Evolution of Technology

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Abstract

Intelligent technology is nowadays unavoidable topic to almost everyone. To understand the concepts behind the intelligent technology, it is better to start with the behind reason why we need such technologies and the technologies developed in prior to it. Therefore, it is necessary to introduce the evolution of technology and elucidate the societal needs and the inventions leading to those evolutions. While not comprehensive, the evolution of intelligent technology will be elucidated in five periods of time. Finally, the benefits and threads of the advancement of intelligent technology are discussed.

Contents

1 Introduction

After the invention of steam engine in the 18 century, the industrial and personal usages of technologies have been in a growing demand over centuries. To understand the evolution of technology and the driving forces for the evolution, it is better to start with the period of the Renaissance (1300-1600)[1].

1. Renaissance (15th-16th Century Europe)
2. Scientific revolution (16th Century Europe)
3. British agricultural revolution (17th Century UK)
4. First industrial revolution: Steam engine (18th Century UK)
5. Second industrial revolution: Electrification (1900)
6. Third industrial revolution: Information and communication technologies (1950-)
7. Forth industrial revolution: Artificial intelligence (AI) (Present)

1.1 From the Renaissance to the Agricultural Revolution

During the period of Renaissance, learning and education had been re-advocated in Europe. Along with the invention of printing press, books were printed. Knowledge and ideas were transmitted in a rapid speed. With an increasing number of studies on natural philosophy, new knowledge in scientific discipline were aroused and led to the period of scientific revolution across Europe in the 16th century. While there were wars in the European continent which caused manu casualties, UK on the other hand had a rather peaceful environment. Thus the population of UK grew relatively faster than the other European countries and led to a higher demand on food supply. In this regard, UK had laid new policies to boost the food supply and led to the British agricultural revolution in the 17th century in Edinburgh. Tools and machines were invented for the farmers to agricultural production. It could thus be marked as the first technological revolution in this history.

1.2 Industrial 1.0: Steam Engine

In the 17th century, Europeans switched their main source of fuel from wood to coal. Thus, coal mining became important and highly demanded across Europe. Many coal mines were deepened and became flood after penetrating underground water. Thus, powerful water pumps were needed. In the end, steam engine powered water pump was invented.

Making machines and tools are engineering tasks. They require scientific knowledge, a lot of trials and practises. Perhaps, it is one reason why the

[1] `https://en.wikipedia.org/wiki/Renaissance`.

earliest steam engines were invented by Englishmen and led to the first industrial revolution. Steam engine is an important invention not just it brought to the world the power for automation. It could let a factory locate away from rivers (i.e. water power). Before the invention of steam engines, factories could still use machines and tools to enable their production. However, the factories had to be built along rivers. With steam engine, many factories could be built in other locations. No matter what, a key achievement brought out from the first industrial revolution is production automation. The number of labors was reduced. In addition, redesign production process and the use of new machine could further improve the product quality.

1.3 Industrial 2.0: Electrification

The first industrial revolution marked the change on the source of power, from water power to steam engine. The second industrial revolution marked another major breakthrough – electric power is added on the list. With an increasing number of electricity suppliers and electric motors, together with mechanical engineer like Frederick W. Taylor and brilliant entrepreneur like Henry Ford, various production processes were re-designed based on the idea of assembly line which was driven by a large electric motor. Workers were standing side by side along the assembly line. Each worker only worked for a simple task. The workers were also grouped in various teams. Each team had a supervisor who in charge of the quality of the works in the team. With no doubt, the production cost down and hence the price of a product was then reduced. At the same time, the labors earned more.

1.4 Industrial 3.0: Computerization

World War I and World War II marked another turning point in the history – the invention of electronic computers. To automate a computing task was not a new idea in the 20th century. In the 19th century, Charles Babbage had already designed and built a mechanical computing machine called 'Difference Engine' to perform numerical approximation[2].

With the invention of vacuum tubes, electronic components like diode and triode were made. Eventually, electronic digital computers Z2, Colossus and ENIAC were made and used during the second world war. During the war time, these computers were mainly used as computing machines for scientific researches. The purpose is essentially the same as the purpose of difference machine, for computation.

Until the war was over, digital computers for commercial use had finally been made, LEO from Lyon in England and later the UNIVAC from Remington Rand in US. These computers extended the functionalities of the earlier computers by adding functions, in forms of computer programs, to handle data processing and data storage, i.e. *information management – collect, process,*

[2] `https://en.wikipedia.org/wiki/Charles_Babbage`.

store and disseminate information to support decision making within an organization. These computer machines together with the corresponding programs formed the earliest *computerized information systems*[3].

A good news is that the work used to be done by the accounting clerks could largely be relieved. But, a bad news is that many jobs used to be done by human workers were then be replaced by computers. The focus of automation extended from production process to administrative work. No matter what, the invention of computer started the road to the modern information technology and led to the third industrial revolution.

With the advancement of computer network technologies, the Internet and then the smartphone (like iPhone), the scale of an information system shifts from a single department-scale information system to a firm-scale network of multiple information systems; and then from a firm-scale enterprise information system to an information system connecting the firm, the suppliers and the customers.

1.5 Industrial 4.0: AI and Others

In some countries, like German and US, have marked the middle of 2010s the starting of the forth industrial revolution. One reason is that AI technologies have been used in the industrial sector. Robotic receptionists have been installed in many service firms to handle customers enquires. By using intelligent software robot, customer service could now be implemented without hiring any human worker. Customer relationship management could be raised to the next level.

Market trend could now be conducted and analyzed by an intelligent software program. New products to be developed could then be recommended to the management team. Moreover, marketing executives could use intelligent software to analyze the sentiment of a customer through the posts appeared on the Internet. The executives could also apply AI system to compile marketing strategy and make target marketing more efficient.

There are a lot more jobs that AI could do, like production process design and scheduling. With auto-driving vehicles, the efficiency of logistic control could further be improved. Supply chain management could thus be advanced to the next level.

1.6 Levels of Intelligence

From the first industrial revolution to the forth industrial revolution, one can ready see that technological advancement has brought to the industry from routine labor work replacement to intelligent work replacement, see Table 1. With the technological advancement on the production machines and the information

[3] It should be noted that information system has already appeared for centuries. In the ancient China, accounting information system already existed. The technologies employed in that time were (i) manual writing the data on a paper accounting book (i.e. ledger book) for data collection and storage, (ii) abacus for data processing, and (iii) birds, horses and human messengers for information dissemination.

systems, it is anticipated that the jobs to be done by human workers could largely be replaced. To this end, what a human being could do for the society would be a challenging question.

