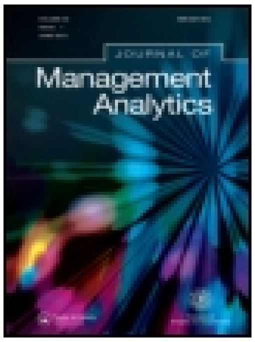

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Artificial intelligence: a survey on evolution, models, applications and future trends

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Artificial intelligence (AI) is one of the core drivers of industrial development and a critical factor in promoting the integration of emerging technologies, such as graphic processing unit, Internet of Things, cloud computing, and the blockchain, in the new generation of big data and Industry 4.0. In this paper, we construct an extensive survey over the period 1961–2018 of AI and deep learning. The research provides a valuable reference for researchers and practitioners through the multi-angle systematic analysis of AI, from underlying mechanisms to practical applications, from fundamental algorithms to industrial achievements, from current status to future trends. Although there exist many issues toward AI, it is undoubtful that AI has become an innovative and revolutionary assistant in a wide range of applications and fields.

Keywords: artificial intelligence; deep learning; Internet of Things; Industry 4.0; graphic processing unit; big data

Introduction

Beginning with the invention of computers that required human manipulation in the 1950s, researchers spent more than half a century on developing the independent learning capability of computers. This leap is not only a milestone in computer science, but also in industry and human society. In a sense, computers have evolved to the point where they can complete new tasks themselves. Future artificial intelligence (AI) will adapt to and interact with humans through their native language, movements and emotions. With the popularity and interconnection of various intelligent terminals, people will not only live in real physical space, but also stay in the digital virtualized network. In this cyberspace, the boundaries between human and machines will be pre-diluted (Doshi-Velez & Kim, 2017; Goertzel, 2007; Russell & Norvig, 2016).

Any theory, method, and technique that helps machines (especially computers) to analyze, simulate, exploit, and explore human thinking process and behavior can be considered as AI. It's the computation and computing of data in intelligent ways. AI is the study of features of human activities, constructing a certain intelligent system, to make computers complete the tasks that only human is able to do in the past, and to apply computer hardware and software to simulate the underlying

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theories, approaches and techniques of human behavior. Has been developing for more than 60 years, AI has become a multidisciplinary and interdisciplinary of natural sciences and social sciences consisting of diversified disciplines (Došilović, Brčić, & Hlupić, 2018; Mata et al., 2018; Murphy, 2012; Tan & Lim, 2018).

AI is more widely used in specific industrialization and commercialization projects, showing new development trends. (1) Deep Learning plus Big Data has become the mainstream for the development of AI. Artificial Neural Networks (ANNs) enable robots to learn and think like humans and to handle more complex tasks. (2) AI has gradually entered the stage of technological R&D and industrialization initiated from the experimental research. It has matured commercial products in image and speech recognition, national language processing (NLP), predictive analysis, etc. (3) The application of AI is gradually expanding from the commercial and service industries to the manufacturing and agricultural fields, which make the general technology and basic technical features of AI more prominent and spread (Doshi-Velez & Kim, 2017; Došilović et al., 2018; Goertzel, 2007; Mata et al., 2018; Murphy, 2012; Russell & Norvig, 2016; Tan & Lim, 2018).

AI is a broad field, which attracts many attentions from different countries and institutions. In detection and forecasting, Chinese scholars construct different types of artificial intelligent models to predict petroleum consumption, and different models provide attributes from various angles about oil consumption (Li, Wang, Wang, & Li, 2018). Multiple artificial intelligent algorithms are applied and compared to analyze rainfall of summer and fall seasons in India. The prediction accuracy is closely related to data, hidden layers, and procedures (Dash, Mishra, & Panigrahi, 2018). AI algorithms are employed to assess the water level in Morocco and Poland. Practice has proved that the wavelet transform is an efficient pre-processing tool, which can get more accurate prediction (Baali, 2018; Piasecki, Jurasz, & Adamowski, 2018; Yu et al., 2018). And compared with regression, ANN associated with image recognition can better predict stand parameters of the forest in Turkey (Sakici & Günlü, 2018).

In education, according to an online survey of students from Canadian medical schools (Gong et al., 2018; Tang et al., 2018), education could add AI as a supplement to radiology in the curriculum. In the financial market, there exist big amount of data, which could be utilized by artificial intelligent algorithms. But the results from the AI analysis of US and Chinese stock market claim that artificial intelligent mechanisms need to be adjusted and verified based on conventional economic analytics (Chen et al., 2018; Weng et al., 2018). In Luxembourg, AI-related data-driven courses are offered at the PhD degree level (Bordas, Natarajan, & Zilian, 2018).

In the healthcare industry, Chinese hospital uses AI-based clinical support system to treat patients who have lung cancer (Liu, Liu, et al., 2018). In software and mobile technology, developers adopt specific AI algorithms to program a mobile game (Ultranus), which distinguishes classification and difficulty levels of different groups of people (i.e. children and adult) by traditional Indonesian culture storyboard composed of snakes and ladders (Rokhmawati, Kusumo, Wahyoho, & Irawati, 2018). In addition, many countries or places start to constitute policies and regulations accompanying to the upcoming AI society, such as Asia (India), Europe (UK), Latin America, and North America (US) (Cath, Wachter, Mittelstadt, Taddeo, & Floridi, 2018; Corvalan, 2018; Marda, 2018).

Popular scenarios of AI

Robot is an important product of AI. It has been widely used in space exploration, warehouse management, medical diagnosis. For example, in space exploration, due to the fragility of the human body, there is a large amount of radiation in many places. People in these areas cannot enter, so robots can be used instead of humans to detect and explore. AI developed a warehouse management system in logistics warehousing applications. Warehouse management can use the camera, temperature and humidity sensors, mold sensors to obtain warehouse information, provide this information to warehouse administrators in real time, and analyze historical warehouse data to ensure warehouse operations and safety. Medical diagnosis has always been an important area of information development and application. In order to improve the level of medical diagnosis, pattern recognition technology is introduced in CT image processing, and the contours of various organs in the image are found by combining the characteristics of various organs of the human body. The introduction of AI into medical diagnosis can greatly improve the level of treatment and medical performance.

In this study, we will answer and explain the following issues:

- Describing the history of AI in details between 1961 and 2018.
- Explaining why deep learning develops so rapidly and listing its popular models.
- Illustrating the current mainstream AI applications and examples in industries.
- Addressing and discussing the potential challenges and issues facing AI.

The survey structure is indicated in Figure 1. Section I is the introduction. Readers could have a general understanding of AI and the current development in different countries. Section II is the research taxonomy. Readers could learn about the specific methods of examining and exploring relevant literature (7752 in total) from 4 databases and other related AI research trends. Section III is the evolution of AI from 1961 to 2018. The basic three stages of development of AI are elucidated. Section IV is deep learning. As the target of today's AI, it is necessary to briefly introduce and explain underlying principles and models in deep learning. Section V is the AI applications in industries. Our research does not include all industries related to AI. The up-to-date industrial applications were illustrated and discussed. Section VI is the potential challenges and future directions of AI. Readers could have a relatively complete view of the various challenges on AI. Section VII is the conclusion.

Research taxonomy

Designed to obtain a comprehensive analysis on the qualified literature (Tranfield, Denyer, & Smart, 2003; Webster & Watson, 2002), we searched articles in four major databases: WoS (Web of Science), IEEE Xplore, INSPEC, and ScienceDirect. The time period is between 1961 and 2018. AI is such hot topic that so many papers and conference proceedings published in journals, thus, our search narrowed to focus on the titles including "artificial intelligence". A total of 8599 articles were searched. The detailed procedure is shown in Figure 2.

