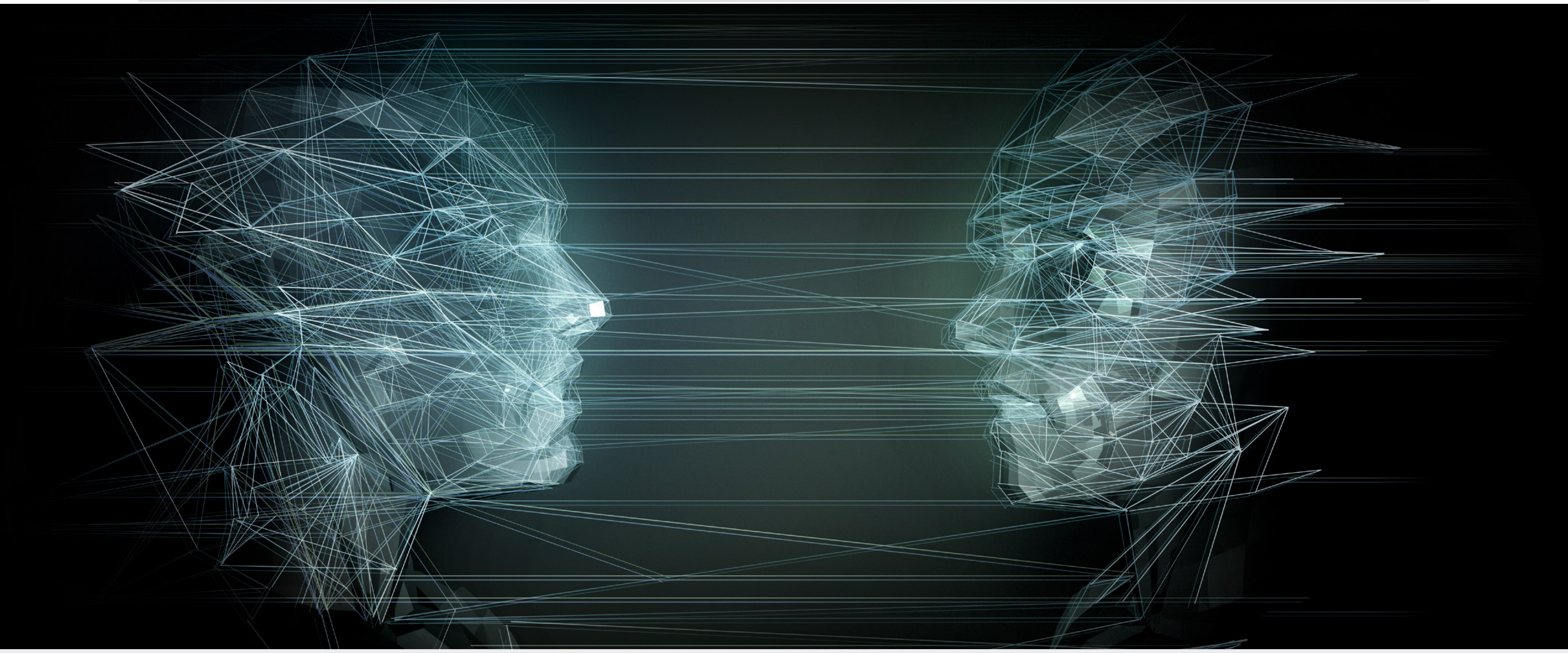


Artificial Intelligence

An Economic Evolution

THE FRONTIER OF THE FUTURE

There has not been a single more profoundly impactful force upon the development of humanity than technology. It alone has been of paramount importance to every major economic expansion throughout history, underpinning the exponential growth in global output since the turn of the 18th century. Each technological revolution brought with it new efficiencies and methods of production on a scale that had been unimaginable. In short, technology has consistently redefined the realm of possibility, delineating the frontier of the future. That frontier now finds itself on yet another new horizon: the advent of artificial intelligence (AI). As with the technological revolutions that have preceded it, AI has the potential to transform the economy and the way in which the labor force works. However, unlike the revolutions before it, AI has the potential to do so on a scale that would eclipse the others in size and scope.

THE SCIENTIFIC REVOLUTION

This year marks the 500th anniversary of the death of one of the foremost pioneers of technological innovation: Leonardo DaVinci. DaVinci is widely known as the quintessential 'Renaissance man.' He excelled simultaneously in the fields of art, architecture,

KEY TAKEAWAYS

Over the short span of six decades, AI has not only matched, but far exceeded the confines of 'natural' intelligence in its sheer size, scale, and scope.

Modern computer chips are now able to execute over 10 trillion calculations per second and over 2.5 quintillion bytes of data are created on a daily basis.

Just as steam power and the assembly line drastically improved overall output via increased productivity, AI will have a similarly profound impact on the growth of the global economy.