2 Automation & Electrification

Automation refers to automatic control a process to run with minimum operator intervention and it started when Watt invented an advanced steam engine in 1788. The term "automation" was introduced in 1947 when Ford Motor Company vice president Del Harder set up an automation department [1] aiming at applying technologies – hydraulic, electromechanical, and pneumatic – to speed up operations and enhance productivity on the assembly line. Later in the 1950s, the emergence of the programmable computer led many radical restructuring of operation design in the industry to fully automate as much of the production process as possible [1].

With the advance of electric motors, electric circuits and computer, computerized automatic control systems could be made and help in almost every step in production. Furthermore, the advance in robotic technologies has also made many production works simpler and faster. For instance, car manufacturers install robotic arms for car frames painting and assembling components. While the major advantage of automation is not to change the management practice, it does change the quality management style from monitoring a labor intensive factory to an almost laborless working factory (i.e. lights out factory).

3 Information Technologies

Technologies have been booming and influenced our lives and business operations for many years. These technologies normally have no direct influence on management. But their indirect effects are tremendous in various aspects of management practise.

3.1 Computer

The first computer was invented by John W. Mauchly and J. Presper Echert in 1946. They created the first automatic computer which was called ENIAC. After long-term development and improvement, in 1970s, the microprocessor-based computer was invented. A notable model is the Apple II personal computer. Its size is smaller and the price is cheaper. Thus, small and medium enterprises (SME) and families could afford for a computer. Then, computers rapidly spread everywhere, starting the generation of personal computers.

With the emergence of the computer, business operations are simplified. In the past, managing information in a company, like the business and customer information, was accomplished by paper documents. With personal computer, paper documents are replaced by electronic files so that all the information

Table 1: Changes in the industrial works

Stage	Job Replacement	Level of Intelligence
1st	–	Nil
2nd	Production labor	Low
3rd	Production labor	Low
	Administrative staff	Middle
4th	Production labor	Low
	Administrative staff	Middle
	Marketing staff	High
	Customer service	High
	Order placement	Low
	Order fulfillment	Low
	Retailing	Low
	Shop management	High
X	Production labor	Low
	Administrative staff	Middle
	Marketing staff	High
	Customer service	High
	Order placement	Low
	Order fulfillment	Low
	Retailing	Low
	Shop management	High
	Product/Service design	Very high
	Production process design	Very high
	Market survey	Very high
	Research and development	Very high
	Scientific research	Very high
	Social science research	Very high
	Report writing	High
	Story composition	Very high
	Video/Film production	Very High
	Music composition	Very high
	Education	Very high

can easily be stored and retrieved. In addition, the physical space for storing information is largely reduced.

Besides, many software like the Words and PowerPoint in MS Office ease the managers and secretaries in preparing reports and presentation slides for meetings. Spelling-check, grammar-check and auto-correction functions of MS Word even reduce the time spent in preparing a report as compared with that in the 1980s. As the time spent in compiling a document is reduced, staffs could spend more time in organizing the contents and formatting the presentation slides in a better way. Communication gaps amongst the managers and their subordinates are definitely reduced. Management is more effective.

3.2 Network Technology

With network technology in the late 1980s, computers could be connected to form a local area network exchanging data amongst each others. Memorandums are replaced by emails. Informal discussions on the issues related to works can be accomplished by emails. Documents could be shared within the company. New policies and decisions to be sent from the top manager to the staffs could be arrived instantaneously at anytime from anywhere. Administration can be done more effective than before. Productivity could further be improved by re-designing some of the core processes, as witnessed in the era of business processes reengineering [2].

3.3 Internet

In the early 1960s, packet switching technology was invented for communication between different computers. In 1969, the project Advanced Research Projects Agency Network (ARPANET) was launched and was the first packet switching networks connecting selective universities and research laboratories in the US. In subsequent decades, different networks were then emerged all around the world. Owing to facilitate the inter-connectivity among different networks, technologies for inter-networking were developed and eventually the Internet formed in late 1980s. In the late 1980s and early 1990s, commercial Internet service providers (ISPs) began to emerge, following by the decommissioned of ARPANET. The Internet became fully commercialized in the U.S. As a result, the size Internet started to expand rapidly in the world as a lot of commercial firms install their own network servers with dedicated IP addresses and connect them to the Internet.

Technologies combined with the Internet have given a new dimension to collect and disperse the information. One example is human resource management. Nowadays, most human resource managers collect the resumes through e-mail or human resource agency websites instead of mails or in person. Another example is marketing management. Through the Internet, overwhelming price and product information can be distributed to the buyers. The manager needs to figure out what content of information can attract customers.

Internet facilitates collaboration among employees from different geographical regions (different time zones) in an organization. Managing a project involving employees from geographical regions is possible. If a manager is on a business trip, he can inspect the progress of a project at any place and at any time. If necessary, the manager can also hold a meeting, via social network systems like Facebook and Line, with his team members and make decision on any critical issue. Workers are able to work in a café, in a car, in a ferry, in an airport departure hall and even in a toilet. Before a marketing presentation to a client, a salesman could use iPad to access the information from the company database and modified the slides while having a coffee at Starbucks.

Take Verifon, an American electronic payment and transactions corporate, for example. It locates its R&D and manufacturing department in Taiwan, Department of system development in India, and service department in North America and West Europe. Though the departments are scattered around the world, Verifon can still manage each department effectively through the Internet [3].

3.4 Enterprise Information Systems

With further advancement on the hardware and network technologies, various enterprise-wide information systems like supply chain management (SCM) systems, customer relationship management (CRM) systems, enterprise resource management (ERP) systems have been developed for the companies to manage their global supply chain, customer relationship, finance and daily adminstration [4]. Beyond that, customer could access the website, surf for the products, place an order and settle the payment online. On the other side, the order fulfillment center will be notified the new order placement. Then, the workers in the center pack the items into a package. The partnered 3PL will then deliver the package to the customer.

This new product selling process is far more convenience and effective than the traditional off-line process. As an increasing number of customers willing to buy online, online selling has became significant revenue of some firms. Structure of the marketing channels is simplified as compared with the traditional marketing channels. Intermediaries are reduced. Target marketing could be possible. Marketing activities extend from traditional media to Internet & social media, and thus change the way of managing marketing activities.

4 Intelligent Technologies

Making a computer to be intelligent has long been a fascinating topic to scholars. One renowned scholar and the pioneer of AI is definitely the English mathematician Alan Mathison Turing who laid the first reinforcement learning-based framework for learning machines and the proposal of Turing test to examine if a machine is intelligence[5, 6]. Subsequently, the quest of a learning machine has attracted a number of scholars to investigate and develop machines to realize the learning behind a machine [7, 8, 9].