We then processed two rounds of filtering to remove the same articles collected in different databases and to synthesize the content of the selected articles. Specifically, 699 articles were deleted because of duplication and 378 articles were deleted

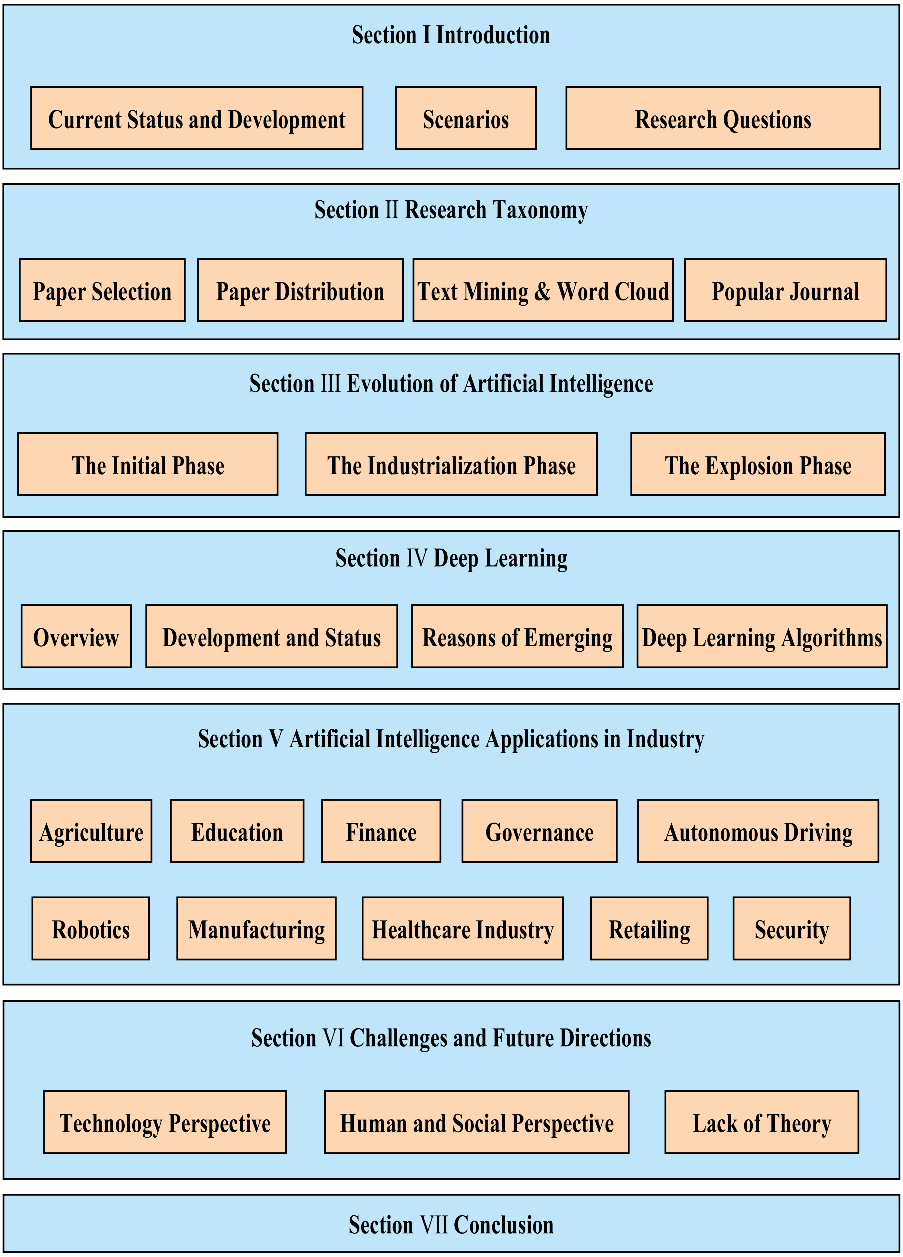

Figure 1. Structure of the study.

through text mining because any article that is not directly related with AI was removed. Finally, 7752 articles were selected as the paper pool for text mining. WoS has the greatest number of articles as 3585, the other 3 databases include even numbers of articles of 1568 (IEEE Xplore), 1303 (INSPEC), and 1066 (ScienceDirect), respectively (Figure 3).

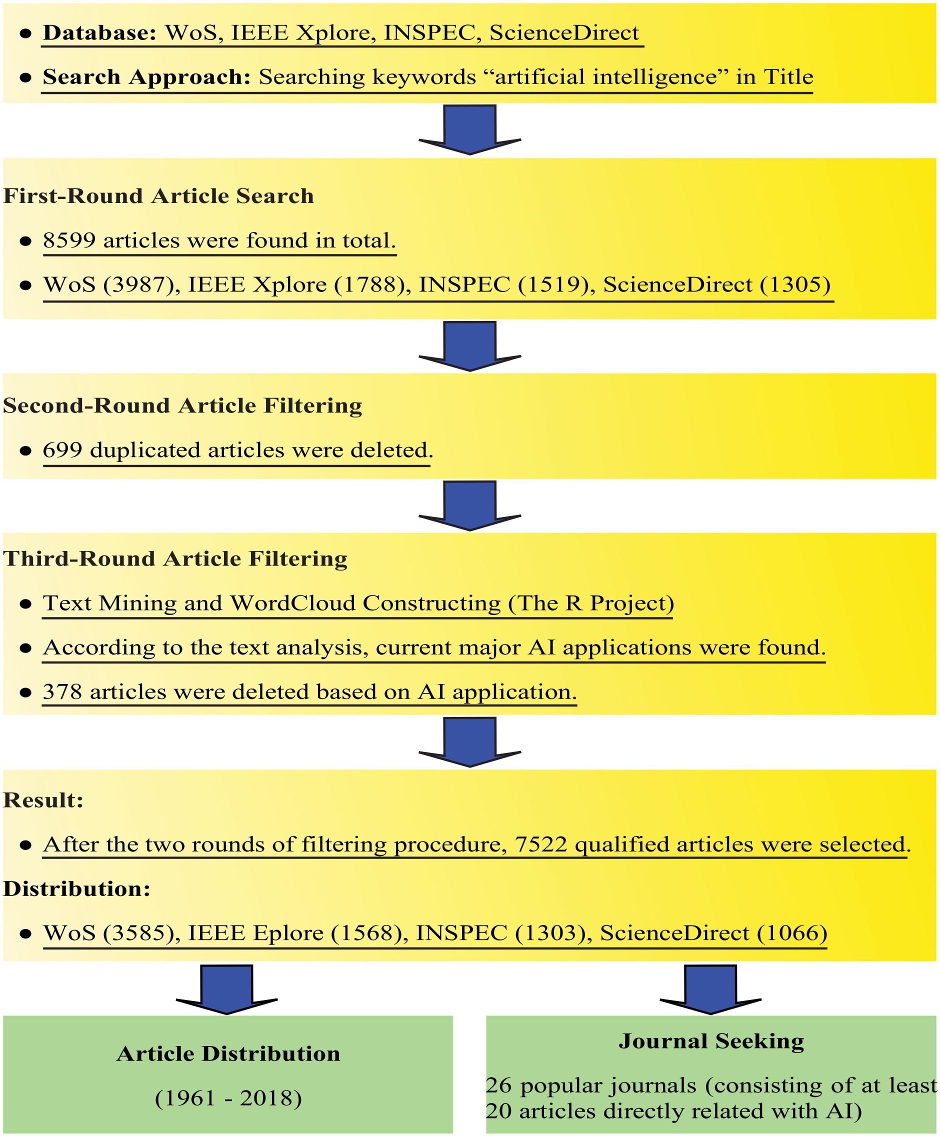

Figure 2. Research taxonomy.

To refine the relevant articles, two criteria were used to examine the title, abstract, and keywords: (1) Word Cloud and (2) Word Frequency. We implemented R project to text mine and synthesize the contents of each of the selected 7752 papers. For criteria (1), word seeking and "Word Cloud" techniques were used to implement keywords, such as "artificial intelligence", "healthcare", "robotics", "techniques", "system", "recognition", "manufacturing", "energy", "education", "agriculture", etc.; for criteria (2), the minimum frequency of the common words is 50 times. As shown in Figure 4, common words related to AI were collated and constructed as a word cloud, from which a holistic picture of the main

