An Introductory Survey of Artificial Intelligence: Concepts and Key Models

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Abstract. Artificial intelligence（AI） is an emerging subfield of computer science. A hundred years ago, it was unimaginable for people to conceive of a machine that could study as a human. At an early stage of artificial intelligence, the father of artificial intelligence, Alan Turing, designed an advanced test named the Turing test, which inspires people to believe that a machine is capable of imitating humans. Following his step, a lot of scientists made significant contributions to artificial intelligence development. Nowadays, AI is a complex field, encompassing machine learning and deep learning as two key examples. Both of these two examples are inspired by the human' thinking process. Machine learning focuses on learning and analyzing data to produce a reliable output, while deep learning can simulate the structure of human' brain and address the problem by using neural networks. Knowing the development of artificial intelligence and how these algorithms work is crucial for understanding this interesting new branch of computer science.

Keywords: Artificial Intelligence; Machine Learning; Neural Networks; Deep Learning;

1. Introduction

Artificial intelligence (AI), a popular topic in today's world, plays a crucial role in many different aspects. However, most people are unfamiliar with the professional definition of it. Machine learning and deep learning are the representative work of AI. Before discussing machine learning and deep learning, it is important to clarify the basic definition of artificial intelligence. First of all, AI refers to a program that performs at least as well as humans. This is obvious but essential if people want to have a deeper understanding of AI. Basically, their jobs are helping humans instead of getting help from humans. In biology, we humans have our own mechanisms to think and act, which we do not always realize in our daily lives. In human history, many scientists dedicated their whole lives to studying human bodies. Nowadays, even humans know much more knowledge, which is considered to be mysterious in the past, about their bodies. However, we humans must acknowledge that our explorations and cognitions on human bodies still have some potential improvement. Importantly, the original of artificial intelligence is based on increasing understanding of human bodies. This paper focuses on both introducing the history and working principles of artificial intelligence. Specifically, the discussions about background, machine learning, and neural networks are included. In the mid-20th century, people did not realize the potential value of machines. In their cognitions, machines can only do some repetitive tasks, such as turning the screw. Alan Turing, the father of artificial intelligence, illustrated the connections between humans and machines by conducting the Turing test. This idea shocked people's cognitions at that time. After a century of development of artificial intelligence, it is divided into many sophisticated fields, including machine learning and neural networks. All of the algorithms of artificial intelligence are created by imitating humans' thinking mechanisms. For example, machine learning is about how machines provide an accurate prediction based on previous learning on available data. This process is quite similar to the human learning process. When the artificial intelligence makes an inaccurate prediction, it will analyze and adjust according to its algorithms. These algorithms can be roughly divided into supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning. For a neural network, it is more related to humans' thinking mechanisms than machine learning is. Basically, a neural network is trying to imitate a human brain. In the human brain, there are billions of neurons. Each neuron can receive and send information. As a result, humans can make a response to a stimulus. In contrast, scientists create neural networks by applying a huge number of computing units. Each unit functions as a neuron, receiving and sending data. It also has its own algorithms to process the data it receives before sending it. This complicated system allows the models to output a reliable result. A lot of applications of artificial intelligence in daily lives are supported by these models. By discussing the details of the history of artificial intelligence and different models, readers will have a better understanding of artificial intelligence.

The rest of this paper is organized as follows. Section II introduces the background of AI. Section III mainly focuses on machine learning in AI. In addition, section IV shows the neural networks of deep learning. Finally, section VI concludes the paper.

2. Background

In the past decades, the development of artificial intelligence has been remarkably rapid, far exceeding initial expectations. As the AI era unfolds, the prediction of AI's future development has become a popular topic. It is important to have a basic understanding of AI to make a reasonable prediction. This section provides an overview of the history of AI development, the application of AI in our daily lives, and the technical architecture of AI.

2.1 History of AI development

The origin of artificial intelligence (AI) can be traced back to the last century. According to Fusheng Sun, AI cannot exist without computer science. The first invented computer, ENIAC, existed at the University of Pennsylvania in 1946. The significance of it on the development of AI is not only the improvement in the aspect of hardware, but also verifies that computers are able to process complex logic. [1] This idea contributes to the further development of AI. In 1950, a famous British computer scientist, Alan Turing, the father of computer science and artificial intelligence, first published “Computing Machinery and Intelligence”. In this paper, Turing introduced the Turing test, originally called the imitation game. He proposed that if a machine can communicate with humans without being identified as a machine, the machine is intelligent. This means that thinking is possible for a machine, which contributed to the later development of AI. In 1956, the Dartmouth Conference was held. Scientists like Marvin Lee Minsky proposed the term “Artificial Intelligence”, which basically means machines with intellectual capabilities. AI became an independent subject at that moment. [2] After that, the development of AI entered a period of winter. This period was when AI development hit a bottleneck due to the optimal expectation from humans. A lot of problems came up, including a lack of computing power and data scarcity. To solve this problem, individuals and governments invested more money in AI development, attempting to commercialize AI. Finally, more and more applications of AI are discovered and designed. Nowadays, more and more complicated functions of AI are achieved. The definition of “deep learning” is proposed. Deep learning involves computational models with multiple processing layers that learn data representations at various levels of abstraction. [3] AI’s thinking ability is out of everyone’s expectations.

