Research on the Development of Integration of Neuroscience and Artificial Intelligence

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Abstract: Since the birth of the subject of artificial intelligence, the long-term goal of this subject is to realize the intelligent system of human level. However, after nearly 60 years of development, no general intelligent system has been able to approach the level of human beings: it has the ability to cooperate with a variety of different cognitive abilities; it has a strong adaptive ability to complex environments; it has the ability of self-learning to new things and new environments. With the development of Brain and Neuroscience and Cognitive Science, it is possible to observe some activities of Brain Neural Networks under various cognitive tasks at different scales and obtain relevant data. Therefore, inspired by brain working mechanism, the development of Brain-like Intelligence has become a hotspot in the field of Artificial Intelligence and Computational Science in recent years. Machine Intelligence Brain-like Intelligence System (MIBS) inspired by cognitive behavior mechanism and realized by hardware and software cooperation is similar to human beings in information processing mechanism, cognitive behavior and intelligence level. The goal is to enable machines to realize various human cognitive abilities and their coordination mechanism, and ultimately reach or surpass the level of human intelligence. In this paper, we will study from the perspective of brain science, cognitive science and artificial intelligence. This paper reviews the history, current situation and research focus of brain-like intelligence research, and looks forward to its development direction, potential application fields and potential far-reaching impact.

1. The History, Present Situation, Essential Characteristics and Development Bottleneck of Artificial Intelligence Technology

1.1 History of Artificial Intelligence Technology

The exploration of machine intelligence can be traced back to Turing, even earlier Pascal and Leibniz. In the embryonic period of this discipline, Turing put forward a high demand and long-term vision for intelligent science, that is, to hope that future intelligent systems can think like human beings. At the beginning of the establishment of artificial intelligence discipline in 1956, relevant scholars put forward "simulation, extension, expansion of human intelligence" and " Basic Definition and Long-term Objectives of "Science and Engineering for Manufacturing Intelligent Machines"

After nearly 60 years of development, artificial intelligence has laid a number of important theoretical foundations and made many progress: such as the principles and methods of machine perception and pattern recognition, the establishment of knowledge representation and reasoning theory system, the theory and series of algorithms related to machine learning, etc., in the practice of intelligent systems, IBM DeepBlue system defeated chess world champion Kasparov. IBM Watson Question Answering System (QA) defeats human rivals such as Siri in the "Dangerous Edge" Challenge, and the emergence of automated man-machine dialogue and service systems, and Google Auto Driving show the progress in this field from different perspectives. However, all the breakthroughs mentioned above are only that intelligent systems approach or exceed human intelligence from a certain perspective in a particular field and related theories. Algorithms and systems can hardly be extended to other fields to solve other types of problems.

From the point of view of computational basis, Turing machine model and Von Neumann computer architecture have laid two cornerstones of modern information processing and computational technology respectively from the aspects of computational essence and computational structure. However, the common problem between them is lack of adaptability. The essence of Turing computing is to process a set of input symbols with predefined rules, and the rules are limited. Also limited by the predefined form, Turing machine model depends on people's understanding of the physical world, so people limit the machine description problem, the degree of problem solving, and von Neumann architecture is stored programmed computing, the program is pre-set, cannot self-evolve according to external changes and changes in demand. These two foundations have supported the modern information office. Limited by the Turing Machine and Von Neumann Architecture, the development of science and computing technology in the past 60 years has a huge bottleneck in many aspects such as perception, cognition and control. For example, it is difficult to realize selective perception and attention of massive multimodal information, and the processing mechanism and efficiency of pattern recognition and language understanding are still obviously insufficient compared with human brain, which relies more on it. In the future, it is urgent to break through the relatively fixed computing mode of input and processing. Instead, it will be more flexible and more human-like intelligent information processing and computing mode.