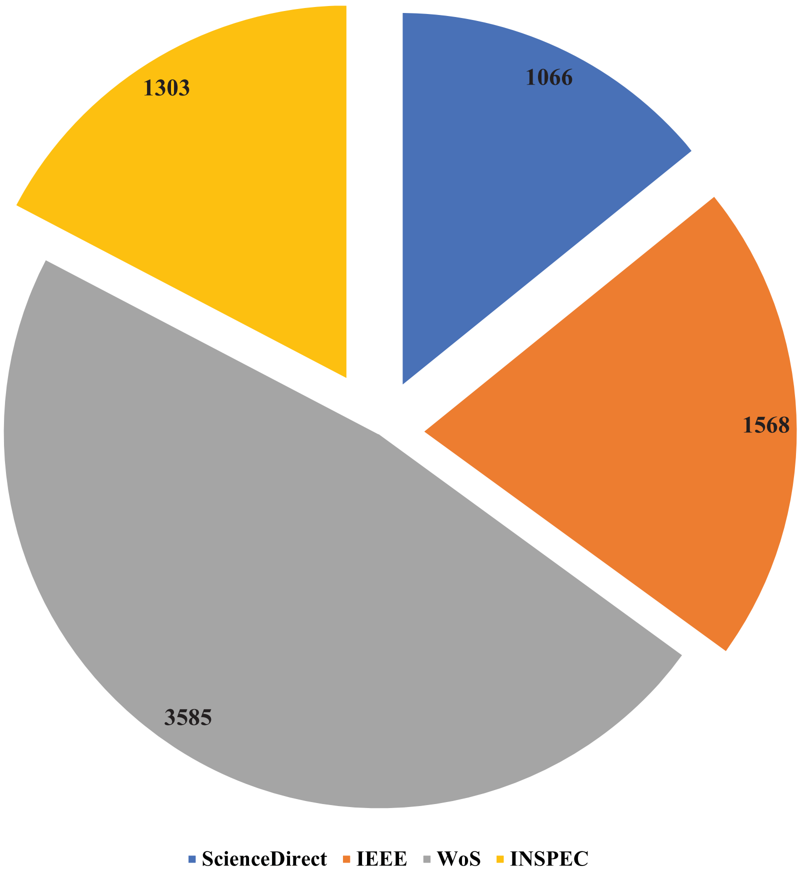

Figure 3. Number of articles from the four databases.

application of AI in industry is illustrated as well. Based on the text mining results and the selected articles, industries that AI applied and highlighted in this study are agriculture, autonomous driving, education, finance, governance, intelligent robotics, manufacturing, the healthcare industry, retailing industry, and security.

The next step is the distribution of the article. During the years 1961 and 2018, all 7752 articles were examined. As can be seen in Figure 5, the overall distribution (gray line with stars) clearly shows that the development of AI has experienced two summits: the first was between 1985 and 1995, the second was started since 2006. By comparing articles distributed in the four databases, the distribution of articles from 1961 and 2018 is very similar. It supports the evolution of AI: the initial phase (1961–1980), the industrialization phase (1980–2000), and the explosion phase (2000–).

Another step of literature analysis is journal seeking. In our study, we found 26 popular journals that published at least 20 directly related AI papers (Figure 6). The top three journals are Expert Systems with applications, AI Magazine, and IFAC Proceedings Volumes, with 92, 80, and 80 papers respectively.

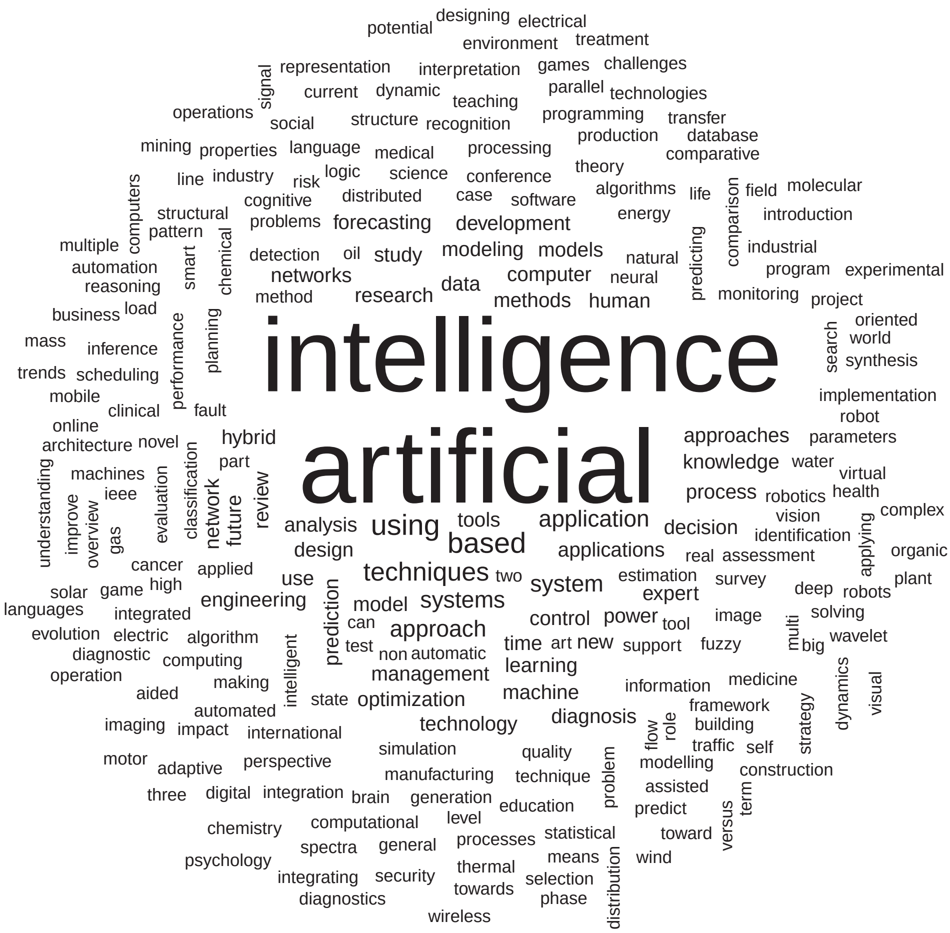

Figure 4. WordCloud of key applications in AI.

Evolution of AI

In terms of time dimension, AI has gone through about three steps of development (Table 1): the initial phase (1956–1980), the industrialization phase (1980–2000), and the explosion phase (2000–).

The first major development of AI was from 1956 to 1980, when AI was only used to solve algebraic application problems, proving geometric theorems and learning English. In 1956, at Dartmouth University in the United States, some young and promising scientists such as McCarthy and Minsky participated in a conference to study and explore the use of machine simulation intelligence. At this gathering, they tried to find out how to make the machine think like a human, how to let the machine communicate in natural language, how to get the machine to a certain extent of intelligence, and the first time to provide AI. The Dartmouth conference is also known as the origin of AI.

The second major development of AI was from 1980 to 2000. The Japanese government allocated huge amount of money to support AI and began the fifth-generation

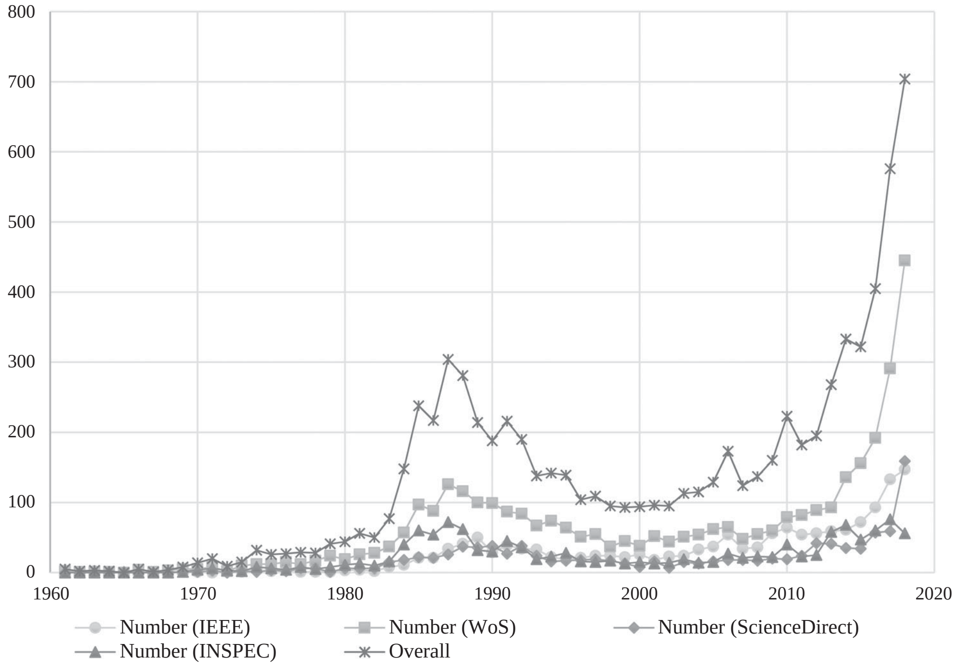

Figure 5. Article (7752) distribution between 1961 and 2018.

computer program. The goal was to create machines that support human-machine dialogue, translation and image recognition. Subsequently, some developed countries in Europe and the United States also responded and began to provide substantial funding for AI research. At this stage, “knowledge processing” is the focus of AI research.