Their very first purpose is to see if it is possible to make a machine thinks or behaves like human being. Since then, various researchers have joint the effort to investigate on the above issue. Here, I simply outline some major breakthroughs. Readers could refer to the links in the footnote below for further information[4].

4.1 AI Research in the 1950s – 1960s

Since after electronic computer has been built, many attempts on the use of computer to realize human intelligence have been started. The approaches to realize such purpose could be classified as the symbolic logic approach and biological brain approach.

4.1.1 Symbolic Logic (Psychological)

One group of researchers followed the line of thought of Alan Turing and John von Neumann. We call this line of thought the symbolic logic approach. Every event and object in the world could be represented as a symbol. Each symbol can then be encoded as a binary code. Our human logical thinking is essentially a process of symbolic manipulation. If the process of symbolic manipulation is mapped to a program, a digital computer could mimic human logic thinking. In contemporary terminology, the system built by using this idea is called multi-agent system.

This approach has also attracted many psychologists who are interested in artificial intelligence, especially the behavioral psychologists and cognitive psychologists. They applied the theories to develop learning algorithms for the program to be running in a computer.

About the same period of time, a professor in a management school was working on organizational decision-making. In his autobiography, he mentioned[5], "*Meanwhile, however, the descriptive study of organizational decision-making continued as my main occupation, in this case in collaboration with Harold Guetzkow, James March, Richard Cyert and others. Our work led us to feel increasingly the need for a more adequate theory of human problem-solving if we were to understand decisions. Allen Newell, whom I had met at the Rand Corporation in 1952, held similar views. About 1954, he and I conceived the idea that the right way to study problem-solving was to simulate it with computer programs. Gradually, computer simulation of human cognition became my central research interest, an interest that has continued to be absorbing up to the present time.*". This professor is the Laureate of the 1978 Nobel Prize in Economic Science, Hebert Simon.

[4] *Timeline of AI*, its URL is https://en.wikipedia.org/wiki/Timeline_of_artificial_intelligence. *History of AI*, its URL is https://en.wikipedia.org/wiki/History_of_artificial_intelligence. Both of them are from Wikipedia. Moreover, an early history of machine learning can be found in the URL https://www.doc.ic.ac.uk/~jce317/history-machine-learning.html

[5] https://www.nobelprize.org/prizes/economic-sciences/1978/simon/biographical/.

Symbolic approach has then been one major approach in AI research. Fuzzy set theory, which was introduced by Lotfi Zadeh in 1965 [10], is one example along this approach. Later on, the research works on expert systems in 1970s-1980s, intelligent agent researches starting from 1980s [11] and case-based reasoning starting from 1990s are also along this approach.

4.1.2 Neural Network (Biological)

In contrast to symbolic logic approach, another approach is to develop an intelligent system based on the finding from biological brain. One key finding in the 1940s was from Warren S McCulloch, Walter Pitts and their co-worker [12, 13] on modeling the behavior of a neuron as a threshold logic unit, which is currently called the McCulloch-Pitts neuron.

Neural network approach is referred to the pioneer work by Frank Rosenblatt on his work on Perceptron in the 1950s [9, 14, 15]. Perceptron is a hardware machine mimicking human biological neuronal network with a learning mechanism. Perceptron has multiple layers of neurons. Each neuron is modelled as a threshold logic unit, except the neurons at the input layer. Each neuron at the input layer is modelled as a linear unit. The synaptic strength between two neurons is coded as a real number. The working principle of a simple perceptron with two inputs and one output unit could be described by the following example.

Let $\mathbf{x} = (x_1, x_2)^T$ and $z(\mathbf{x})$ be the input vector and the output. The input signal u to the output node z is given by

$$u = w_0 + w_1 x_1 + w_2 x_2.$$

The output $z(\cdot)$ is given by

$$z = h(u), \quad \text{where} \quad h(u) \begin{cases} 1 & \text{if } u \geq 0, \\ 0 & \text{if } u < 0, \end{cases}$$

where w_0, w_1 and w_2 are called the synaptic weights, or simply weights. Let say, there are two groups of samples on a two dimensional plane. If, by visual inspection, we can draw a straight line to separate two groups, we can then find out the equation of the straight line. Let say the equation is that

$$3 + 2x_1 + x_2 = 0.$$

Then, we get that $w_0 = 3$, $w_1 = 2$ and $w_2 = 1$. However, for higher dimension data, it does not work. Then, we will need to apply the Perceptron learning rule to find the weights.

Above example is just a very simple Perceptron, with no hidden layer. In reality, some Perceptron models proposed by Frank Rosenblatt have multiple hidden layers and multiple output nodes. Besides, some models have feedback connections from the output layer to the hidden layers as well. Reader who is interested in this neural network model could refer to [15] for further information.

4.2 AI Research in the 1960s – 1970s

This period of time is also called the AI winter. While Perceptron has drawn public attention in its initial release, it soon encountered its saliency period from 1960s to 1970s. Before the saliency period, neural network approach of learning algorithms development with applications had already attracted many scholars from electrical engineering. Many new models and learning algorithms were proposed and developed, together with vigorous mathematical analysis on the properties of those models and algorithms. These models and algorithms were largely be applied in signal processing and system control. During the saliency period, there were a number of researchers still working on neural network modeling while neural network project did not easily get funded. So, scholars from the major universities (eg. Stanford and UC Berkeley) avoided to put the terms, like 'intelligent', 'neural' and 'learning', on their project titles in order to secure funding from the National Science Foundation, USA. Instead, they use the term 'adaptive system' – the project has nothing to do with neural network.

In this saliency period, many scholars still developed new neural network models and learning algorithms [16, 17, 18]. Many of them were then applied to solve toy problems and some of them were applied to solve real problems. At the same period of time, some scholars worked on the theoretical aspects of neural networks and AI/ML [19, 20, 21, 22, 23, 24]. Some scholars worked on a more general framework and theory for AI/ML and brain [25, 26, 27, 28]. Some scholars investigated the relations between a neural network and a computer from the perspective of theoretical computer science [29, 30, 31, 32, 33, 34]. Three notable scholars in this period are Shun'ichi Amari, Michael A. Arbib and Stephen Grossberg who laid the earliest theoretical foundation for neural networks, AI and the brain. Along with neural network researches, another milestone in this period is the theory of fuzzy set [10, 35, 36].

4.3 AI Research in the 1970s – 1980s

During the second half of the AI winter to the 1980s, there was a gradual growth in the number of research works in neural networks and AL/ML. A number of neural network models and probabilistic models were then introduced. Some notable models are introduced in the following.