1.2 Development Status of Artificial Intelligence Technology

Artificial intelligence researchers have realized the potential benefits of learning from the mechanism of brain information processing. The advances in brain and neuroscience also provide the necessary basis for AI to learn from the mechanism of brain information processing (for example, electrophysiological experiments have been carried out for different types of neurons to collect their discharge patterns). In addition, functional calcium imaging technology and nuclear magnetic resonance equipment Researchers in brain and neuroscience are also trying to apply the knowledge of brain information processing to a wider scientific field. The development of this subject is driven by information technology and intelligent technology, and in turn, brain and neurology. Learning will also inspire the next generation of information technology change. In this context, national-level brain plans have been launched by academia, government and Europe, the United States and Japan. Several of the major research projects have made strategic deployments for brain-like intelligence research. Among them, the core research goal of the European Union Brain Project launched in 2013 is through supercomputing. The Brain Program of the United States (BRAIN), which was launched in 2013, did not plan to be closely integrated with AI research. Then the Advanced Intelligence Research Agency (IARPA) began to organize a new kind of machine intelligence in 2014. The project MICrONS (Machine Intelligence from Cortical Networks) aims to inspire new machine intelligence through the study of the cerebral cortex, especially to change traditional machine learning. The project will be launched in 2015 and is now incorporated into the American Brain Project.

In terms of specific research progress, after 2010, both academia and industry have pushed the related research on brain-like intelligence to a new climax. The related work can be roughly divided into two directions: brain-like model and brain-like information processing, brain-like chips and computing platforms.

1.3 Essential Characteristics and Development Bottleneck of Artificial Intelligence Technology

Artificial intelligence researchers have realized the potential benefits of learning from the mechanism of brain information processing. The advances in brain and neuroscience also provide the necessary basis for AI to learn from the mechanism of brain information processing (e.g., electrophysiological experiments can be conducted to collect the patterns of discharge activity of different types of neurons at present). In addition, functional calcium imaging technology and nuclear magnetic resonance equipment are also available for AI to learn from the mechanism of brain information processing. Researchers in brain and neuroscience are also trying to apply the knowledge of brain information processing to a wider scientific field. The development of this subject is driven by information technology and intelligent technology, and in turn, brain and neurology. Learning will also inspire the next generation of information technology change. In this context, national-level brain plans have been launched by academia, government and Europe, the United States and Japan. Several of the major research projects have made strategic deployments for brain-like intelligence research. Among them, the core research goal of the European Union Brain Project launched in 2013 is through supercomputing. The Brain Program of the United States (BRAIN), which was launched in 2013, did not plan to be closely integrated with AI research. Then the Advanced Intelligence Research Agency (IARPA) began to organize a new kind of machine intelligence in 2014. The project MICrONS (Machine Intelligence from Cortical Networks) aims to inspire new machine intelligence through the study of the cerebral cortex, especially to change traditional machine learning. The project will be launched in 2015, and has now been incorporated into the American Brain Program. In terms of specific research progress, academia and industry have pushed the related research of human brain intelligence to the next stage after 2010. The related work of the new climax can be roughly divided into two directions: brain-like models and brain-like information processing, brain-like chips and computing platforms.