The third major development in AI was from 1993 to the present. With IBM’s deep blue victory, Google’s AlphaGo defeated the sensational event of world champion Li Sedol, let the world see some of the iconic results of AI. Especially in recent years, with the development of the Internet, big data, and graphic processing unit (GPU), AI technologies such as speech recognition and image recognition have been applied to the real life of ordinary people.

In the late 1990s, early 2000, a lot of work in the field of AI was building the theoretical foundations and machine learning (ML) tools to process and analyze data. In the first 10 years of the twenty-first century, the world was experiencing an explosive growth of the Internet age and the information age. The world was starting to be filled with data, especially data from cyberspace. And, as the sensors and devices started to collect a lot of different types of data. So quietly these two things along with the progress of computing and hardware. The slower that was carrying the information age, really started to converge in a way that most people didn’t expect. Toward the very end of the first decade of the twenty-first century, around 2010, 2011, 2012, the field of AI was suddenly playing with a lot of data. Using algorithms that have gone through generations of trials and errors started to see the amazing effect. The key moment of deep learning on the network was 2012.

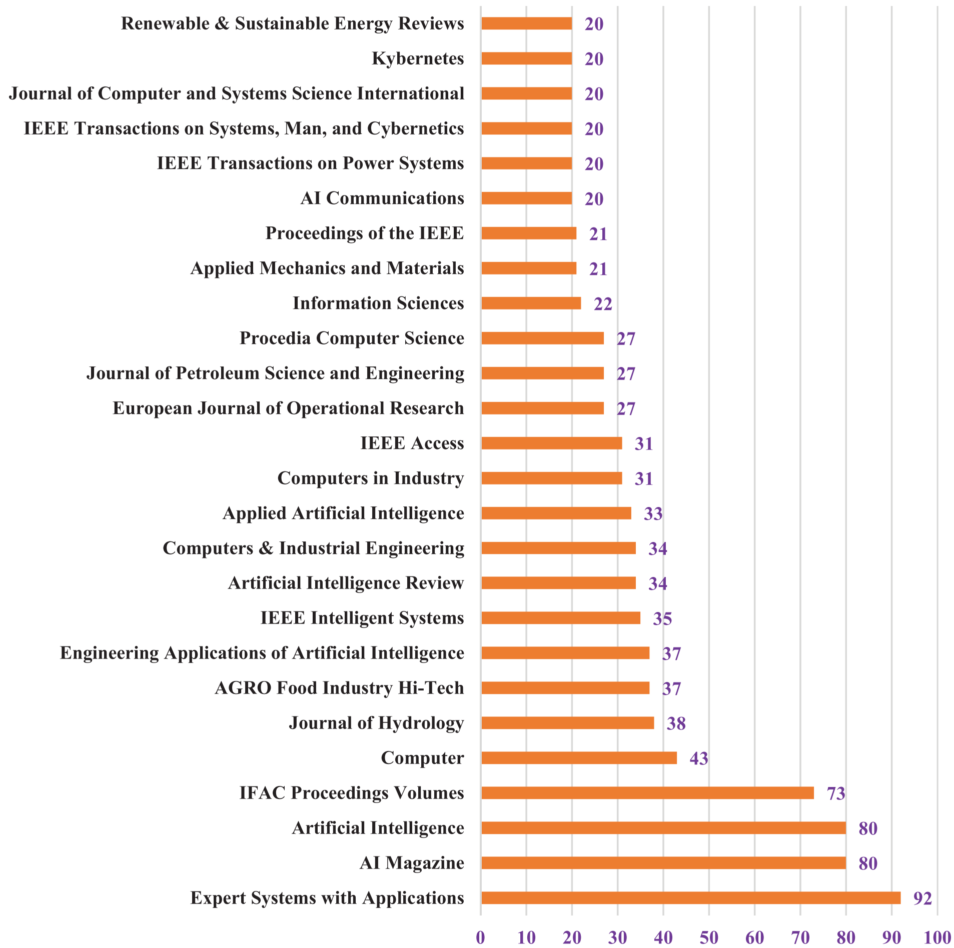

Figure 6. The distribution of publication in journals (20 papers or more).

In the past 20 years, since IBM "Deep Blue" defeated Kasparov in the chess games, the technology has received extensive attention, but the foundational theory has not seen a breakthrough. Due to the rapid development of network information technology and distributed computing theory, the computing power available in the world has grown exponentially. Some AI applications have exceeded expectations, and AI has once again become a hot topic in all walks of life.

Deep learning

Overview

How to analyze and identify heterogeneous data and information has attracted wide attention. Deep learning has opened a window for us to understand the world to a higher level. Deep learning techniques simulate large-scale structures of the cerebral cortex through large-scale data training, and design complex multi-layer ANN models. Through multi-level learning of the data, we finally learn different levels of

Table 1. Evolution of artificial intelligence.

Time	Events	Country
The Initial Phase (1956–1980)		
1950	Alan Turing published a landmark paper indicating that machine was possible to be intelligent. The Turing Test was the first proposal in the philosophy of AI.	UK
1956	The Dartmouth Conference in the United States gathered the first researchers to determine the name and mission of AI. This event is the starting point for AI.	USA
1957	Frank Rosenblatt, a psychologist at Cornell University, implemented a neural network "perceptron".	USA
1957	GPS (General Problem Solving) extended Wiener's feedback principle and solved many problems.	
1958	McCarthy developed LISP (List Processing) language.	USA
1967	Waseda University launched the WABOT project in 1967 and assembled the first full-size smart humanoid robot WABOT-1 in 1972.	Japan
1969	The International Federation of Artificial Intelligence was established in Seattle, USA, and held its first meeting.	USA
1974–1980, because of the limitation of computing and related techniques, AI was under a low level of development.		
The Industrialization Phase (1980–2000)		
1980	Carnegie Mellon University designed an expert system called XCON for DEC and achieved great success.	USA
1982	Japan invested 850 million US dollars to develop AI computers. The goal is to enable machines to think in the same way as human, achieving human-computer interaction, language translation and image recognition.	Japan
1982	Physicist John Hopfield invented a neural network that could learn and process information in new ways.	USA
1986	The appearance of multi-layer neural networks and BP response propagation algorithms improved the accuracy of automatic recognition.	
1980–1987, companies around the world have adopted AI programs called "expert systems", and knowledge expression systems have become the focus of mainstream AI research.		
1988	The German Artificial Intelligence Research and Center was established. It is the world's largest non-profit AI research organization.	Germany
1997	The "Deep Blue" defeated the chess champion. After being influenced by Moore's Law, computing power began to increase dramatically.	USA
1987–1993, AI was under a low level of development for the second time.		
The Explosion Phase (2000–)		
2003	Garry Kasparov ties Deep Junior	USA
2003	Garry Kasparov tied X3D-FRITZ	Germany
2005	Stanford's robots automatically drove 131 miles on desert roads.	USA
2006	Hinton proposed an unsupervised learning training method based on DBN. His doctrine prompted the academic community to begin in-depth research in deep learning.	Canada
2011	IBM Waston defeated human.	USA
2012	Deep learning has begun to be widely used in different fields.	
2014	The "Turing Test 2014" organized by the Royal Society of England passed the test for the first time.	UK
2016	AlphaGo defeated former World Go Champion.	USA

abstraction to provide strong support for subsequent processing. AI is a science, ML is the most mainstream AI implementation, and deep learning is a branch of ML and the most popular ML. The concept of deep learning is proposed by Hinton in 2006. Based on the Deep Belief Network (DBN), an unsupervised greedy layer-by-layer training algorithm is proposed, which brings hope to solve the optimization problem related to deep structures. Then the deep structure of the multi-layer auto-encoder is constructed. In addition, Lecun built Convolutional Neural Network (CNN), which is the first achieved multi-layer structure learning algorithm that used spatial relative relationships to reduce the number of parameters and improved training performance. Deep learning establishes a hierarchical model structure similar to the human brain. It extracts input data from the bottom layer to the upper layer and establishes the mapping from the underlying signal to the high-level semantics (Hinton, Osindero, & Teh, 2006; LeCun, Bengio, & Hinton, 2015).