4.3.1 Neocognitron

Inspired by David Marr's theory on cerebellar cortex and cerebellum neocortex [37, 38], a Japanese scholar Kunihiko Fukushima developed Cognitron [39] and later Neocognitron [40] computational models for object recognition. These models have later influenced Yann LeCun to develop the convolution neural network for character recognition in the late 1990s [41] and today deep learning [42].

4.3.2 Self-Organizing Map (SOM)

Data clustering is an important problem in statistical analysis. Given a set of unlabelled multi-dimensional data, one would need to figure out how many groups of data in the set. Usually, two criteria are defined to measure the goodness of the clustering. First, each group has to be far away enough from other groups. Second, within a group, the data must be close enough among each other. This problem has not just attracted researchers in statistical analysis but also attracted researchers in electrical engineering and computer science. It is because clustering problem is essentially the same as the data compression (equivalently vector quantization) problem in communication engineering.

While various algorithms had already been proposed in 1970s and applied in real applications, those algorithms were unable to get the topographic relations among clusters, i.e. the neighborhood relations among clusters. In the 1970s, researchers in brain science had already found that the neurons on cerebral cortex can self-organize to form topographic map. Inspired by this finding, Teuvo Kohonen proposed a clustering algorithm called self-organizing map (SOM) [43]. This new algorithm is able to do data clustering and at the same time find the topographical relations among clusters. In the 1990s, SOM has largely been applied in data dimension reduction problems, mapping of a set of high dimensional data to a lower dimensional space.

4.3.3 Oja PCA

Owing to map a set of data from high dimensional space to single dimension space, Erkki Oja proposed a neural network model and a learning algorithm[6] that can let the neural network to learn from the set of data the dimensional space corresponding to the principle component [44]. As the work done by the neural network is exactly the same as the statistical model principle component analysis (PCA)[7], this Oja model is sometimes called the PCA network or simply PCA.

4.3.4 Hopfield Network

Influenced by the binary state of a neuron, John Hopfield showed that a fully connected recurrent neural network with proper design is able to solve travelling salesman problem [45, 46, 47][8] Later, scholars have found that this neural network can be applied to solve other combinatorial optimization problems. Moreover, scholars have showed that the problem solving ability of Hopfield networks could also be enhanced by using the idea of simulated annealing [48, 49, 50, 51].

[6]It is called the Oja rule in some textbooks on neural networks and AI/ML.

[7]If you are familiar with the factor analysis (FA) model, you can consider the PCA model is a special case of FA model, in which the FA model has only one factor.

[8]Today, this recurrent neural network model is commonly called the Hopfield network.

4.3.5 Associative Memory

Alongside with the Hopfield network, associative memory models have been introduced in almost the same period of time [18, 52, 53]. These models are mimicking the memory property of our brains. The earliest models of this type are fully connected, like Hopfield network. The learning rule for these models is the *Hebbian learning*, a learning rule postulated by Donald Hedd in his book entitled *The Organization of Behavior* [54]. Sooner, Bart Kosko presented an associative memory model with two layers [55]. For the neuronal nodes of the same layer, there is no connection among each other. Bart Kosko named it bidirectional associative memory (BAM).

Interestingly, Hopfield network or associative memory has the same structure as the Boltzmann machine (to be introduced shortly) which was introduced by Geoffrey E. Hinton in the same period of time [56]. BAM has the same structure as the restricted Boltzmann machine (RBM) [57] and the logistic belief network [58] introduced by Geoffrey E. Hinton in the 2000s. These models are part of the deep neural networks.

4.3.6 Multi-layer Perceptron (MLP)

In the early 1980s, neural network research came to its second wave in the history. Co-founded by James L. (Jay) McClelland[9] and David E. Rumelhart[10], a group of scholars from various disciplines and different universities across US was formed in UCSD, called the PDP research group, to investigate the psychological basis of human perception and mental phenomena by parallel and distributed processing (PDP) models, i.e. neural network models. The results obtained by the PDP group have later been included in a two volume monographs [59, 60]. By their joint effort, many new neural network models have been proposed and new learning rules are developed. Two notable models are the multilayer perceptron (MLP) and the Boltzmann machine. Instead of using threshold logic unit as the neuronal model, the transfer function of the neurons in the MLP is modelled as a sigmoid function.

$$z(u) = \frac{1}{1+\exp(-u)}.$$

The learning algorithm developed for training a MLP is called the backpropagation (BP). It is also called error BP. Basically, backpropagation is derived based on the idea of gradient descent. With loss of generality, it is assumed that the MLP has only one output node. Given a set of data $\mathcal{D} = \{\mathbf{x}_k, y_k\}_{k=1}^{N}$. Let the model of a MLP is simply denoted by $f(\mathbf{x}, \mathbf{w})$, where $\mathbf{x}$ is the input vector and $\mathbf{w}$ is the weight vector (model parameters). The cost function to measure

[9] `http://www.standford.edu/~jlmcc`.

[10] `https://en.wikipedia.org/wiki/David_Renelhart`.

how good the MLP is given by

$$E(\mathbf{w}) = \frac{1}{N}\sum_{k=1}^{N}\left(y_k - f(\mathbf{x}_k, \mathbf{w})\right)^2.$$

The learning algorithm is given by

$$\mathbf{w} \leftarrow \mathbf{w} - \mu\nabla_{\mathbf{w}}E(\mathbf{w}).$$

MLP has then been applied in solving many engineering problems, like pattern classification, image recognition and system control.

4.3.7 Botlzmann Machine

Boltzmann machine is a fully connected stochastic network. That is to say, the output of each neuron will have to feed to all other neurons. Suppose that the network has n neurons. The output of the i^{th} neuron is denoted as z_i and $z_i \in \{0, 1\}$, a two-state neuron. The weight connecting the i^{th} and the j^{th} neurons are denoted as w_{ij}. Besides, $w_{ji} = w_{ij}$. Each neuron is also associated with a bias θ_i. Now, we can describe the working principle of this Boltzmann machine. For the i^{th} neuron, the total signal received is given by

$$u_i = \sum_{j=1, j\neq i}^{n} w_{ij}z_j + \theta_i.$$

This value determines the probability that the output z_i is one in accordance with the following probability mass function.

$$P(z_i = 1|u_i) = \frac{1}{1 + \exp(-u_i)}, \quad P(z_i = 0|u_i) = \frac{\exp(-u_i)}{1 + \exp(-u_i)}.$$

Once a neuron's output has been updated, another neuron is randomly picked and its output is updated by the same manner. To understand the idea behind the learning algorithm of Boltzmann machine, knowledge in advanced calculus and statistics is required. I stop short in here. If you are interested in this theoretical background, you can refer to the monographs [59, 60] for detail mathematical derivation of the learning algorithm.