AI has the potential to reduce risk and cut costs via increased accuracy and automation, driving both profitability and value to the consumer.

In most jobs, a robot cannot yet completely eclipse the value of human labor and all of its complexities.

astronomy, anatomy, science, math, engineering, and invention, amongst many others. Though many classical polymaths preceded him (notably, Archimedes of Syracuse), DaVinci is considered to be one of the foremost fathers of modern technology. Centuries before the advent of electric power or computing, DaVinci designed his automa cavaliere, a fully functional and autonomous mechanical knight. It could be considered one of the world's first 'robots' and first precursors to AI, albeit in a rudimentary form.

Throughout the Renaissance and the Enlightenment, eras so named for the 'rebirth' and 'reeducation' of humanity, DaVinci and other luminaries led the way in laying the foundations of modern science. Through their observation, deduction, and innovation, the modern scientific method was born. The ramifications of these developments on the progression of humanity were profound.

THE INDUSTRIAL REVOLUTION

Up until the early 18th century, economic output throughout the world was much the same as it had been in the previous millennium (Figure 1). Economic activity largely consisted of subsistence agriculture, small-scale hand-manufacturing, and the trade of goods. Yet, with the advent of entirely new innovations and inventions by way of the scientific method, the economy and its workforce changed radically (Figure 1). Advances in agriculture, including crop rotation and nitrogen fixation, enabled societies to support ever larger populations and reduced the risk of widespread famines. The development of steam power and machine tools paved the way for modern manufacturing. As such, the composition of the workforce changed dramatically, shifting from agriculture to manufacturing, bringing with it unparalleled economic expansion.

Figure 1: Innovations, Inventions, and Increase in GDP (Trillions of £)

For the assessment above, the whitepaper relies upon economic data from England, which offers a far more extensive and reliable record than the brief historical record in America.
Source: Office for National Statistics