2. The History, Present Situation, Essential Characteristics and Development Bottleneck of Neuroscience

2.1 History of Neuroscience Development

The starting point of modern neuroscience is the understanding and analysis of nervous system structure by neuroanatomy and histology. Blood flow signals and so on have made us have a considerable understanding of the possible involvement of various brain regions in certain brain functions. [Due to the diversity of neurons in each brain region, the complexity of local micro-loops and long-range projection loops, in order to understand the working principle of nervous system processing information, it is necessary to have neuron-level neuronal connection structure and electrical activity information] Some landmark breakthroughs have also been made, such as Cajal's analysis of the cellular basis of the nervous system and the polar structure and morphology of neurons, Sherrington's definition of nerve circuits and spinal cord reflex arcs, Adri-an's discovery of neural information encoding the magnitude of information by the frequency of action potentials, Hodgkin's and Huxley's discovery of the ionic mechanism of action potentials and various neurotransmitters. Katz and Eccles'analysis of chemical synaptic transmission, Hubel and Wiesel's discovery of the characteristics of various visual neurons from simple to complex receptive fields, Bliss and Ito's discovery of long-term synaptic enhancement and weakening, O'keefe's discovery of neurons responsive to specific spatial localization, etc., enabled us to have a clearer understanding of how neurons encode, transduce and store nerve information. Understanding, however, how the characteristics of these neurons are generated through local and long-range loops is still very limited. The key to a more superficial understanding of how the neural information in the loops produces perception, emotion, thinking, choice, consciousness, language and other cognitive functions of the brain is our understanding of the structure of neural loops related to brain function and neurological information. The interpretation of the information processing mechanism is still very unclear.

As the only reference and inspiration source of AI in nature, brain science will be the beacon to illuminate the direction when AI research and development goes astray, just as the inspiration of convolutional neural network comes from the visual cortex of cat's brain. After the second wave of AI came to a low ebb, the United States initiated the Brain Research Program in the 1990s and named 1990-2000 the "Decade of the Brain". After the proposal, the International Brain Research Organization (IBRO) and the corresponding academic organizations in many countries responded to it and promoted the "Decade of the Brain" Program.

2.2 Current Situation of Neuroscience Development.

In the summer of 1956, a group of visionary young scientists, led by McCarthy Minsky and others, explored the use of machine simulation intelligence and put forward the term of artificial intelligence. In the past 60 years, the theory and technology in this field have developed rapidly.

Turing Award winner Allen Newell explores the cognitive architecture with cognitive psychology as the core. [Up to now, the cognitive architecture SOAR and ACT-R, which are widely used in the field of cognitive psychology and artificial intelligence, have been developed under Newell's direct leadership or inspired by them. On this basis, David Marr has realized the modeling of various human cognitive functions. The pioneers of computer vision have also laid the foundation for computing the storage, processing and transmission of information between neuron groups, especially for the modeling of neural computation of learning and memory visual related circuits. Hodgkin and Huxley have created the first fine action potential model based on physiological experiments. Misha et al. have constructed the synaptic calculation model between neurons. The Blue Brain Project initiated by the Federal Polytechnic University of Lausanne (EPFL) in Switzerland has been implemented since 2005. After 10 years of efforts, the Blue Brain Project has been focusing on the very fine modeling of micro-neurons and their micro-loops, and has completed the computational simulation of cortical columns in specific brain regions relatively completely.

The starting point of artificial intelligence symbolism research is the high-level abstract description of human thinking and behavior. The expert system that emerged in the 1970s is the representative of this kind of method. The starting point of connectionism represented by artificial neural network is the preliminary simulation of the structure of brain nervous system and its computer mechanism. The research of artificial neural network can be traced back to the 1940s. In the 1990s, some of them also borrowed the Hebb's rule of synaptic connections between brain neurons as their learning theory. Perceptron is the representative of shallow artificial neural networks. Because of its self-learning ability of weights, Min-sky et al. pointed out that the deficiency of single-layer perceptron in expressing exclusive or function made the research of artificial neural networks fall into a low ebb, while the back-propagation algorithm. The second problem Minsky raised in the literature was that the improvement of computing power at that time was not enough to support large-scale training of neural networks, which had long restricted the development of artificial neural networks. Until the birth of deep learning and the development of its supporting hardware platform, Rumelhart et al. re-raised the error before deep learning was put forward. Back-propagation algorithm, whose powerful performance in non-linear pattern classification has led to a boom in the research and application of artificial neural networks. [LeCun et al.'s convolutional neural network was inspired by Neocognitron's deep learning algorithm proposed earlier by Fukushima et al.] After the introduction of GPU parallel computing and the emergence of large-scale data, more training has been done on large-scale data. Layer neural network is possible, which greatly improves the learning and generalization ability of neural network. However, the artificial neural network with increased layers is still a rough simulation of brain nervous system, and its learning flexibility is still far less than that of human brain.