4.3.8 Recurrent Neural Network

Owing to understand how speech is perceived, James J. McCleland and Jeffrey L Elman of the PDP research group developed a recurrent neural network model called TRACE [61]. In subsequent decades, various recurrent neural network models were developed and applied in speech recognition. Hopfield network, associative memory, Boltzmann machine and TRACE mark the stage for the early recurrent neural network development.

4.3.9 Belief Network

Belief network or Bayesian network was proposed in 1980s [62]. It conceptualizes the probabilistic reasoning for expert system design. It calculates the probability the happening of an event Z given the appearance of events A, B, C and so on.

4.3.10 Reinforcement Learning

One more remarkable contribution in this period of time is the reinforcement learning [63, 64, 11], in which the idea is advocated by Andrew Barto and Richard Sutton in the early 1980s. It conceptualizes from psychological theory on human learning – operant conditioning – an agent gets reward if its action can reach a temporal goal and otherwise the agent will be penalized. If the agent has been rewarded, the agent reinforces the association between the stimuli and the action. So, the agent could get another reward if the same stimuli appears again. Otherwise, the agent degrades the association between the stimuli and the action. As a result, the agent could avoid punishment if the stimuli appears again.

4.3.11 Applications

In this period of time, major research works in neural networks focused on developing models to explain psychological behavior of a human being, like object and speech recognition; and game playing. Only a few models, from the works in fuzzy systems, have been applied in industrial automation and mechanical control.

4.4 AI Research in the 1990s – 2000s

The UCSD PDP Group has proposed and developed a number of models which could be applied to interpret human reasoning. Since then, explosive number of research works on AI/ML have been conducted. Neural network, fuzzy system and AI/ML had then emerged as hot topics in 1990s and attracted scholars from different disciplines to work together on these areas. Their disciplines include psychology, neuroscience, mathematics, statistics, physics, computer science, electrical engineering, economics, linguistics, philosophy and others.

4.4.1 Computational Intelligence

At the same time, fuzzy logic[11] and genetic algorithm[12] came in place. Genetic algorithms refer to the optimization algorithms mimicking genetic mutation and evolution. Strictly speaking, genetic algorithm is not part of AI/ML. But, genetic algorithm could be applied in neural network researches and fuzzy systems researches. Today, the name genetic algorithms has evolved to the name called

[11] `https://en.wikipedia.org/wiki/Fuzzy_logic`.
[12] `https://en.wikipedia.org/wiki/Genetic_algorithm`.

evolutionary computation. Neural networks and learning systems, fuzzy systems and evolutionary computation become three major topics of interest in the IEEE Computational Intelligence Society.

In the area of neural networks, pioneer researchers in the 1980s continued to develop new models and new algorithms advancing the models and algorithms developed in the 1980s. Other new models and new algorithms from other scholars were proposed in this period of time. Many of them were applied in real-life applications. Thus, some models their designs are no more biological brain-orient. Instead, their designs are application-oriented. For instance, functional-link networks [65], radial basis function (RBF) networks [66, 67, 68, 69] and NARX/NARMAX models [70, 71] are essentially mathematical models oriented. They have no biological or psychological essence.

4.4.2 Statistical Learning Models

In this period of time, a lot of models were proposed. Theoretical analytical works on the properties of the models were conducted. A notable model called support vector machine (SVM) was introduced in the 1990s [72, 73]. Later support vector regression (SVR) machine [74, 75] was introduced. These models have largely been applied in classification problems.

Moreover, the logistic belief network [76], the long short term memory (LTSM) model [77], the restricted Boltzmann machine (RBM) [57] and the deep belief network [58] were developed. They have thus been embraced in statistical learning models and then machine learning models. These models have laid the foundation for the deep neural networks in the 2010s.

4.4.3 Spike Neural Networks

In the 1990s, some scholars in the area of computational neuroscience shifted the model of a neuron from sigmoid function to the biological-inspired neuron models. They include the Lapicque integrate-and-fire model [78], Hodgkin-Huxley model [79, 80, 81, 82, 83], the FitzHugh–Nagumo model [84, 85], the Morris-Lecar model [86] the Hindmarsh-Rose model [87, 88] and others[13].

These neuron models are applied to model biological neuronal networks. Their behaviors could be investigated by computer simulation. This type of neural network is called the third generation neural network, while the early neural network like Perceptron with threshold logic unit as the neuron is called the first generation neural network and the neural network with sigmoidal neuron like MLP is called the second generation neural network.

In the third generation neural network, many new learning algorithms have been developed. Some followed the idea of backpropagation. Some followed closely to a biological learning rule – Spike-timing-dependent plasticity (STDP). The idea is basically the Hebbian learning with the time difference between the firing time of the postsynaptic neuron and the firing time of the presynaptic neuron. If the postsynaptic neuron fires after the receiving of the firing of

[13] https://en.wikipedia.org/wiki/Biological_neuron_model.

the presynaptic neuron, the synaptic strength between the two neurons will be incremented. If the time difference is shorter, the incremental change will be larger. On the other hand, if the postsynaptic neuron fires before the receiving of the firing of the presynaptic neuron, the synaptic strength between the two neurons will be decremented. If the time difference is shorter, the decrement will be larger.

While the spike neural network has captured the most biological brain structure, theoretical analysis on this type of neural network is difficult as the neuron models are complicated. With STDP learning, the analysis is even harder. Therefore, various researches are limited on simulations. While difficult, this area of research has drawn substantial attention in European Union (EU). Thus, a 10-year EU funded *Human Brain Project*[14] has launched in 2013. The project employs some 500 scientists at more than 100 universities, teaching hospitals, and research centres across Europe. Hopefully, more mysteries about our brains could be revealed in the future.

4.4.4 Applications

In this period of time, those intelligent technologies have not yet been transferred to commercial products. Large number of application-oriented researches, especially in system control, were conducted [69, 71, 89, 90, 91, 92]. Various artificial neural network models and fuzzy systems were applied in pattern recognition, automatic target tracking, truck parking, echo noise cancellation, medical diagnosis.

Many intelligent technologies were applied in recommendation systems for product recommendation, search recommendation and target marketing. Some of them were applied in big data analytic for customers preference analysis and consumer behaviorial research.

4.4.5 Notable Events

One remarkable event has to be mentioned. This event has brought to the public the attention on the phenomenal ability of an AI machine. IBM Deep Blue defeated the reigning world chess champion Garry Kasparov[15] in 1997. A computer could defeat human brain.