2.2 Application of AI in our daily lives

AI has helped humans a lot in their daily lives. To introduce the application of AI, it is reasonable to start with some daily examples. When using social media, it will always push the videos to users who they prefer. This is common sense in daily life. To give a further explanation, this is related to AI analysis. All the data from the users, including the videos they comment on, the age of users, and the videos they searched for, will be analyzed by AI. As a result, the users can always watch the videos they like. AI can also remind users to be careful by marking scam calls. It can evaluate the probability of a phone call being a scam call based on the regions of the phone number and other parameters. AI can be applied in many situations in daily life (smart home, healthcare, transportation, social media, education, finance, etc.). Scientists believe that AI can substitute fifty percent of jobs in the world after ten years.

2.3 Technical architecture of AI

To understand the basic working principle of AI, it is necessary to introduce its technical structure. The technical structure will be divided into three layers, which are the foundation layer, technology layer, and application layer. This part will start with discussing the foundation layer. The name "foundation layer" implies that the core role of this layer is to provide the underlying support for AI systems. This layer includes data resources, software infrastructure, and hardware infrastructure. Data resources are just like a memory bank. AI needs data to learn common sense and the knowledge in different fields. Software infrastructure, including AI cloud platforms and big data platforms, can offer scalable computing power and development tools and enable storage and preprocessing of massive datasets. Hardware infrastructure, such as a GPU, can speed up model training, which is crucial for further development of AI.

The next layer is the technology layer. This layer is used to deliver core AI capabilities. There is a lot of technology, and it will be divided into general technologies, algorithm models, and frameworks. General technologies include natural language processing, computer vision, and intelligent speech. Algorithm models include machine learning, deep learning, and reinforcement learning. Frameworks include distributed storage and deep learning frameworks.

The last part is the application layer. It is easy to realize that this layer is strongly related to applications. Therefore, this layer is used to connect technologies with real-world situations. For example, smart speakers, facial payment systems, autonomous driving, robots, etc.

3. Machine learning

It is undeniable that machine learning is a crucial field contributing to AI development. A lot of applications, such as autonomous driving in the real world, would not be possible without the technology of machine learning. Many people have probably heard this term before. However, most of them do not have a clear understanding of this term. In this case, a clear introduction to machine learning becomes necessary for understanding AI.

3.1 Definition of machine learning

There are many different ways to describe definitions. Machine learning has three common definitions. The first one is "Machine learning is a scientific discipline within artificial intelligence, with its primary focus on AI, particularly on how to enhance the performance of specific algorithms through experiential learning". The second one is "Machine learning is the study of computer algorithms that can automatically improve through experience". The third one explains that Machine learning utilizes data or experience to optimize the performance criteria of computer programs.

These definitions might seem abstract, but all of them point out that AI can learn from its experience, which is data it receives, improving its performances. There are three key words of machine learning, which are algorithm, experience, and performance. The algorithm helps to construct the model, which is used to predict results. The dataset will be imported to test the effectiveness of the model. If the model does not reach the standard, the algorithm will be adjusted based on this experience. This iterative cycle helps AI to keep improving its performance.

This process is very similar to how humans learn knowledge. For example, most people might have the experience of learning to ride a bike at an early age. Initially, one observes how other people ride a bike, trying to imitate them. There might be some difficulties, such as keeping balance. It is normal to fall off the bike initially. After that, the Learner will analyze the problems to avoid them from happening again. Finally, they can ride a bike.

3.2 History of machine learning development

The history of machine learning can be separated into four parts: the Enthusiastic Period (mid-1950s to mid-1960s), the Cold Period (mid-1960s to mid-1970s), the Revival Period (mid-1970s to mid-1980s), and the Modern Development Stage (since 1986).