In the research of artificial neural networks, most scholars are mainly concerned with improving the performance of network learning. [Poggio and his collaborators'work is a model of the development of artificial neural networks towards a more human brain, especially a series of work on the HMAX model which imitates the human visual information processing pathway.]In addition, Bengio and his collaborators fused the basal ganglion and the prefrontal lobe of the brain. Information processing mechanism, proposed brain-like reinforcement learning, is also an influential work of artificial neural networks in the direction of more brain-like development. [SPAUN brain simulator of Eliasmith team, University of Waterloo, Canada, is a landmark work in the field of MULTI-BRAIN Area Collaborative computing. [Hierarchical Temporal Memory model proposed by Hawkins draws more deeply on Brain Information Office The physical mechanism is mainly embodied in the model, which draws lessons from the six-layer structure of the cerebral cortex and the information transmission mechanism between different levels of neurons, the information processing principle of the cortical column and so on.

As far as the goal of problem solving is concerned, almost all AI systems need to be modeled artificially and transformed into a kind of specific computing problems (such as search, automatic reasoning, machine learning, etc.) for processing. Therefore, AI systems are called special AI systems. IBM DeepBlue systems defeat chess world champion Kasparov and IBM Watson QA systems. In the "dangerous edge" challenge, defeating human rivals, the emergence of automated human-computer dialogue and service systems such as Siri, and the emergence of automatic driving of Google automobiles show the progress in this field from different perspectives. The most striking thing is that in March 2016, Google's Alpha Google program first used in-depth learning technology to defeat the emergence of human Go world champions. It promotes the development of AI technology and application, and makes AI become the most noticeable field in IT field.

2.3 Essential Characteristics and Development Bottlenecks of Neuroscience

The development of brain-like chips and computing platforms based on neuron information processing mechanism is a trend of exerting the superiority of brain-like intelligence at the hardware level. At present, many countries in Europe and the United States have carried out extensive research in this direction. [SpiNNaker project of Manchester University in the United Kingdom constructed a brain-like computing hardware platform through ARM chip and learning from neuron discharge mode, which is characterized by fewer physical links. Connecting Rapid Transfer Peak Pulse This project has now become part of the EU Brain Program

The motivation of the research on brain-like chips and computing platforms is to achieve high-performance and low-power computing systems by learning from the working principles of the brain nervous system. The ultimate goal is to achieve high intelligence. In 2014, IBM launched TrueNorth chip, which integrates memory and computing by learning from the working principles of neurons and their information transmission mechanisms. The chip contains 406 nuclei, 1 million neurons and 2.56 neurons. With 100 million synapses and less than 70 mW energy consumption, Qualcomm has developed a multi-objective learning task with ultra-low power consumption. [Prezioso et al., University of California and Stony Brook, New York State University, developed a neural network chip based entirely on memristors. Now Qualcomm has also launched a NeuroProcessor NPU, which can sense and learn 3 *3-pixel black-and-white images. In addition, as one of the core components of the European Union Brain Program, Brain Scale S project proposed by Heidelberg University in Germany has made progress in brain-like mechanism and high-performance computing. Its basic idea is to integrate super-large-scale synapses on crystals to reduce communication costs and improve computing performance. The present situation and literature are discussed in a more comprehensive way.

Domestic research in this field is still in its infancy. [Chen Yunkuo, Institute of Computing Technology, Chinese Academy of Sciences, has developed a series of deep learning chips. The chips have been customized and optimized to achieve deep learning. DaDianNao uses a multi-core architecture, which can achieve 450.65 times of a single GPU in deep learning tasks, and 150.31 times less energy consumption for 64 nodes. Column chips have made a series of breakthroughs in power consumption based on the working principles of the nervous system. In the future, the team plans to incorporate more brain information processing mechanisms to improve the existing deep learning chips.