Another two remarkable events were the release of Apple iPhone in 2006 and the release of Apple iPad in 2010. iPhone is the world first smartphone in the history. Android phones were then designed and manufactured. These smartphones marked the era of mobile commerce in the 2000s and beyond. Subsequently, intelligent APPs were developed for use in these smartphones.

[14] `https://www.humanbrainproject.eu/en/about/overview/`.

[15] `https://en.wikipedia.org/wiki/Deep_Blue_(chess_computer)`.

4.5 AI Research in the 2010s

In this period of time, many notable events had happened. Intelligent products and intelligent services have been developed and available in the marker. As the number of notable events and the number of intelligent products/services are huge, it is not possible to mention them all. Here, I have only selected some of them.

4.5.1 Notable Achievements

IBM Watson defeated human players in an Q&A game Jeopardy in 2011[16]. IBM Watson is actually a collection of intelligent services. It is able to listen to human speech and understand its meaning. If the speech is a question, it is able to search over the Internet for the information to answer the question *verbally*. Apparently, it acts like an intelligent robot. After the Jeopardy challenge, IBM Watson together with other intelligent services have been released to the market for enterprises.

As an assistant professor in Princeton, Fei-Fei Li grouped a team of researchers creating a labelled photo dataset which consists of more than one million photos in 1000 object categories. The dataset named ImageNet was then introduced in 2009 in the *Conference on Computer Vision and Pattern Recognition (CVPR)* in Florida. In the next year, *ImageNet Large Scale Visual Recognition Challenge (ILSVRC)* was launched[17].

A research team in University of Toronto developed an object recognition system won the 2012 championship in the ImageNet Large Scale Visual Recognition Challenge. This system named AlexNet is an extension of the convolution neural networks originated from Kunihiko Fukushima's Neocognitron [40] and Yann LeCun convolution neural network [41] with the use of GPU as computing accelerator. The remarkable fact is that the recognition accuracy of AlexNet achieved 84 percent as compared with the 2011 champion 74 percent. Following the line of research, an advanced version of the system eventually surpassed human-level performance in 2015[93]. These promising results have eventually triggered a booming growth of deep learning researches and the use of GPUs as accelerators. In 2017, most systems could achieve 95 percent accuracy.

Google AlphaGo defeated Sedol Lee in a five-game match of Go game[18] in 2016. In the subsequent years, Google developed advanced versions of AlphaGo, the AlphaGo Master, the AlphaGo Zero and AlphaZero, and started the matches between machines.

In 2016, Google has also released a new version of Google Translator which applies a new translation system called Google Neural Machine Translation System[19].

Moreover, various intelligent virtual assistants were developed in this period of time. Apple released Siri for iPhone in 2011. Google developed Google

[16]https://en.wikipedia.org/wiki/Watson_(computer).
[17]http://image-net.org/index.
[18]https://en.wikipedia.org/wiki/AlphaGo.
[19]https://en.wikipedia.org/wiki/Google_Neural_Machine_Translation.

Assistant for use in Android phones and Google Home. Amazon developed Alexa for use in Amazon Echo. Google Home and Amazon Echo are intelligent assistants for use at home.

4.5.2 Intelligent Services on Cloud

Today, many cloud platforms (Amazon Web Service, Google Cloud, Tencent Cloud, Alibaba Cloud) have provided intelligence services and APIs for developers to develop new services over these cloud platforms. Besides, some of these platforms have also provided virtual GPU service for those who would like to develop new intelligent technologies.

4.5.3 Industrial AI Research

Various tech giants have invested in their AI research programs. Apart from IBM and Microsoft which have a long history in AI research, Google, Amazon, Facebook, Intel, Nvidia, BMW, Tecent, Alibaba, Baidu and many others have allocated budget for AI & Machine Learning research and applications. Moreover, they have formed research teams with particularly focus on the theory and applications of AI & Machine Learning. Some of them, like Google and Facebook, have even developed AI libraries for the community to develop advanced applications of AI & Machine Learning. Here is a list of industrial research centers on AI and machine learning.

1. Alibaba Research Center For Complexity Sciences.
2. Amazon Research Center, Amazon Lab 126 (`https://www.lab126.com`).
3. Apple Machine Learning Research.
4. Baidu Research Institute.
5. Cisco Research Center.
6. Facebook Research.
7. Google Research.
8. Huawei AI.
9. IBM Research.
10. Intel AI Research.
11. Microsoft Research.
12. Nvidia Research on Machine Learning and AI.
13. Oracle Labs.
14. Qualcomm Research.

15. SAP Innovation Center Network.

16. Tencent AI Lab (Theoretical research) and Tencent YouTu Lab (Applications)

Along with the advancement in (1) computer technologies like multi-core processors and nano-scale fabrication technology, (2) information & communication technologies (ICT) like 4G/5G and WiFi; (3) intelligent technologies like deep learning and (4) robotic control, AI/ML has finally been applied in various professional disciplines, including but not limited to medical diagnosis [94, 95], business administration [96, 97], auto-driving[20] and many industrial applications[21]. Researches on making machine more intelligent have been undergoing. Something amazing could appear in the future, see Table 1.

4.6 Recent Applications

Similar to that of information technologies, intelligent technologies are something that have tremendous indirect effects on management practise. Spelling-check, grammar-check and auto-correction functions in MS Word ease a lot of work of a staff. These functions are basically realized by a number of intelligent algorithms embedded in the software. In a famous enterprise resource planner (ERP) SAP, intelligent algorithms have also been embedded to help solving supply chain management, materials requirement and other difficult mathematical problems.

In the Internet, various different kinds of intelligent technologies have already been applied in various aspects in network routing, network management and security management. Without such technologies, lots of management activities could not be running smoothly. In the end, the performance of a management process will definitely be affected.

If you have been using Google to search for information, you will notice that Google can intelligently give appropriate suggestions to your query. This intelligent function always can reduce the time spent in searching. This intelligent feature can also be found in other platform. Amazon gives recommendations while you are searching for one particular item. While you are searching for some particular things, Google will put some appropriate advertisements for you, so as in YouTube, FaceBook and Bing.

In the development of automation and robotic technologies, various different kinds of intelligent technologies have already been applied in the design of the control systems for such mechanical systems. With the new automation and robotic technologies, light-off factories are made possible.

[20] `https://en.wikipedia.org/wiki/Self-driving_car`.

[21] `https://en.wikipedia.org/wiki/Artificial_intelligence_in_industry`.

5 Benefits & Threads

5.1 Advancing Development of Technologies

Internet of Things (IoT) will be the future trend of the technologies development. It means that every device is connected to the Internet integrating computing capabilities and using data analysis to extract meaningful information. As devices are connected to each other, they can become an intelligent system of systems sharing data over the cloud. It will then transform the business, our lives and our world in countless way, such as creating better products faster with lower development costs, or optimizing energy generation and consumption. More intelligent personalized services could be deployed in the future.