The Enthusiastic Period is the origin of machine learning. In 1943, McCulloch and Pitts first proposed the term "artificial neuron model". They presented the idea that it is possible to use propositional logic to describe neural activity, constructing a connection between neuroscience and computational logic. [4] Furthermore, in 1949, Donald Hebb proposed Hebbian learning. In his paper, he believed that when the axon of neuron A repeatedly or continuously stimulates neuron B and neuron B thereby generates an action potential (or discharge), the synaptic connection between the two neurons will be enhanced. This idea has a huge contribution to the development of machine learning. [5] Alan Turing, who is mentioned in the "background" part, also contributed a lot to machine learning by presenting the idea that machines can think. Importantly, Arthur Samuel, who first invented a chess game program in 1952, created the term "machine learning". [6]

The next period is the Cold Period. Due to the limitations of technology in the early period, the research interest in machine learning dropped dramatically. In 1969, Minsky and Papert published "Perceptrons", which proved that single-layer perceptrons are unable to solve nonlinear problems (such as XOR), leading to a slump in neural network research. [7] The development of AI did not stop even during the Cold Period. From 1965 to the 1970s, the expert system rose. This system focused on creating a program based on rules and logical thinking, which can be used to figure out complicated problems in specific fields. However, the ability of these AI is limited in that period. Furthermore, the American government reduced its investment in AI in the 1970s, which further worsened AI development.

After the Cold War, AI experienced a period of revival. A lot of new theories and methods are proposed, such as the proposal of the Decision Tree algorithm, the breakthrough of Backpropagation, and the rise of Bayesian networks. People paid more attention to machine learning.

Nowadays, machine learning is applied everywhere in our daily lives. For example, some internet search engines rely on machine learning to search for results based on clients' preferences. Machine learning can also be applied in autonomous driving. Its main function is to learn how to drive in stereoscopic vision. In conclusion, machine learning plays a very important role nowadays in our lives.

3.3 Machine learning classification and common algorithms

Machine learning can be categorized into four categories, which are supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning.

First, supervised learning is making predictions about unknown data by learning the relationships between input and output for training data with labels. Some common algorithms of supervised learning include the regression algorithm, neural network, and Support Vector Machine (SVM). The following sentences will explain each of these algorithms. It will start with a regression algorithm. This algorithm has two subclasses, which are linear regression and numerical regression. Linear regression focuses on fitting a straight line to best match all the data, while numerical regression is very similar to it, but numerical regression is a sorting algorithm. The next algorithm is a neural network. A neural network's core idea is to gradually extract the abstract features of the data through weighted calculation and nonlinear transformation of multiple layers of artificial neurons (nodes). For example, when processing an image of a square, the first layer will be used to detect the boundaries of this square. The second layer will then combine adjacent edges into a more complete local shape. After that, the third layer will integrate all local features to identify the complete geometric shape. Lastly, the Support Vector Machine will be introduced. It is mainly used for classification and regression tasks. Its core objective is to find an optimal hyperplane that separates data of different categories and maximizes the classification boundary. The advantages of SVM include excellent performance in high-dimensional Spaces and strong robustness to overfitting, but it has high computational complexity and is sensitive to parameter selection.

Second, unsupervised learning is different from supervised learning in terms of training data. Unlike supervised learning, the training data has no labels, which means AI does not know the output corresponding to each input. Therefore, unsupervised learning is commonly used when data has no labels or it is very difficult to access labels, such as predicting the preferences of social media clients. There are several algorithms belonging to unsupervised learning, including clustering algorithms and dimensionality reduction algorithms. These two algorithms will also be introduced one by one. A clustering algorithm is to separate data into different clusters, so it is a sorting algorithm. To understand this algorithm, it is important to know the definition of a hyperplane. A hyperplane is a decision boundary in an n-dimensional space. This algorithm is trying to find a suitable hyperplane to separate different kinds of data.

Finally, the definition of semi-supervised learning and reinforcement learning will be introduced. Semi-supervised learning is a method between supervised learning and unsupervised learning. It uses a small amount of labeled data and a large amount of unlabeled data to jointly train the model, solving the problem of high labeling costs. Reinforcement learning is a machine learning paradigm that enables agents to interact with the environment and learn the optimal strategy through a trial-and-error mechanism to maximize the cumulative reward.

4. Neural networks

4.1 Artificial neural network/neuron

The idea of an artificial neural network is inspired by the structure and function of the nervous system in biology. In biology, the human brain consists of neurons, glial cells, nerve stem cells, and blood vessels. A neuron is the fundamental unit in the human brain's nervous system. Each neuron has three main parts: a cell body, dendrites, and an axon. These three components have their own functions. The human brain nervous system contains nearly 86 billion neurons, which scientists believe can be applied in the artificial intelligence field, designing artificial neural networks and neurons. Similar to the neural network of the human brain, an artificial neural network also consists of a lot of neurons. Each neuron acts as a computing element that receives inputs from other neurons, each associated with a specific weight. It then produces an output that is passed either to subsequent neurons or as the final outputs if it belongs to the output layer. This complex structure creates a strong algorithm.