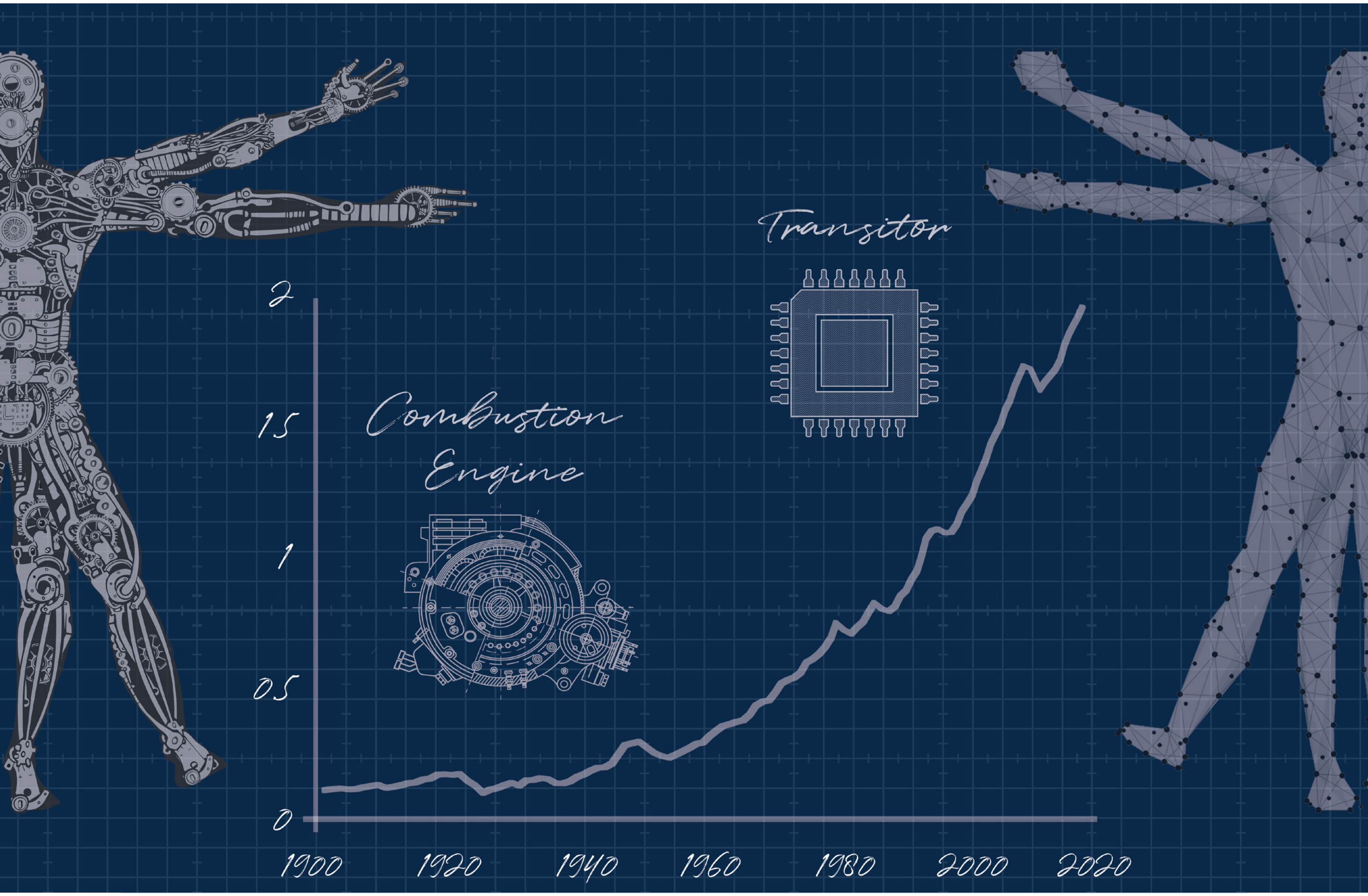
THE TECHNOLOGICAL REVOLUTION

As the industrial revolution continued to mature, it ultimately ushered in the technological revolution, which gave way to yet more groundbreaking innovations. The introduction of the assembly line, widely attributed to Henry Ford in 1913, led to even greater productivity in manufacturing and overall output. Engines became more efficient and more powerful as their fuel evolved from steam, to diesel, to batteries. Transportation became ever faster as locomotives were succeeded by automobiles, which were succeeded by airplanes.

Yet the greatest innovation of the 20th century was the advent of modern computing. As steam power was the catalyst for the industrial revolution, so too would computing be the catalyst for the technological revolution. Following their introduction in the mid 20th century, computers fundamentally changed the nature and composition of the economy. With advances in integrated circuit technology that enabled the use of more and smaller transistors, the scale and scope of computing grew exponentially (Figure 2).

This expansion in computing power comprises the foundation for AI, the next and newest revolutionary chapter in this series of economic and techonlogical advances.

Figure 2: Scale, Scope, and Surge in GDP (Trillions of £)



For the assessment above, the whitepaper relies upon economic data from England, which offers a far more extensive and reliable record than the brief historical record in America.
Source: Office for National Statistics

ARTIFICIAL INTELLIGENCE DEFINED

Intelligence, as broadly defined by the Oxford English Dictionary, is the "ability to acquire and apply knowledge." Until recently, humans and other organic organisms were the only entities to possess intelligence, the product of billions of years of evolution. Yet, for the first time in history, that stage is now shared with non-organic entities: computers. Unlike previous machines which were dependent upon human programming for their computational capabilities, modern computers now have the ability to acquire and apply knowledge independent of human input. Thus the birth of 'artificial' intelligence.

Over the short span of six decades, AI has not only matched, but far exceeded the confines of 'natural' intelligence in its sheer size, scale, and scope. Were it to be represented in terms of brainpower, AI currently has the capability to perform more calculations than a googolplex[1] of human minds in a matter of seconds. This colossal computing power has endowed AI with the ability to acquire and apply newfound knowledge in ways previously unimaginable. Autonomous automobiles can whisk passengers to destinations, robots can perform complex surgeries, and automated accounting systems can evaluate billions of transactions. In short, AI will have a profound impact on the global economy, the composition of its workforce, and the makeup of modern markets.

FUNDAMENTAL FOUNDATION

For all of its complexities, the manner in which modern computing writes and reads data is remarkably simple. Computing relies on binary code, which consists entirely of two digits: 0 and 1. Most all computer coding consists of translating data into this format, which can then be read and processed by a computer. Traditionally, humans had to act as an intermediary in the coding process. However, recent developments have lessened computers' dependence on humans, thus forming the foundation of AI. Natural language processing, machine learning, and artificial neural networks have been the most crucial of these advancements.

As its name implies, natural language processing enables a computer to understand someone in his 'natural' (i.e., non binary) language. This is the technology behind the virtual assistants Siri, Alexa, and Cortana that can perform a variety of tasks when commanded, such as composing and sending a dictated text message.

Machine learning allows a computer to learn from its environment and through trial and error. In essence, it is the difference between being taught not to do something (e.g., touching a hot stove) or learning through experience (e.g., avoiding touching a stove after being burned once). Until machine learning, a computer could only be 'taught' (i.e., coded) to do things. With machine learning, a computer can learn through its own trial and error process, teaching itself to be more efficient the next time it attempts the same task or avoiding errors it encountered in the past.