Here is an example of a big picture of IoT. There is a smart traffic camera and the camera can monitor the road for congestion, accidents, and weather conditions with data from other cameras, creating an intelligent citywide traffic system. The intelligent traffic system will also be connected to other transportation systems, which get data from their own intelligent devices. If a traffic accident occurs near the airport or school, they can be notified by these smart systems, so that the airport or school can adjust their schedules. Also, people can be notified to drive optimal routes around the accident and the system will send instructions on the city's digital sign system to guide drivers around the accident.

5.2 Advancing Intelligence of Machines

Another big change will be the intelligent technologies. As mentioned in Section 4, IBM Deep Blue, IBM Watson and Google's AlphaGo have already demonstrated their intelligence in many games competing with human contestants. Their successes are due to two major breakthroughs. One is the huge back-end computational resources networked to the front-end terminals. The other is the machine learning (AI) algorithms for analyzing the information to give the best answer. Through the front-end terminal, the engineer could access and control the back-end computational resource to collect huge volume of information over the Internet, analyze the information by some machine learning algorithms and then give the best answer to the engineer. The processing time is almost instantaneous.

On-going researches on artificial intelligence and machine learning have recently conducted intensively in Amazon[22], Facebook (Facebook AI Research[23]), Google (Google Brain[24]), IBM (AI and Cognitive Computing[25]), Microsoft (Machine Learning and Optimization[26]). Even Apple, she has started her AI research in 2016 [98]. One major driver for these researches is NVIDIA's graphical

[22] https://aws.amazon.com/amazon-ai/.
[23] https://research.fb.com/category/facebook-ai-research-fair/.
[24] https://research.google.com/teams/brain.
[25] http://research.ibm.com/cognitive-computing/.
[26] https://www.microsoft.com/en-us/research/group/machine-learning-and-optimization/.

processing units (GPU) [27] and the cloud technologies.

Running a machine learning algorithm is always time consuming if the program is running in any conventional multi-core computer. GPU is basically a CPU specialized design for mathematical computation. Initially, it was designed for processing graphical data. As its computational speed is hundred to thousand time faster than the normal CPU, it has then been applied in running computational intensive machine learning programs for tagging 1.3 millions images [99] and tagging 8 millions video [100]. Another major drive is clearly the cloud, a network of memory and computational resources.

Some of these research results together with their cloud platforms have already been commercialized as intelligent services for anyone who is interested in developing more sophisticated intelligent services for users, like Amazon Machine Learning Services[28], Google Cloud Machine Learning Platform[29] and IBM Watson[30]. Some of these have been commercialized as intelligent business solution for enterprises, like SAP HANA Cloud Platform[31]. Researches in AI for sure will never stop. More intelligent results will show up in the future and more intelligent services will come in the market. More new automation and robotic technologies will be advanced due to the application of AI [101].

5.3 Decline Demand of Administrative and Managerial Staffs

Earlier in the nineteenth century, political economists had already observed and raised the issue on the reduction of wages or quantities of labors due to the employment of machinery. As asserted in the book entitled *On the Principles of Political Economy, and Taxation* written by David Ricardo in 1821 [102], (P.22) *The principles that the quantity of labour bestowed on the production of commodities regulates their relative value, considerably modified by the employment of machinery and other fixed and durable capital.* Ricardo clearly stated that the value of a labor has to be compared with what a machine could do. If a machine could do a better job than a labor, the value of a labor declines.

In the late nineteenth century to the earlier twentieth century, many firms hired a lot of clerks and secretaries to use typewriters for typing paper documents. In the middle of twentieth century, photocopier and computer were invented. Their works were thus replaced by these machines (see P.64-65 in [103]). With further advancement in automation and robotic technologies, demand of human workers in agricultural and manufacturing industries will certainly decline.

Networking technologies led to the reduction of office assistants. Advancement on the intelligent functions of information systems (including management information systems, decision support systems, executive information systems,

[27] `https://www.nvidia.com/en-us/deep-learning-ai/`.
[28] `https://aws.amazon.com/machine-learning/`.
[29] `https://cloud.google.com/products/machine-learning/`.
[30] `https://www.ibm.com/watson/`.
[31] `http://www.sap.com/developer/topics/hcp.html`.

supply chain management systems, customer relationship management systems and enterprise resources planning systems) not just eases the jobs of administrative and middle management staffs but also reduces the demand on such staffs. With such powerful information systems, the jobs used to be done by these administrative and middle management staffs could now be easily handled by the senior management staffs.

With further advancement in big data, Internet of Things, automation & robotic, and artificial intelligence, (i) a lot more management information systems could be available in the market, (ii) the intelligent levels of such systems would be raised and (iii) factories could be networked together to form a giant autonomous factory producing every thing[32]. As a result, administrative and middle management jobs will also decline [33].

5.4 The End of Middle Management

In an article in BBC entitled "The end of middle management?" [107], Sydney Finkelstein has pointed out that technology (like computer) is not the only factor leading to the end of middle management. The culture of start-up firms do not like middle managers. The behavior of millennials at work – they believe that they know more than they do. All these factors constitute the down-value of middle management and eventually lead to the end of middle management.

Once the demand of the administrative, production and middle management staffs declines, the roles of human resource management will change and the demand of human resource professionals will definitely be reduced. In the future, the works of senior managers and executives could also be replaced by AI [108]. In the end, management schools would be obsolete. Some of them would have to change their focuses and their roles in the society. Some might have to scale-down the number of undergraduate programs, as the students educated in these programs might not be able to compete with the future AI systems.

Moreover, I agree what Jeffrey Joerres mentioned in P.79 in [104]. Management schools should be refashioned to educate graduates with skills that the companies need. But, I like to add a point which is in a spirit originally from Chester Barnard (P.176 in [109]). Management schools should re-focus their roles in helping students to learn how to learn in their life-times.

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[32] Imagine that the factory will look like the research center built by Dr. Will Caster (Johnny Depp) and his wife Evelyn (Rebecca Hall) in the movie *Transcendence*. See `https://www.youtube.com/watch?v=VCTen3-B8GU` for the official trailer and `https://en.wikipedia.org/wiki/Transcendence_(2014_film)` for introduction.

[33] Readers could refer to an article in *Harvard Business Review* [104] (specifically P.76) for the viewpoints from a former CEO of a multinational human resources consultancy firm on the decline demand of human labors, an article in Forbes [105] on the issue about how AI replaces human labor, and an article in Forbes [106] that looks at the issue in an opposite side.