4.2 The structure of the neural network

This part focuses on discussing the structure of the neural network, which includes the universal approximation theorem, the reasons for depth, common neural network structures, and other considerations in structural design.

The universal approximation theorem is the basic foundation for understanding how the neural network works. It states that a single-hidden-layer feedforward neural network with enough neurons can approach any function with any precision, where the hidden layer is the layer between the input layer and the output layer. This theorem demonstrates the representational ability of the neural network.

As the universal approximation focuses on a single layer, it will then be discussed in terms of the depth of the neural network. The depth of the neural network refers to the number of hidden layers. There are several reasons that neural networks need depth. First of all, although a single-hidden-layer network can approximate any function, the required neurons may grow exponentially. If more layers are created, the number of linear regions will grow exponentially. Furthermore, the effectiveness of depth is also proved by some experimental results. In the handwritten digit Recognition (MNIST) task, as the depth of the network increases, the test accuracy continues to improve. This is because deep networks can automatically learn hierarchical features, reducing the reliance on artificial feature engineering. However, there is a common misunderstanding about depth. The improvement in the performance of the model is mainly caused by the hierarchical feature learning ability instead of the increase in parameters. In other words, the number of parameters is not the determining factor for the performance of the model. Rather, too many parameters may increase the risks of the model overfitting. Therefore, when designing a model, a reasonable sequence is to adjust the depth of the model to a proper number first. After that, some layers may be enlarged if necessary.

Since the previous paragraphs of this section have introduced some basic concepts and properties of neural networks, this paragraph will focus on three common structures of neural networks. These three structures are the feed-forward network, the memory network, and the graph network. The feed-forward network is the most fundamental neural network structure. Each neuron is divided into different groups according to the order in which it receives information, and each group can be regarded as a neural layer. The neurons in each layer receive the output from the neurons in the previous layer and pass it on to the neurons in the next layer. Importantly, information in this structure can only flow in one way. Due to its fundamental structure, it can be trained efficiently. Many advanced models are based on this structure, such as the convolutional neural network (CNN) and Transformer. Next, the memory network is a little complicated structure compared with the feed-forward network. It has the function of memory. Neurons can not only receive information from other neurons but also their own historical information. In addition, unlike the feed-forward network, Information dissemination can be either unidirectional or bidirectional. Lastly, the most complicated structure among these three structures is the graph network. The definition of the graph structure is necessary to introduce before discussing the graph network. The graph has many nodes and many edges. The edges function as connection lines between nodes. Furthermore, the graph structure can be divided into the directed graph and the undirected graph, which distinguish the graph that has edges with direction and the graph that has edges no direction. Therefore, the graph network is the neural network that has a graph structure. Every node in the graph can be a neuron or a group of neurons, and the connection between nodes can be directed or undirected. The connection allows every node to receive the information from the connected nodes or itself. Finally, the graph network has many different ways to achieve, such as Graph Convolutional network, Graph Attention network, and Message passing network.

In addition to depth and width, the structure of neural networks also has diversity in other aspects. The method for connecting nodes is one of the other considerations. For example, the connecting methods between layers can change. If neurons of the former layer only connect to a part of the region in the latter region, the number of parameters can be largely reduced, which will greatly improve the efficiency of the model. Secondly, there is another possible change for the connecting method, which is the Jump connection. The definition of this term is just like the name of this term. This connection allows some layers to directly connect to the layers that are not adjacent to them. This property can solve the problem of vanishing gradient. The vanishing gradient means that during the backpropagation process of neural networks, the gradients of parameters closer to the input layer become extremely small, causing these layers to be almost unable to update. This results in the failure of training deep networks.

