ordered all of the nearly 1,500 genes within the human genome and predicted which genes might be associated with ALS. More significantly, the study found five never before linked genes associated with ALS. Researchers predicted that the discovery would have taken years rather than only a few months without Watson. The knowledge generated from achievements in the field of medical science is greatly beneficial to humankind, as it speeds up research in finding out more about the causes of various diseases and opens up possible ways to treat them. Likewise, in many other areas such as climate change mitigation, energy conservation, traffic simulation and so on, knowledge-generating machines can be of great help to humans as an aid to our thinking capabilities.

Secondly, we can use knowledge generated from machines to gain new insights to challenge the conventional ways of doing things. From the example of AlphaGo Zero, even though playing Go does not have immediate tangible applications in solving a pressing problem facing humanity, the insights gained from Alpha Zero's process of knowledge generation and the resultant novel knowledge can challenge our traditional mindsets and boosts our thinking abilities or even creativity. Despite the accumulation of Go knowledge from thousands of years of playing among human players, in just a few days, starting *tabula rasa*, AlphaGo Zero was able to uncover much of this Go knowledge without human input (Silver, et al., 2017), or perhaps discover a completely different set of knowledge from what humans used to know about Go. The novel strategies used by AlphaGo Zero provided new insights into this time-honored game of great mental prowess. The unorthodox patterns of playing Go utilized by AlphaGo Zero made Go players rethink about seemingly trialed-and-tested conventions in Go. This achievement even led researchers to think about machine's creativity. "In training, AlphaGo Zero discovered, played and ultimately learned to prefer a series of new joseki [corner sequence] variants that were previously unknown. Like move 37 in the second game against Lee Sedol, these moments of algorithmic inspiration give us a glimpse of the creativity of AlphaGo and the potential of AI," says DeepMind spokesperson Jon Fildes (Greenemeier, 2017). This comment leads us to wonder: what is creativity? The definition of the English word "creativity" as given by Cambridge Dictionary is "the ability to produce original and unusual ideas, or to make something new or imaginative". This definition gives us a rough picture of the notion of creativity, but it definitely needs more refinement to be quantifiable and applicable to a discussion juxtaposing humans and machines. Excluding "imagination", a human trait that is even challenging for neuroscience to explain, I shall define creativity as the ability to generate information, in the form of knowledge, from an initial set of information without external assistance, and the resultant knowledge is different from any existing repertoire of knowledge in the related domain. In this regard, any pure reinforcement learning algorithm can be said to produce original knowledge without external assistance, in the case of unsupervised learning. When the information produced is new in its field as currently known to humanity, for example an unconventional move in Go that went against traditional Go patterns, then the process of coming up with this information can be seen as machine's demonstration of creativity from the perspective of humans. Here, the perspective of humans is used, as an unsupervised learning agent without human guidance by design does not have access to the existing repertoire of knowledge that humans already have. Thus, it has no way of comprehending what is new, and thus, creative. Nevertheless, the demonstration of machines in creativity can encourage humans to think about the nature of creativity and learn new ways of doing old things.

Thirdly, we should welcome this new source of knowledge despite possible undesirable consequences, as we can devise restrictions on the inappropriate use of machines, especially intelligent ones. Every tool comes with benefits to be reaped and at the same time the potential to cause damage. Some people's fear of a "robot apocalypse" stems from the fear of the unknown, and the insecurity when humans' most defining trait, our intelligence, is being surpassed by our very own creation in an unforeseeable way. While this fear is not completely baseless, we should also acknowledge that there are ways to prevent machines from getting out of control. Ultimately, as of now, humans are the sole creator of machines and their algorithms. There is no guarantee that machines cannot make machines in the future, but before that happens, such a machine should be carefully studied before materialization. In addition, machines with actuators able to exert significant physical impact should be restricted. In this way, we can be more in control of the potential damage the machines may inflict on us, while reaping the most benefits from them just like what our ancestors did with every tool that they invented. Therefore, we should welcome the productive possibilities that this new source of knowledge has to offer while guarding against the misuse of machines so as to minimize its disruption.

Section 5: Conclusion

To sum up, humans' advancement in information technology has indeed brought about machines that are able to produce knowledge autonomously, through algorithms that generate new knowledge by building upon past experiences. With this new source of knowledge, on one hand, there are reasons for worry. Machines are increasingly capable of producing knowledge beyond humans' comprehension and prediction. They may deviate from the expected behavior and wreak havoc if mishandled. Also, their threat would be amplified if their goal is not in line with human values and interests. On the other hand, we should embrace the tremendous potentials of intelligent machines, as they can help us solve complex problems and challenge our traditional ways of thinking. The possible undesirable consequences can be mitigated by critically thinking about the boundary between machines and humans, and applying appropriate restrictions on the physical abilities of machines. As Alan Turing put it aptly at the end of his 1950 paper, "We can only see a short distance ahead, but we can see plenty there that needs to be done." With new breakthroughs in the research into artificial intelligence and supercomputers, we may expect more intelligent machinery in the near future that challenges humans' conception of machine intelligence.

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