Deep Learning is a method based on data representation and learning process in ML. It is a ML approach that mimics the neural structure of the human brain. Deep learning stems from the study of ANNs. The ANN extracts the human brain neural network from the perspective of information processing, establishes a simple model, and forms different networks according to different connection methods. Thus, deep learning, also known as Deep Neural Network (DNN), was developed from ANN model. A multi-layer learning model with multiple hidden layers is an architecture for deep learning. Deep learning can discover distributed feature representations of data by combining low-level features to form more abstract high-level categories or features. Deep learning can learn deep nonlinear network structures, implement complex function approximations, characterize distributed representations of input data, and demonstrate the powerful ability to learn the basic characteristics of data sets from small sample sets. Multiple layers are able to represent complex functions with fewer parameters (Bengio, 2009; Goodfellow, Bengio, Courville, & Bengio, 2016).

The essence of deep learning is to learn more useful features by building ML models with many hidden layers and a large amount of training data, and ultimately improve the accuracy of classification or prediction. Therefore, the "depth model" is the approach, and the "feature learning" is the goal. Deep learning emphasizes the depth of the model structure, highlights the importance of feature learning, and transforms the feature representation of the sample in the original space into a new feature space through layer-by-layer feature transformation, making classification or prediction easier. The use of big data learning capabilities is more capable of portraying rich data intrinsic information than methods that construct features through manual rules (Deng & Yu, 2014; Hinton & Salakhutdinov, 2006).

Development and current status

The development of ML has gone through two important phases, the shallow learning phase and the deep learning phase. The shallow learning phase refers to the various shallow ML models proposed in the 1990s. They were widely used in many areas of AI, and their theories were constantly being improved and developed. Deep learning since 2006 has enabled training data for multi-layer neural networks and built various deep learning models in many areas of AI. The theoretical analysis of shallow models is relatively mature and has been successful in many applications, such as web search sorting, spam partial filtering systems, and various recommendation systems. The shallow learning model has a simple structure with only one hidden layer or no hidden layer at all. For complex unconstrained problems such as large-scale image recognition and speech recognition, shallow learning seems to be incapable. The structure of deep learning is relatively complex. Deep learning proposes a method of computer automatic learning mode features, and integrates feature learning into the model building process, thereby reducing the incompleteness caused by artificial design. At present, some deep learning has realized the recognition or classification performance beyond the existing algorithms in the application scenarios that satisfy certain conditions (Bengio, Courville, & Vincent, 2013; Schmidhuber, 2015).

The reasons of emerging

The rise of deep learning depends on the improvement of big data and machine or computing performance. Big data is a generic term for data with a large amount of diversity and low value density. Deep learning is an effective way to handle big data. And what distinguishes that from previous approaches is the ability to train on very large data sets. When you train on large data sets, you get better performance, better accuracy, for tasks like image classification and natural language processing. Taking acoustic modeling as an example, it usually faces 1–10 billion training samples. The experiment found that the model is not suitable after training, so big data requires deep learning (Chen et al., 2016; Chen & Lin, 2014; Hinton et al., 2012).

We are no longer getting the year-over-year speed ups that we've grown accustomed to from serial processor architectures. CPUs are no keeping up with the demands of today's technology and research. GPUs on the other hand are continuing to scale. There is parallel architecture with each new generation's greater number of processing cores. CPUs have a small number of very high-performance cores that are great at executing serial tasks like running operating system taking input from the user running the serial portions of workload. GPUs on the other hand, have a very large number of simple cores. Each of these GPU cores by itself may not be very impressive but when we put hundreds or thousands of them together on the same die, it enables to address many of the more difficult problems in computing. Researchers, scientists, and developers are turning to GPUs to solve problems in molecular biology and climate simulation in astrophysics in intelligent machines. It turns out that many of the hard and interesting problems in computing are parallel in nature and they need a general-purpose architecture in order to run efficiently. In the past what we have taken months or years to train a neural network using a CPU can now be done in a manner of hours or days making deep learning a practical solution to many of the hard problems in computing with massive dataset. It's such a powerful technique in fact that in many cases not only does it perform better than all previous approaches but in some cases it performs better than human (Gregg & Hazelwood, 2011; Mittal & Vetter, 2015; Owens et al., 2008).

Deep learning algorithms

Deep learning has developed rapidly. Most depth models consist of multiple layers of neuron nodes. The training algorithm concludes two main processes: initialization and iterative training. For deep learning, the idea is to stack multiple layers, the output of that layer is the input to the next layer. In this way, the input information can be represented hierarchically. Based on the study of information expression in mammalian brains, the human brain's perception of information is not based on information directly projected by the external world onto the retina but based on information identified by the aggregation and decomposition processes. Therefore, the function of the visual cortex is to extract and calculate the sensory signal instead of simply reproducing the image of the retina. This human perception hierarchy greatly reduces the amount of data processed by the vision system and preserves the useful structural information of the object. Deep learning captures the basic features of structured data with potentially complex structure, such as images, videos, and speech (Lee & Mumford, 2003; Lee, Mumford, Romero, & Lamme, 1998; Rossi, Desimone, & Ungerleider, 2001; Serre, Wolf, Bileschi, Riesenhuber, & Poggio, 2007).

Deep learning can obtain a distributed representation, and the main driving variables of the input data can be obtained through a layer-by-layer learning algorithm. Human information processing mechanisms need to extract complex structures from different perceptual inputs and reconstruct internal representations. Human language system and perceptual system both have distinguishing hierarchy structure. From the perspective of bionics, this is the theoretical basis for the validity of DNN's multi-layer network structure (Bengio, Lamblin, Popovici, & Larochelle, 2007; Matsugu, Mori, Mitari, & Kaneda, 2003). In general, deep learning consists of three processes: initiation, iteration, and acceleration (Figure 7).

The initialization process first introduces the model parameters with random numbers and then needs to pre-train some models. This process can help the model avoid falling into local optimization in subsequent iteration training. The iterative training process first reads and processes the training data and compares the actual output to the expected output to obtain training errors. The training error and parameter error are then propagated layer by layer through the Error Back Propagation. Based on the comparison and calculation, the model parameters are upgraded by the optimization algorithm. Finally, testing whether the conditions of the iterative training

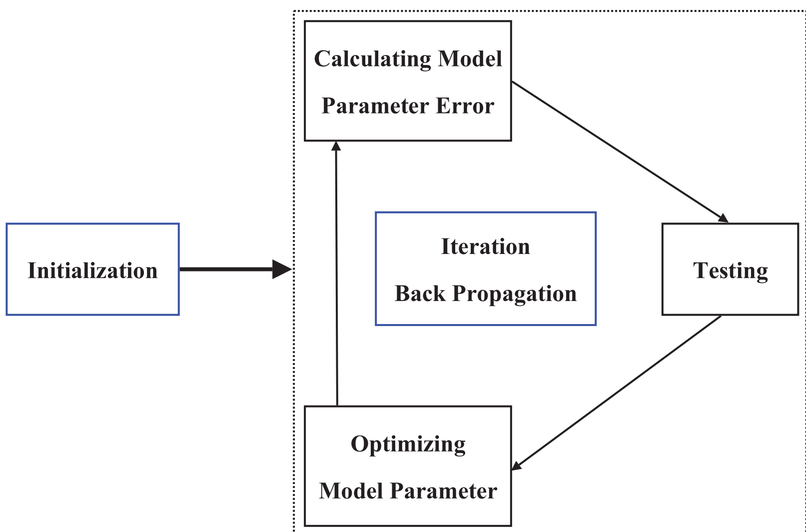

Figure 7. Deep learning algorithm process.

are met to terminate or continue the iterative process. By designing a complex multilayer neural network model, using a large amount of training data, consuming plenty of computing resources, deep learning can extract multiple layers of abstract features of the data. However, low parallelism, high computational complexity, large memory overhead, and extensive iterations lead to poor performance in deep learning. At the same time, the use of more training data and the addition of training models have become an important means to improve the accuracy of deep learning. With more and more complex models, more and more training data ultimately requires more and more computing power. This means that the performance of deep learning will have an increasingly greater impact on the development of deep learning. In addition, with the development of wearable devices and smart hardware, more and more personal data can be collected and analyzed, such as wrist accelerometers can capture motion information, microphones capture sound information, and smart appliances capture usage habits (Bengio, 2009; Bengio et al., 2007; Hinton et al., 2006; LeCun et al., 2015)

For deep learning, the training set is used to solve the weight of the neural network, and finally the model is formed. The test set is used to verify the accuracy of the model. The motivation is to build and simulate neural networks for human brain analysis and learning. DL mimics the mechanisms by which the human brain interprets images, sounds, and text. Deep learning can make computers have the same wisdom as human do. Deep learning can learn deep nonlinear network structures, implement complex function or approximations, characterize distributed representations of input data, and demonstrate the powerful ability to learn the basic characteristics of data sets from small sample sets. It is important to identify potential valuable information from large amounts of data through the application process. Massive data includes not only text and image, but also audio and video, and other different types. Information, mixed with a lot of noise, will affect the accuracy and reliability. Hence, AI is employed many advanced deep learning techniques and models, including BP neural networks, support vector machines (SVMs), and genetic algorithms. In the future, more simulated annealing, convolutional networks, fuzzy mathematics and other techniques will be introduced to further improve the accuracy, versatility and scalability (Bengio, 2009; Goodfellow et al., 2016; Hinton et al., 2006; LeCun et al., 2015).