4.3 Feedforward neural network (convolutional neural network)

While the previous section provides a brief overview of different kinds of network structures, this section delves into discussing the feedforward neural network in detail. The section examines each component of the feedforward network in sequence. First of all, the precondition is that the input data is a matrix X $\in R^{n*d}$, where n represents the sample size and d represents the feature dimension. $W_1 \in R^{d*h}$ is the weight matrix from the input layer X to the hidden layer H, where h is the number of neurons in the hidden layer. And b1 $\in R^{1*h}$ is the bias vector of the hidden layer H. Similarly, W2 $\in R^{h*k}$ and b2 $\in R^{1*k}$ are parameters from the hidden layer H to the output layer Y, where k is the number of categories. Under this condition, when data enters this model through the input layer X, it reaches the hidden layer H by passing the weight matrix W1 and b1. In this case, the formula connecting the input layer and the hidden layer is mathematically represented as $H = X * W1 + b1$. The connection between the hidden layer and the output layer follows similar working principles, which has the formula that $Y = H * W2 + b2$. This indicates that the formula will also be linear after it passes the hidden layer, although the hidden layer can have different dimensions. This result is attributed to the lack of an activation layer. The role of the activation layer is to introduce non-linearity into the models by nonlinear equations. For example, the ReLU is a widely used activation function. It outputs zero when the input is less than or equal to zero, and it returns the input itself when positive.

After the data enters the output layer Y, standardizing the output becomes essential. This is because the output Y may not be interpretable and friendly for people to perceive. In this situation, a function named Softmax will convert the result into a probability value. The formula of this calculation is defined as $Si = \frac{e^i}{\sum_j e^j}$. It calculates the probability value of each output.

However, the probability value comes from the calculation instead of the real value, so a method to evaluate the performance of the model is necessary. A common metric for evaluation is to calculate the negative value of the logarithm of the output from the Softmax function. Since a good output from the Softmax function should approach a hundred percent, the neural network aims to minimize the calculated value to zero during the training process as much as possible. This calculated value is known as Cross-Entropy Loss.

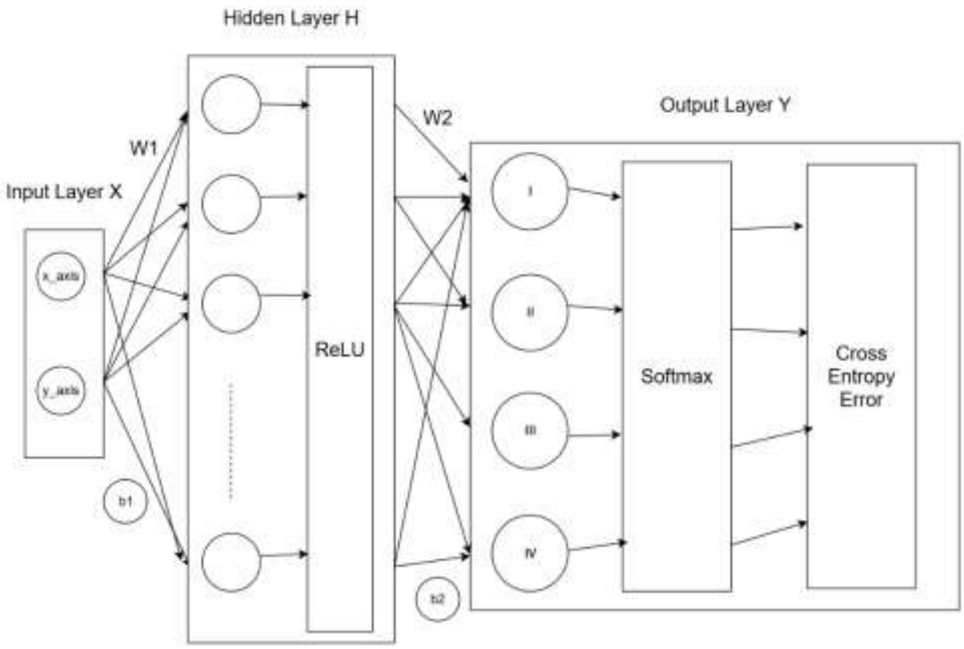

Fig. 1 Schematic Diagram of a Multi-Layer Convolutional Neural Network

5. Conclusion

When people are taking photos, smartphones can automatically analyze the situation, adjusting parameters to ensure the quality of the photos. This function relies on machine learning. The algorithm of SVM and YOLO is applied to help identify the place and the location. Knowing the importance of this, this paper mainly talks about machine learning and the neural networks of deep learning. For machine learning, we focus on machine learning classification and common algorithms. And for neural networks, it can achieve more complicated functions to make up deep learning, such as bokeh. Obviously, artificial intelligence is widely applied in our lives. Therefore, it is convenient and efficient to leverage model training in deep learning and machine learning to do tasks. In addition, artificial intelligence can sometimes uncover patterns or insights beyond human intuition. Therefore, artificial intelligence is an incredible discovery. Scientists are constantly exploring different algorithm models and pursuing breakthroughs. Understanding artificial intelligence provides an opportunity to enhance their cognition and awareness.

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