"IF EVERY PERSON ON EARTH COMPLETED ONE CALCULATION PER SECOND, IT WOULD TAKE

305 DAYS

TO DO WHAT THE WORLD'S MOST POWERFUL COMPUTER CAN DO IN ONE SECOND"

- INTERNATIONAL BUSINESS MACHINES (IBM)

Artificial neural networks empower a computer to tap into the collective 'consciousness' of all other computers within a network. It is loosely analogous to the interdependent nature of human society, whose advances have been made possible by access to collective knowledge and past discoveries. Even though the average motorist is neither the geologist who discovered oil, the petrochemist who discovered the distillation of gasoline, nor the mechanical engineer who designed the first piston engine, he still fills up his car with gas knowing that it will get him to his destination. He knows this because he has access to the shared knowledge of human society. The same can be said of computers. Were each computer to exist in isolation, it would have to make each 'new' discovery on its own. However, by accessing the collective knowledge and data of machines across an entire network, computers can make many more connections and 'discoveries' than would have been possible otherwise.

[1]Googolplex: A googolplex (10^10^100) written out in ordinary decimal notation is 1 followed by 10^100 zeroes.

FROM HERO TO ZERO

To gain a greater appreciation for the sheer scope and scale of AI's abilities, one need not look further than the Chinese game of Go. Unlike chess, which is played with 32 pieces on an 8x8 board, Go is played with over 360 pieces on an 18x18 board. As such, it is infinitely more complex. Whereas the total possible number of moves in chess is estimated to be 10^123, the total number of possible moves in a typical game of Go is estimated to be 10^10^100 (i.e., a Googolplex). To put those numbers in perspective, the total number of atoms in the observable universe is only estimated to be roughly 10^80.

"A GOOGOLPLEX OF GRAINS SMALLER THAN THE PERIOD AT THE END OF THIS SENTENCE COULD NOT BE CONTAINED WITHIN THE ENTIRE VOLUME OF THE OBSERVABLE UNIVERSE."

To represent these numbers in a visually-familiar context, a googolplex of grains smaller than the period at the end of this sentence could not be contained within the entire volume of the observable universe. In short, the game is so elaborate that the reigning Go champions spend the better part of a lifetime mastering the game. A computer powered by AI did so in just three days.

DeepMind, a computing firm, developed a program utilizing AI, which it aptly named "AlphaGo." AlphaGo 'learned' to play Go by analyzing millions of previous games, assigning positive odds to winning strategies, and negative ones to losing positions. The program then played countless games against itself, further improving its game. AlphaGo ultimately went on to defeat the reigning Go champions many times over.

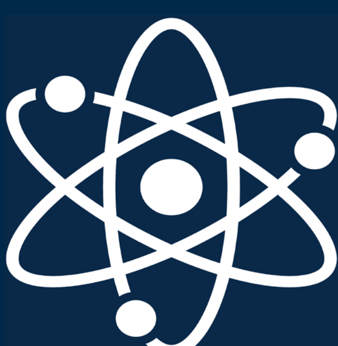
While such a feat is certainly impressive for any program, the prowess of AlphaGo was quickly dwarfed by its successor: AlphaGo Zero. For all of its capabilities, AlphaGo's greatest weakness was its inability to originate 'new' moves; all of its knowledge of the game was based on previously played games. This is where AlphaGo Zero excelled. Whereas AlphaGo was given access to millions of previous games to analyze, AlphaGo Zero was only given access to the rules of the game. The only way it could 'learn' to play Go was by playing games against itself. However, unlike AlphaGo, AlphaGo Zero was also powered by an artificial neural network.

In just three days, AlphaGo Zero had evolved to such a degree that it was able to beat its predecessor, AlphaGo, over 100 times in a row. AlphaGo Zero is a quintessential example of the sheer scope and scale of AI, and a microcosmic insight into its infinite future potential.

ZERO TO INIFINITY ... AND BEYOND?

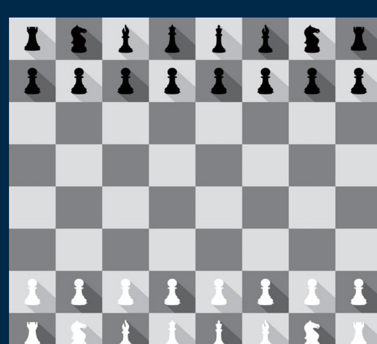
ATOMS IN THE UNIVERSE

10^{80}



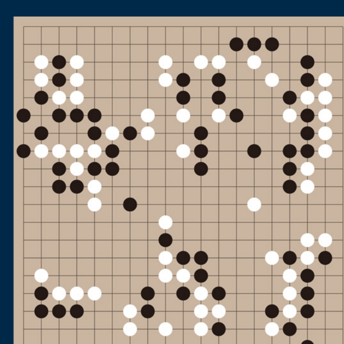
POSSIBLE MOVES IN CHESS

10^{123}



POSSIBLE MOVES IN GO

$10^{10^{100}}$



TYPES OF AI

Though the abilities and functions of AI are myriad, most all of them fall neatly into three broad categories: Artificial Narrow Intelligence, Artificial General Intelligence, and Artificial Super Intelligence. In order to better understand these different types of AI, the following examples outline AI's current and potential influences upon the universally familiar task of driving a car.