After years of development, deep learning has produced many key algorithms and models. It can be divided into two categories, supervised and unsupervised learning. Supervised learning can make full use of AI prior knowledge to build robust data analysis models. Supervising training and learning models can improve the universality of model applications and improve the accuracy of data analysis. Unsupervised learning does not require any prior knowledge. Data analysis models can automate information mining and automatically build learning models. Unsupervised learning has been widely used in speech recognition and text retrieval (Erhan et al., 2010; Glorot & Bengio, 2010; Ngiam et al., 2011).

BP neural network is a supervised learning based on biology, neurology, psychology and statistics. It mimics the nervous system of the human brain, builds traditional computational models, and integrates multiple neural network nodes. Forming a system together can largely simulate human brain function, and it is also the application and embodiment of biological system in computer information processing. At present, BP neural network has been widely employed in speech recognition, image processing and video tracking. In order to improve the accuracy of data analysis, BP neural network began to introduce deep learning rules. As a multi-level perceptual neural network, BP neural network can use the intensity value vector and the depth data of the matrix vector to implement features, identification and extraction more accurately and effectively (Jin, Li, Wei, & Zhen, 2000; Li, Cheng, Shi, & Huang, 2012).

Support Vector Machine (SVM). SVMs can provide users with very powerful AI technology, build a powerful sample size for nonlinear data mining, and can be more effectively applied to high latitude data patterns. SVMs can perform classification and regression analysis. Given a set of data samples, each sample can indicate this category. The SVM algorithm constructs a training learning model, assigns new instances, and classifies them into non-probability binary linear classifications. The most important objective function of SVM is the kernel function. If the sample is in a low-dimensional space, the solution is to map it to a high-dimensional space, but it is easy to increase the computational complexity. kernel functions can solve this problem. SVMs have been applied in the field of spatial data modeling and map information analysis, as well as better modeling information processing functions to ensure application reliability and AI integrity. The development problem of SVMs is low precision. Therefore, adaptive resonance theory is introduced to further exploit valuable information hidden in the data. Based on this information, mining and classification operations are performed to classify from different perspectives and improve the accuracy of data processing (Chang & Lin, 2011; Hsu & Lin, 2002).

Based on structural and technical applications, deep learning is divided into unsupervised (generated), supervised (differential) and hybrid deep learning networks (Table 2). Common unsupervised learning models are RBM (Restricted Boltzmann Machine), DBN, DBM (Deep Boltzmann Machine), AE (Auto-Encoder), SAE (Sparse Auto-Encoder), DAE (Denoising Auto-Encoder). The first three models are based on energy and the latter three models are based on AE. Typical supervised learning models include CNN, RNN (Recurrent Neural Network) and DSN (Deep Stacked Network). To compensate for the deficiencies of the generated model, the hybrid model is often supplemented by the results of an unsupervised or supervised model. Representative models are mixed depth neural networks, such as DNN-HMM and DNN-CRF, and mixed deep belief Network, such as DBN-HMM (Dahl, Yu, Deng, & Acero, 2011a, 2011b).

AI applications in industries

AI has become the cornerstone of Industry 4.0 after automation, electrification and informationization (Lu, 2016, 2017a, 2017b). There are many revolutionary technological innovations of AI in industries, such as agriculture, autonomous driving, education, finance, governance, intelligent robotics, manufacturing, the medical industry, retailing industry, and security, etc.

AI in agriculture

Today, with the continuous development of AI, we have a great chance to combine advanced industrial technology and information technology to design and build agricultural facilities, and gradually achieve the goal of industrialization, customization

Table 2. Summary of typical unsupervised and supervised models.

Model	Structure	Evaluations	Article
Unsupervised Learning			
RBM	No connection within a layer, full connection between layers	Provide pre-training for supervised learning models; Unable to calculate the representation effectively	Nair and Hinton (2010), Larochelle and Bengio (2008)
DBN	Full connection between the two top layers, directional connection between the other layers	Prevent overfitting; Unable to train effectively	Hinton et al. (2006), Mohamed, Dahl, and Hinton (2012)
DBM	Full connection with the layers, multiple hidden layers	Provide pre-training for supervised learning models; solving Bayesian variational inference problem; low efficiency	Salakhutdinov and Larochelle (2010), Srivastava and Salakhutdinov (2012)
AE	Consisting of encoder and decoder	Used for feature extraction and dimensionality reduction; slow learning	Bengio et al. (2007), Deng et al. (2010), Sainath, Kingsbury, and Ramabhadran (2012)
SAE	Consisting of encoder and decoder, sparse restriction	For dimensionality reduction and coding; poorer performance than supervised	Bengio, Courville, et al. (2013), Hinton et al. (2012)
DAE	Consisting of encoder and decoder, random noise	Used to predict missing values; robustness	Vincent, Larochelle, Bengio, and Manzagol (2008), Bengio, Yao, Alain, and Vincent (2013)
Supervised Learning			
CNN	Alternate connection between the convolutional layer the down sampling layer	Used to process image data, to solve overfitting	Krizhevsky, Sutskever, and Hinton (2012), Abdel-Hamid, Deng, and Yu (2013)
RNN	Directional acyclic structure, directional recurrent in the hidden layer	Focusing on processing sequence data; Strong computational and modeling capabilities	Martens and Sutskever (2011), Sutskever, Martens, and Hinton (2011), Graves and Jaitly (2014)
DSN	Block stacking	Convex optimization problem; Solving overfitting	Deng, Yu, and Platt (2012), He, Zhang, Ren, and Sun (2016)

and personalization of agricultural production. By simulating the nature of intelligence, AI provides a way similar to human intelligence, effectively integrating human knowledge, principles, and experience, studying various problems in the agricultural field through high-speed computing, and applying the results to practice (Meunkaewjinda, Kumsawat, Attakitmongcol, & Srikaew, 2008; Moskvins, Spakovica, & Moskvins, 2008).

Before planting crops, some preliminary analytics can be done by AI, such as analyzing the land suitable for planting, the proper nutrient content of the soil, and the type of crop suitable for each plot. In the past, these could only be obtained through years of personal experience, and without the support of actual scientific data, it could not maximize the benefits. AI can improve the efficiency and economic benefits of crop production. For example, ANNs have begun to be used in agricultural intelligence applications, such as soil analysis. By simulating human brain neurons, non-invasive ground-detecting radar imaging techniques are used to detect soil properties and collect signals from electromagnetically sensing soil sensors. Analysis of soil clay content data can determine which crop is suitable for growing each plot (Elakkiya, Karthikeyan, & Ravi, 2018; Patrício & Rieder, 2018; Perea, Poyato, Montesinos, & Díaz, 2018).

Livestock and poultry farming can be achieved remotely and automatically through AI. With a remote HD camera, farmers can film the face and body of animals. The software was used to image analysis to determine the health and physical condition of each animal. In addition, farmers can use wearable devices (such as smart sensors attached to the neck of an animal) and detectors (around a farm) to collect data and upload this data to a cloud server. Calculated by algorithms, farmers can easily identify large amounts of data and grasp coping strategies to solve the potential problems (Soltani-Fesaghandis & Pooya, 2018).