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A List of Technologies Before 1990

1. Four inventions: Compass, gunpowder, papermaking, printing
2. Scientific revolution (16 Century)
3. Agricultural revolution (17-18 Century)
4. Steam engine (18 Century, Industrial revolution)
5. Automatic control (mechanical components)
6. Electricity, electric motors, electricity supply (19 Century)
7. Vacuum tube (John Ambrose Fleming 1904): diode, triode, other electronic components
8. Automatic control (mechanical and electrical components)
9. Tube-based electronic computers (1930s)
10. Semiconductor devices (1947)
11. Monster computers and information systems (1950s, LEO and UNIVAC)
12. Transistor-based electronic computers (1950s)
13. IBM System 360, IC-based electronic computers (1960s)
14. Computer networking 1965-1983 (Computer communication, computational resources sharing, email)
15. Microprocessor (1960s)
16. Microprocessor-based electronic computers (1970s), microcomputer.
17. Personal computers and personalized systems (1970s, Apple)
18. Automatic control (mechanical and electrical control systems equipped with programmable electronic controllers or computers)
19. Mobile phone (1980s)
20. Reduced instruction set computing (RISC) processors (1980s)
21. Internet and World Wide Web, 1990s (Websites, application software sharing, e-commerce, cross-border information systems, Web 2.0)
22. Robots (Robotic arms, entertainment robots, humanoid robots)
23. Business process automation

B List of Current ICT

1. 4G LTE, 5G; WiFi, WiMax
2. Multicore CPU, RISC, ARM, Systems on Chip (SoC)
   - Case Study (SoC): Qualcomm Snapdragon
3. GPU, GPGPU, NPU, VPU, TPU
4. IBM Power processor series
5. Sensors: Accelerometer, barometer, body temperature sensor, gyroscopic sensor, heart-beat sensor, magnetometer, proximity sensor
   - Case Studies: iPhone 8 and iPhone X
6. Network (Information) security
7. Mobile devices – Notebooks, iPhone, iPad
8. Wearable devices – smartbands, Apple Watch
9. Virtual reality (VR), augmented reality (AR) – HTC Vive, Google Glasses, Microsoft HoloLens
10. Personal area networks – iPhone + NBs + Headset
11. Mobile ad hoc network (MANET) – Mobile sensor network (MSN), Vehicular ad hoc network (VANET).
    - q Case Studies: Google Loon and Facebook Aquila
12. Peer-to-peer computing (1990s-2000s)
13. Cloud computing (2000s): Alibaba Cloud, Amazon Cloud Service, Google Cloud Platform, IBM Cloud, Microsoft Azure, SAP Cloud Platform, Oracle Cloud, Salesforce, Tencent Cloud, Dropbox, etc.
14. Fog and edge computing (2010s-)
15. Internet of Things (IoT) : Cyberphysical systems (Networking of customers, manufacturers (workers and machines), R&D teams, 3PL firms (workers, machines, trucks, vessels, planes), government agencies (officers and machines), and etc.), agriculture and farming, heath care
16. 3D printing, flying robots
    - Case Study: Walmart Robot `https://www.youtube.com/watch?v=_PErP8gGli4`
    - Case Study: Carrot harvesting `https://www.youtube.com/watch?v=xDsZC-s6V9g`

- Case Study: Rice box production `https://www.youtube.com/watch?v=NT2FZ5PbdhI`
- Case Study: Automated BMW Car Factory `https://www.youtube.com/watch?v=VpwkT2zV9H0`

C List of Current Intelligent Technologies

1. Intelligent agents (software robots)
2. Data mining, big data analytic and data science
3. Image/Language/Document/Video understanding
   - Case study: iPhone Siri
   - Case Study: Deep Learning in 11 Lines of MATLAB Code `https://www.youtube.com/watch?v=-ENmRfKWjmo`
   - Case Study: Facebook photo tagging, Google image tagging, Google Captioning Project
   - Case Study: Google Image Search, PlantSnap
   - Case Study: Google Translate, Apple QuickType
   - Case study: Amazon Alexa, `https://www.youtube.com/watch?v=sulDcHJzcB4` and `https://www.youtube.com/watch?v=FQn6aFQwBQU`
   - Case Study: BMW Intelligent Personal Assistant `https://www.youtube.com/watch?v=NP-ZzuKAD8k`
4. Video: Deep Learning Research and the Future of AI – `https://www.youtube.com/watch?v=5BrNt38OraE`
5. Recommender systems
6. Sentiment analysis (Text, images, sound, video)
7. Social network analysis
8. IBM Deep Blue, AlphaGO, IBM Watson
9. Machine vision, object recognition, target tracking, sentiment analysis
   - Case study: IBM Creates First Movie Trailer by AI for 20th Century FOX, `https://www.youtube.com/watch?v=gJEzuYynaiw`
10. Autonomous vehicles
    - Case Study: Automated guided vehicles (AGV) in Amazon Fulfillment Center `https://www.youtube.com/watch?v=dAXdeqcHBp4`
    - Case Study: AGV in Amazon Warehouse `https://www.youtube.com/watch?v=UtBa9yVZBJM`
    - Case Study: Alibaba warehouse robots `https://www.youtube.com/watch?v=FBl4Y55V2Z4`
    - Case Study: Self-Driving vehicles, Autonomous trucks, Intelligent Autopilot System

11. Brain machine interface – Engineering brain-computer interfaces to regain control of movement https://www.youtube.com/watch?v=ZpTgdQEJc6I

12. Integrating Brain-Computer Interface Technology with Augmented and Virtual Reality. Paul Sajda, https://www.youtube.com/watch?v=fn9eBJFvSuA

13. Probabilistic processors

14. AIML Platforms/Environments

    - Google Cloud
    - Amazon Web Services
    - Alibaba Cloud
    - Tencent Cloud
    - Vertex.AI
    - Apple Core ML 2

15. AI/NN Chips

    - Apple "Neural Engine" in A11 Bionic (should be for deep learning)
    - Apple "Image Signal Processing Unit" (ISP) in A11 Bionic
    - Huawei "Neural Processing Unit" (NPU) in Kirin 970 (deep learning)
    - Google on-device AI "Federated Learning"
    - Google "Tensor Processing Unit" (TPU)
    - IBM TrueNorth Chip (Spike NN, 1 million neurons and 256 million synapses)
    - Intel Movidius Myriad "Vision Processing Unit" (VPU)
    - Intel Nervana Neural Network Processor family (previous codename Lake Crest, deep learning)
    - Nvidia "Graphic Processing Unit" (GPU), deep learning accelerator.