Artificial Narrow Intelligence (ANI), also known as Weak Artificial Intelligence, is the form of AI that is programmed by humans and is able to perform a single task. Some common examples include voice recognition software, translation devices, chat bots, and navigation systems. For instance, the first generations of global positioning softwares (GPS) were loaded with static maps and used a basic algorithm to calculate the route to destination. Unlike its predecessors, modern navigation systems utilize real-time user data and machine learning to calculate the shortest route to a destination, and even re-route drivers if traffic conditions worsen. However, ANI is incapable of performing any task that it is not programmed to do, and therefore is limited to whatever task it was created for.

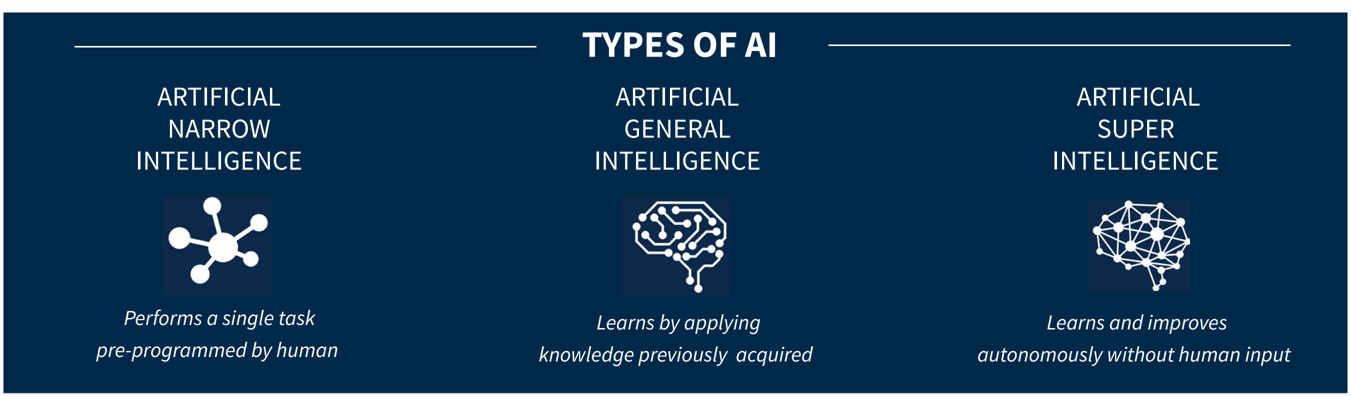
Human brains might not process data very fast, especially when compared to the processing power of a modern computer, but they are still an impressively efficient machine. Artificial General Intelligence (AGI), also known as strong AI, is the concept that a machine can be as smart as a human. This is possible due to something called meta-learning, which is the ability to learn new skills by applying knowledge previously acquired, just like humans do. For instance, self-driving cars use AI to determine a pre-established safety distance from the car in front and either accelerate or decelerate accordingly. However, if the car is involved in unforeseen circumstances, the ANI would not know how to react as it was not programmed to do anything else than keeping a certain distance from the car in front. On the other hand, AGI will react based on its preexisting experiences, and acting similarly to human intuition, it might be able to avoid an accident.

It is hard to predict when Artificial Super Intelligence (ASI) could happen, but this is when humans no longer program AI, but when AI will teach and improve itself without human input. Once this level is reached, AI could explore seamlessly 100% of the data that is available, and make thousands of years of technological advancement in a matter of days. The results and innovations could be outstanding, and likely too complex for us to understand. However, a simple example could be that once autonomous cars replace all current vehicles, an ASI collecting live-data from all means of transport could orchestrate traffic patterns and virtually eliminate gridlock.

AI is supported by the pillars of computing power, data availability, and innate intelligence. There is an ample abundance of both power and data; modern computer chips are now able to execute over 10 trillion calculations per second and over 2.5 quintillion bytes of data are created on a daily basis. The greatest obstacle to the progression of AI has been the development of innate intelligence, the ability of a computer to teach itself more efficiently and effectively. As AI becomes increasingly effective and efficient, near-infinite amounts of existing and newly produced data can be analyzed and synthesized, which, in turn, enables ever more innovative solutions for society.

AI, AI CAPTAIN

As with every other technological revolution that has come before it, AI will come to define the evolution of the global economy, its financial markets, and its labor force. Though it remains in a relatively nascent stage of its development, AI has become the harbinger of the next era of significant 'creative destruction', the process by which old methods are replaced by more effective, efficient, and profitable ones. The next captains of industry will be those who harness the power of AI most successfully. Just as Cornelius Vanderbilt rose to prominence due to his prowess with railroads, Andrew Carnegie with steel, John D. Rockefeller with oil, Henry Ford with the automobile and assembly line, and Bill Gates and Steve Jobs with computers and software, so too will the next captains rise to prominence in proportion to their prowess with AI.