AI in autonomous driving

Autonomous driving is a robotic system. There are three main technologies involved: perception, path planning, and control decisions. Intelligent perception is the foundation, and the latter two content relies on the research and application of AI and related technologies. Autonomous vehicles use deep learning to continually optimize driving behavior, which is the current effective solution. The travelling vehicles experience a variety of traffic conditions and unexpected situations, resulting in large amounts of data. This data is transferred back to the cloud platform to provide training samples. After a lot of training and learning, you will get the driving experience of your own driving, as well as the learning and training results of other vehicles. As the training of samples continues to increase, the drive technology will be upgraded accordingly, making autonomous driving technology greatly improved. Meanwhile, autonomous driving faces great challenges, such as technical issues, costs, regulations and laws (Li, Wang, et al., 2018; Lin, Wooders, Wang, & Yuan, 2018; Marina, Trasnea, & Grigorescu, 2018; Shalev-Shwartz, Shammah, & Shashua, 2016).

AI in education

During this period, AI and education were deeply integrated, and the form of education has undergone tremendous changes: from AI education to educational AI. The education focuses on the concept of people-oriented collaborative education. Educational objects include people and machines. Educational AI research objects become educational activities and educational rules for machines and people.

Therefore, educational AI is defined as transcending technical limitations, returning to the essence of education, guided by the concept of synergy, using AI to understand how learning occurs, how learning is influenced by various external factors, and then to create conditions for learners (Lin et al., 2018; Luo & Xie, 2018; McArthur, Lewis, & Bishary, 2005).

The combination of AI and education has spawned a series of new applications: intelligent robots, intelligent teaching platforms and intelligent evaluation systems, which free teachers from cumbersome teaching and form human-computer collaborative teaching. With the integration of AI and education, the ultimate goal of educational AI is the intelligent network learning space. Cooperating with government, schools, vocational training institutions, enterprises and other multi-party intelligent network learning channels, education will be continuously improved teaching effects, cultivate learning, communication and innovative talents. The teaching model is more intelligence, learning mode shifts to be more personalized, and educational resources become more dynamic and open (Luo, 2018; Spiro, Bruce, & Brewer, 2017).

AI in financial industry

The application of AI in the financial industry has achieved financial digital services. The entire financial industry has benefited with more development vitality. The application prospects of AI in the financial industry have been widely recognized. The adaptation of AI is a gradual process. The application of AI has a very important impact on the development of the financial industry. AI is not only an analysis of financial data, but also a service for the financial industry. For example, AI provides users with comfortable, convenient and safe service, AI provides decision support for transactions, credit and analytics in the finance, and AI can improve the identification, early warning and prevention and control capabilities of various types of risks in the financial system (Bahrammirzaee, 2010; Fethi & Pasiouras, 2010).

AI in governance

AI was first applied to areas where data resources are rich, and scenarios are clear. Although it is still in its infancy in the field of intelligent governance, with the popularity of AI, it has broad application prospects in the fields of virtual government assistant, intelligent conference, robot process automation, document processing and decision-making. AI will improve government efficiency and service capabilities and reduce manpower shortages (Scholl & Scholl, 2014).

AI in intelligent robotics

Broadly speaking, robots are computer-controlled electromechanical products that mimic people's various athletic abilities and are used to replace people in complex and repetitive tasks. Control devices, sensing devices, drive devices and power supply devices are the basic components of the robot. Intelligent robots add sensing, pattern recognition, deep learning and autonomous decision-making to ordinary robots, enabling them to generate intelligent brains similar to humans.

Intelligent robots include industrial robots, service robots, and special robots (Ghahramani, 2015; Jin et al., 2018).

A variety of tasks can be accomplished through intelligent behavior in a variety of complex environments. For example, medical robot is based on robotic arms, enabling them to perform a variety of clinical operations through intelligent control and real-time tracking. Smart home robot is special robots that serve humans. It is primarily engaged in home services, maintenance and transportation, including smart speaker, sweeping robot, smart socket and other equipment. Bank robot can be used not only as a simple function to guide transfer, information inquiry, printing and numbering, but also active marketing such as credit card promotions and wealth management product promotion (Boyd & Holton, 2017; Siciliano & Khatib, 2016; Viejo, Fuentes, Howell, Torrico, & Dunshea, 2018).

AI in manufacturing

The practice of AI and manufacturing integration has increased manufacturing efficiency and economic efficiency, compensated for labor shortages, increased production flexibility, and achieved low cost. Mass customization, more accurate market forecasting and matching supply and demand, promote manufacturing service transformation, and improve manufacturing quality control. Further promoting the deep integration of AI and manufacturing is a complex system engineering. All countries in the world face a series of common problems and challenges, such as AI standardization, Internet technology, information security, and the formulation and implementation of compound talents. For example, intelligent products and facilities, smart plant, intelligent management and service, intelligent supply chain management, intelligent monitoring and decision (Li, Hou, Yu, Lu, & Yang, 2017; Naser, 2018; Renzi, Leali, Cavazzuti, & Andrisano, 2014).

AI in healthcare industry

The development of the medical industry still faces many problems. AI realizes the effective combination of medicine and technology and gives medical science and intelligence. Intelligent healthcare uses advanced networking technologies, especially the widely used Internet of Things (IoT) technology, to create regional medical information platforms for health records. It can realize the connection and interaction between patients and doctors, hospitals and medical equipment, and gradually achieve informationization. At the same time, through the combination of technology and medicine, the medical process can be digital, electronic, fast and accurate. For example, deep learning for gene prediction, NLP for Electronic medical record, and visual technology and image recognition for radiology (Jiang et al., 2017; Litjens et al., 2017; Ranschaert, 2018; Shen, Wu, & Suk, 2017; Vashistha, Dangi, Kumar, Chhabra, & Shukla, 2018).

AI in retailing industry

In the near future, when consumers visit convenience stores to screen items online, machines will serve consumers instead of servants. When consumers don't know how to filter online products, the virtual assistant will make reasonable recommendations based on the consumer's buying preferences and shopping records. Amazon Go is a new store that does not require a checkout counter. This is Amazon's newest intelligent convenience store, which uses some of the world's most advanced shopping inventions, to some extent undermining the operation of traditional convenience stores and even supermarkets. The model combines deep learning, sensor fusion and computer vision technology. The advantage of AI for the retail industry is to achieve a true customer experience of products. The retail industry can make more changes through AI, that is, not only during the consumer purchase process and after the service, but also it should be prepared before consumption. When a consumer performs each action on a purchasing website, the website records the consumer's preferences. Customers can enjoy convenient services and get a personalized or customized experience. For example, purchasing recommendation, intelligent payment system, intelligent customer service, and intelligent delivery (Grewal, Roggeveen, & Nordfält, 2017; Liu, Zhou, Zou, Yeh, & Zheng, 2018).

AI in security

The development and application of AI brings hope and challenges to the field of information security. On the one hand, AI has improved the security protection capabilities; on the other hand, AI itself has security issues such as data security, anti-spoofing, privacy protection, and dynamic environment adaptation. AI can quickly detect massive network data and network attacks caused by various security attacks, and can perform adaptive security defense according to changes in the network environment. The advantages of AI in the field of network security mainly include greatly improving the accuracy of security monitoring. The scale of network traffic is huge, and security devices and systems generate many important security information. AI can solve large-scale data processing and analysis, accurately identify network attacks, and reduce security risks. For example, network surveillance, real-time monitoring, cyberattack real-time defense, security vulnerability and system failure prediction, cloud security, IoT security, network traffic anomaly detection, and network risk assessment (Grzonka, Jakobik, Kołodziej, & Pllana, 2018; Lu & Xu, 2018; Schneier, 2018; Yan, Yu, Gong, & Li, 2016).

Challenges and future directions

Technology perspective

From the perspective of technologies, it is expected that breakthroughs at three levels will further promote the development of AI, platforms (physical devices and systems with AI), algorithms (AI behavior patterns) and interfaces (the interaction between AI and external contexts).