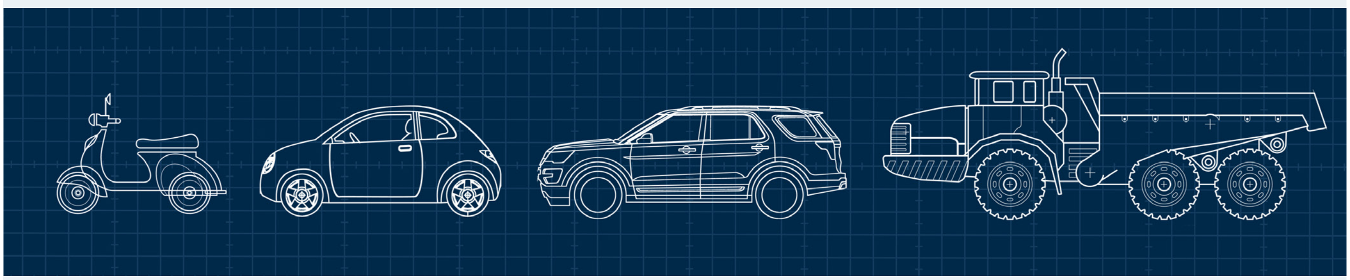
MACHINE LEARNING

Artificial intelligence learns through experience by analyzing data and then tweaking it into statistical patterns on its own, without being programmed to do so. A basic algorithm could learn how to recognize an object by filtering preestablished characteristics.

The algorithm is initially fed rudimentary features of the item, such as its shape and texture. The algorithm is consequently evaluated by testing its ability to recognize the object against a variety of other items, and verifies this against an answer key. The initial output is likely to be discouraging as the algorithm might recognize the object at times, but fail at others. This is where the readjusting process begins, which compares the algorithms' results with the answer key, holding on to features that yielded a correct answer, and discarding incorrect ones. Other features are added to an amended algorithm, until the output is mostly correct.

For instance, a basic algorithm is fed the following features in order to recognize a car: four wheels and six windows. Consequently, the algorithm is tested on its ability to recognize which ones are cars and which ones aren't based on the two criteria. The first test correctly excluded the motorcycle as it doesn't have four wheels or windows, and excluded the semi-truck for having too many wheels. However, the algorithm excluded the SUV for having eight windows rather than six. Therefore, when compared to the answer key, the algorithm will adjust the weight of the feature "window" to a lower degree, allowing vehicles with more windows to still pass the test, and simultaneously it will reinforce the number of wheels to be four. This process is repeated numerous times, until accurate weights are achieved, and the correct result is achieved in perpetuity.

What truly separates machine learning from previous forms of artificial intelligence is its ability to assign weights to the various features in order to achieve the correct result all of the time. This simple concept is at the base of machine learning and all its more complex applications.



ARTIFICIAL NEURAL NETWORKS

There is more to driving than just being able to recognize a car. There are traffic signals, speed limits, pedestrians, weather, sudden stops, construction detours, and more. The computer is able to master these complexities by tapping into the collective 'consciousness' of other computers on the same network. When algorithms using machine learning work in conjunction with each other, a framework of computing systems is created, which is known as a neural network.

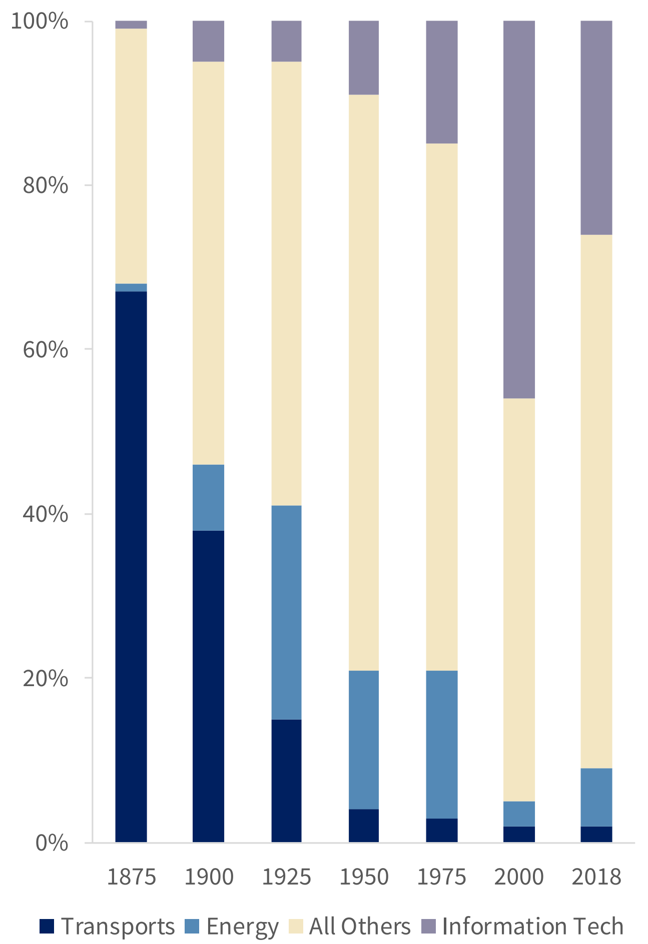
The name and its functionality are inspired by how human brains are developed, where signals are received in the input from a variety of sources such as sensory organs like eyes and ears. These input signals are transported to various neurons interconnected by synapses, which carry out a specific output when activated. These three steps are known as the input layer (sensory organs), multiple hidden layers (neural network), and the output layer (decision).

The hidden layers are where the neural networks come into play. This process allows inputs to be processed, weighted based on importance, and propagated from layer to layer until the desired outcome is obtained. The network learns through training, in fact initially all weights are random and the output is likely to be nonsensical. This is where the training process commences, and the correctness of the output is compared to correct outcomes and the various weights in the hidden layer are adjusted until accuracy peaks. A neural network is ultimately a simple weighted sum of inputs, where weights are adjusted during an iterative learning process, and data is transformed until an output is released.

FOLLOW THE MONEY

True to Benjamin Graham's oft-quoted aphorism that the stock market is a "weighing machine" over the long run, one need only look at the composition of the stock market throughout history to ascertain the most valuable industrial and technological developments at any given time (see Figure 3). Throughout the latter half of the 19th century, railroads comprised well over half of the entire American stock market, reflecting their importance to the economy as a whole. However, at the turn of the 20th century, railroads were quickly eclipsed by oil, the fuel that would power everything from automobiles to planes. Firms that produced oil comprised the greatest share of the stock market until they too were eclipsed at the turn of the 21st century by firms specializing in technology and software. A similar transition is likely to occur by the mid 21st century, as firms which harness the unbounded capabilities of AI are bound to be considered the most valuable to both society and shareholders.

Figure 3: Historical US Market Sectors Composition

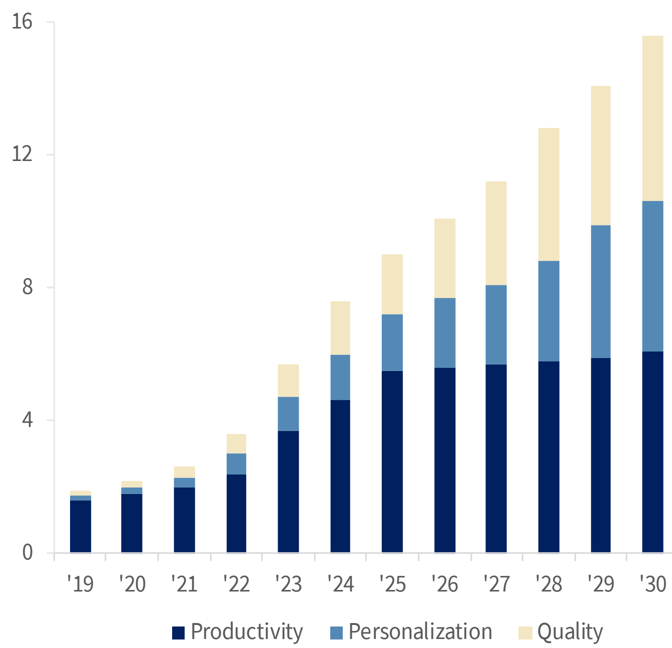


Source: Visual Capitalist

EXPANDING THE ECONOMY

As with the industrial and technological advances that have preceded it, AI has the potential to greatly enhance the efficiency and effectiveness of the economy. Just as steam power and the assembly line drastically improved overall output via increased productivity, AI will have a similarly profound impact on the growth of the global economy.

Figure 4: Productivity, Personalization, and Product Quality (Trillions of $)



Source: PricewaterhouseCoopers

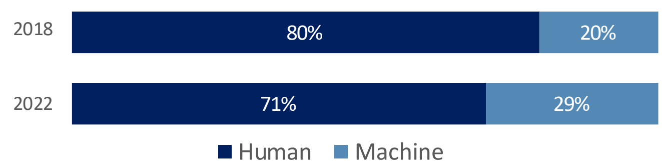
One analysis published by PricewaterhouseCoopers, an accountancy and consultancy firm, estimates that AI will boost global GDP to the tune of $15.7 trillion by 2030, an increase of approximately 20% from today's total output. These gains will largely be derived from enhanced productivity, personalization, and product quality (Figure 4). Furthermore, AI has the potential to reduce risk and cut costs via increased accuracy and automation, driving both profitability and value to the consumer.