At the platform level, most AI relies on computing devices represented by computers. The core CPU (Central Processing Unit) of a traditional computer is mainly used for general-purpose computing tasks. Although it is also compatible with all the intelligent tasks that AI faces, its performance is relatively poor. The development of high-performance platform for AI has become a trend. Intel, Google, NVIDIA, Cambrian and other well-known companies have designed new intelligent processing technologies, such as GPU. The GPU will replace the CPU as the next generation computing and calculating terminal. Future AI will inevitably need to face various intelligent tasks with malicious requirements. Designing a new computing architecture based on various processors to realize an intelligent platform is a major trend in future (Doshi-Velez & Kim, 2017; Goertzel, 2007; Russell & Norvig, 2016). Current computer systems are not suitable for multi-dimensional and multipath parallel processing. Due to timeliness and low-cost benefits, AI is not suitable for scenarios where the amount of calculation is small, but the change is large, the mutual influence is serious, and there are many nonlinear factors. In theory, the use of quantum computing and real-time multi-dimensional processing capabilities can fundamentally solve the problem of nonlinear multivariate interaction and multi-branch prediction. Thus, the rapid development of quantum computing technology, especially the realization of quantum computers, is expected to provide a breakthrough computing platform for future AI (Došilović et al., 2018; Mata et al., 2018; Murphy, 2012; Tan & Lim, 2018). In addition, AI, especially deep learning, is an approach that deal with large amount of data. It is similar to other emerging technologies, such as the blockchain and edge computing. How to integrate these technologies and improve the performance of AI is another potential attractiveness (Lu, 2018a, 2018b; Shi, Cao, Zhang, Li, & Xu, 2016).

The algorithm illustrates the behavioral pattern of AI. AI systems, even if they are supported by the most advanced computing platforms, can only be considered as well-developed and simple-minded people without effective algorithms. Since the emerging of the AI concept, the algorithm design of typical intelligent tasks is one of the core contents of the field. It is conceivable that intelligent algorithms will remain the core of the future development of AI. But unlike the past, today's AI is no longer just academic research, but in various forms of our daily adaptation and application. The social and material world has appeared more and more connections. Can we change the algorithmic implementation of computer programs that were manually entered in the past so that the algorithm automatically adapts to the "changed physical world" through its own evolution? This may be the key to the transformation of "artificial" intelligence into "humanoid" intelligence. In addition, it is worth paying attention to semi-supervised learning. At present, AI is still dominated by supervised learning. If the input changes, the machine cannot adapt unless the supervised learning strategy changes, but supervised learning is not suitable for Interdisciplinary-related data analyses. Therefore, how to make the machine based on partial data for semi-supervised learning and gradually improve the learning ability in different fields will be the focus of future research (Bengio, 2009; Goodfellow et al., 2016).

Deep learning is an important driving force for the development of AI, but deep learning is now more focused on processing data, paying less attention to the development of intelligent, such as memory and logical reasoning, predicting and storing information sequences. In the face of complex real-world tasks, it is necessary to predict and store content that contains sequences of information. In the process of advancing the development of deep learning, we could seek to propose a new hierarchical model, which not only has strong expressive ability, but also is easier to be analyzed theoretically. In addition, we need to design a suitable deep learning model to solve specific problems. Whether in image recognition, speech recognition, or NLP, there are common information processing structures such as DBN and CNN. It is possible to construct a unified deep learning framework for processing speech, images and language. At present, there is still no universal deep network or learning strategy that can be applied to different application tasks, so researchers in the field of deep learning are constantly trying new network architectures and learning strategies to improve the generalization of the network and application (Bengio, 2009; Bengio et al., 2007; Hinton et al., 2006; LeCun et al., 2015).

AI is an application that maximizes certain functions. For example, the expert system solves the decision of a complex problem solution in a certain field, virtual reality technology is the materialized display of life for providing convenience to users, intelligent robots use one of the advantages to assist humans fulfill specific tasks. The widespread adoption of AI has liberated the human, so we can devote more energy to other unknown areas. The relationship between AI and human beings could be mutually reinforcing and developing together. Communication is the basic behavior of human beings. In the virtual digital space, the decomposition of AI and humans is becoming blurred. Therefore, in the society where AI assists human beings to complete a large number of intelligent tasks in the future, how to realize effective communication and collaboration between human and machine will be of great significance. Second, it is worthwhile to develop a new type of human-machine interface (including brain-computer interface) technology. How to quickly realize the direct interaction between human/brain and machine, especially the rapid conversion and exchange of bioelectric signals and digital signals, could become a hot topic in scientific interdisciplinary research (Bengio et al., 2007; Matsugu et al., 2003).

Human and social perspective

Can the machine really imitate human thinking and understand human intentions? Judging and evaluating things, in addition to relying on common sense, human is always mixed with personal preferences and emotions; AI only examines the available data to make reasonable assessment or decision. This issue could be a long-time thinking and research.

The development of AI and large-scale application will also bring a thorny problem: more and more intelligent machines are not only high-tech products, but also affect the rules and regulations of human society. Machine behavior is at black box status, and prejudice and errors are easy to get into the system, leading to some ethical issues. When the machine brings new ideas to humans that are different from human beliefs, what should humans do? As more and more people's knowledge and skills are mastered by AI, humans will become more and more scared: they will be replaced by machines, their motivation of learning and working will be reduced. These will lead to psychological anxiety and panic in humans (Brougham & Haar, 2018; Dasoriya, Rajpopat, Jamar, & Maurya, 2018; Tan & Lim, 2018).

The rapid development of AI has brought us great convenience and amazing wealth, but on the other hand, we are full of doubts about a series of social problems. Who will ensure that the security of AI does not get out of hand? What kind of ethics and responsibilities do AI need? The application premise of any technological innovation is safety. AI is based on cloud computing, algorithms and large amounts of data. The development of the Internet and big data has made the security of AI unpredictable. On the one hand, AI benefits from the big data development resources of the Internet; the other side, Internet-based hackers and viruses can pose a huge threat to AI. AI plays an important role in improving social productivity. However, it also has a great impact on the way people live in society. Hence, it is a sensitive issue to ethicists.

How to prevent ethical and liability problems caused by AI such as AI has always been the focus of many professionals. Such as, who is responsible for traffic accidents? Who is responsible for the medical accident caused by smart medical robots?

Furthermore, in terms of security, AI can self-correct based on knowledge, automation, and independent decision-making. At present, humans cannot fully control it and may lead to unexpected results. In terms of privacy, AI systems can obtain more information related to user privacy through deep mining analysis based on collected seemingly unrelated data, and identify individual behavioral features and even personality traits. By re-learning and re-inferring data, current security measures such as data anonymization are ineffective and personal privacy becomes more easily disclosed to the public (Albayrak, Özdemir, & Zeydan, 2018; Klinger, Mateos-Garcia, & Stathoulopoulos, 2018).

Lack of theory

Deep learning has better representation of nonlinear functions than shallow learning. According to the universal approximation theory of neural networks, we can find shallow networks and deep networks. For some functions, a deep network can be represented by only a small number of parameters. However, expression does not mean learnability. We need to understand the sample complexity of deep learning, that is, how many training samples we need to learn a model of sufficient depth. On the other hand, how much computing resources do we need to get a better model through training. What is the ideal calculation optimization method? Since deep learning models are all non-convex functions, leading theoretical research in this field is difficult (Bengio, 2009; Bengio et al., 2007; Goodfellow et al., 2016).

In addition to the concept of bionics, the theoretical basis of deep learning is still in its infancy. Most of the research results are empirical. There are not enough theories to guide the experiment. Researchers are unable to determine if the network architecture and hyperparameter settings are the best option. There is a lack of in-depth theoretical research behind the success of deep learning. The learning process of deep learning is an end-to-end "black box" operation process. For the hidden layer learning process, the learning effects cannot be monitored and evaluated. The problem of the network model is mainly solved by adjusting external parameters. It is not conducive to understanding and improving network performance. Most of the current research is on network architecture, parameter selection and so on. Furthermore, the result of deep learning is a local optimal solution rather than a global optimal solution. Deep learning has room for further improvement and requires more comprehensive and convinced theories to support its development (Bengio, 2009; Hinton et al., 2006; LeCun et al., 2015).

Conclusion

AI is an important area of computer applications that adopts advanced ML, pattern recognition and data mining techniques to build AI models for information pre-processing, processing, refining and value-added services. As the application base of Industry 4.0, Internet of Things and big data, AI is widely used in various fields. AI provides strong support for people's work and life, and more effectively promotes the informationization and automation of smart society.

AI has experienced explosive growth in both techniques and applications. With the continuous improvement and breakthrough of platforms, algorithms and interaction methods, AI will tend to be more extensive and generalized. Intelligent customer service, intelligent medical diagnosis, intelligent teachers, intelligent logistics, and intelligent financial systems have begun to appear in our lives. The emergence of intelligent systems means the innovation of traditional mechanisms, from human to machine collaboration.

This paper introduces the development status of AI in detail, expounds the key technologies and applications of AI, and predicts the future development directions, which brings inspiration for researchers and practitioners.

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