I, ROBOT?

Perhaps the greatest societal apprehension surrounding AI is that it will render human labor obsolete and that workers will be rapidly replaced by robots. Such fear is certainly merited, as many roles are ripe for automation by AI. Yet, a recent study by McKinsey & Co., a consultancy, indicated that only a varying percentage of responsibilities are automatable for most roles as a direct result of the proliferation of AI. For instance, roles with redundant tasks such as data processing are likelier to be automated (Figure 5). On the other hand, jobs that require decision-making and communication skills are significantly less prone to automation (Figure 6). This is to say that, in most jobs, a robot cannot yet completely eclipse the value of human labor and all of its complexities.

Figure 5: Redundant Roles

Figure 6: Managerial Roles

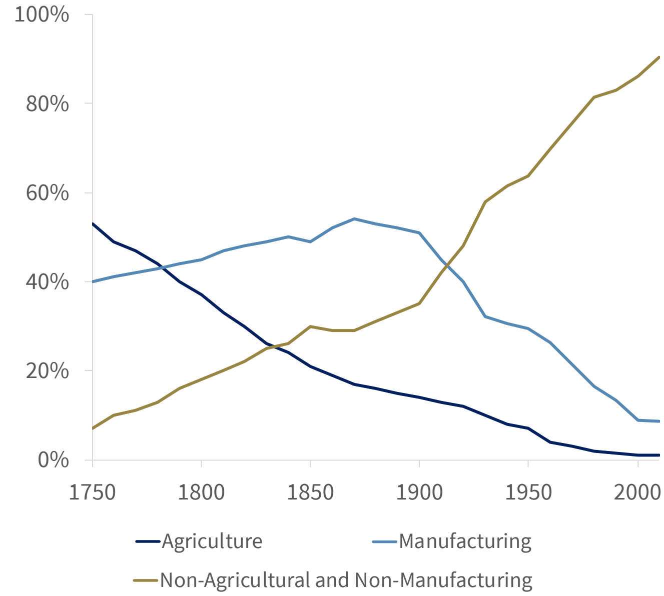


Source: PricewaterhouseCoopers

Again, from a brief review of the historical record, this is a rather common phenomenon. Just as contemporary workers fear the threat of automation at the hands of AI, so too did laborers in ages past fear the rise of prior industrial and technological innovations. With the advent of steam power in the 19th century, skilled weavers feared that they would be permanently displaced by factory machinery, many of whom took up arms against the threat. These 'Luddites' stormed factories and destroyed machinery in the vain hope of stalling industrial progress. A century later, skilled factory workers forcefully opposed the implementation of the assembly line at Ford's automobile plant. Yet, both the economy and the composition of its workforce nevertheless evolved, largely for the better.

In the mid 18th century, over 50% of all laborers were involved in agriculture (Figure 7). Yet, technological advancements would whittle that number down drastically. By the turn of the 20th century, those involved with agriculture had dwindled to fewer than 20% of the workforce; by the 21st century, they comprised less than 1%. These formerly displaced farmers found roles in manufacturing, which quickly overtook agriculture by the turn of the 19th century. By the turn of the 20th century, non-agricultural and non-manufacturing laborers comprised the largest share of the workforce, largely absorbing those who had previously worked in factories or farms.

Figure 7: Labor Force Composition



Source: US Bureau of Labor Statistics; Gregory Clark, UC Davis

Suffice to say, after a period of adjustment and realignment of responsibilities, labor has evolved alongside technology. Barring isolated examples, widespread unemployment and obsolescence of human labor across society did not occur. While AI is irrefutably far more sophisticated than either steam or early generations of software, there is ample evidence that human labor will remain crucial to the global economy, albeit in an altered form.

SYMBIOTIC SYNERGY

There is no finer example of this paradigm than DaVinci Surgical Systems, one of the many namesakes of the Renaissance man. Whereas DaVinci's automa cavaliere could imitate some aspects of human movement 500 years ago, the evolution of robotics has now attained a height that had previously been the exclusive domain of humans: performing incredibly sophisticated surgeries. Yet, even these highly advanced systems still rely upon a human physician to guide its instruments. This symbiotic synergy is in many ways emblematic of most all other applications of AI, changing but not eliminating the role of human labor. Rather than the inception of an entirely new book, the advent of AI is the next chapter in a centuries-long series of creative destruction. The composition of the labor force, the global economy, and financial markets will, as they have in the past, evolve accordingly.

All content written and assembled by the Investment Strategy Group.

ADDITIONAL DISCLOSURES

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