3. Necessity and Feasibility of Integrating Neuroscience and Artificial Intelligence Technology

Following the "ten years of brain" stage, a new wave of brain planning emerged in the early 21st century in the United States, the European Union and other countries in order to promote the analysis of brain principles and the study of brain-like intelligence. Our country also attaches great importance to the development of brain science, actively plans and lays out the layout of brain science, and puts forward the strategic direction of the development of "artificial intelligence 2.0".

Nowadays, brain science and artificial intelligence research go hand in hand. It is particularly important to make rational use of the known brain science achievements to study artificial intelligence, that is, the research methods and methods of brain-like intelligence. This problem can be classified into the category of bionics. Three Research Directions of System Function Simulation.

3.1 Necessity of Integrating Neuroscience and Artificial Intelligence Technology

3.1.1 Necessity of Autonomous Intelligence

Reinforcement learning is a way of learning that interacts with the environment. State, behavior and reward are the three key factors to complete the learning process. At present, the research of reinforcement learning is basically carried out in the computer simulation environment (such as game environment), because the reward and punishment rules are easy to set in this environment, and learning information (data) is easy to obtain.

In fact, like computers, nature itself is an infinite computing system. The smallest unit of operation in a computer is a logic circuit. In nature, every atom can be regarded as a computing unit. The reason for this is that each atom produces corresponding deterministic reactions according to various external actions, and the corresponding input produces deterministic results. This property satisfies the essence of the computing unit.

It can be seen that nature is a system with infinite computing power and infinite information. Therefore, nature cannot be completely simulated by computer. [It takes nearly twenty years for human beings to grow up and mature, not because human development is so slow, but because the brain is the most effective learning and training in the development stage, and the brain needs such a long learning time]. Visible, intelligent system in order to adapt to the complex natural environment and the long experience needed by human society, the number of times of tempering and the huge amount of training data, it is necessary to put AI system into the natural environment, including participating in human social activities.

3.1.2 Integration of Neuroscience and Artificial Intelligence Technology into the Natural Environment

In the environment of nature, the growth and evolution of organisms can be summed up as the category of "reinforcement learning". Survival and reproduction are the only "rules" facing the biology in this environment. From this, huge ecosystems and numerous branches as well as the details of rules under the branches are evolved. It is necessary for AI systems to get out of the computer environment and into the natural environment, whether they can be useful or not. Active acquisition of information will become the first bottleneck. Therefore, the organic combination of sensors and intelligent systems is the first step to endow AI with autonomous learning ability. It will also be an important direction for AI to get rid of its dependence on human beings and develop to a higher level of intelligence.

3.2 Feasibility of Integration Development of Neuroscience and Artificial Intelligence Technology

3.2.1 Necessity of Research on Basic Elements

The basis of brain-like research is not too clear about the physical and chemical principle of nerve cells as basic functional units of brain and the mathematical principle of the smallest information processing unit, the mathematical model of nerve cells, the equivalent circuit and the analog neural network circuit, which belong to this category. Some progress has been made, but it is far from being the mainstream of AI research. [This research field is bound to become one of the breakthroughs in basic brain-like research in the future]

However, the AI research could still draw some inspiration from neuroscience from the following aspects:

(a) Inhibitory neurons and circuits

In current neural network, all the nodes have the same properties, and pass the value in the same way. However, in biological nervous system, there are excitatory neurons and inhibitory neurons. Excitatory neurons pass signals forward, as the common nodes in neural network. On the other hand, inhibitory neurons send the feedback back to earlier part of the circuit. In a feed-forward inhibitory circuit, while excitatory signals pass forward, the inhibitory interneurons send inhibitory signals to neighboring circuits, reduce their activities. In feedback inhabitation, the excitatory signals pass downstream to excitatory adjacent neuron and to inhibitory neuron which reach back and inhibit previous part of the same circuit. Inhibitory neurons play key part in nervous system, so we could consider adding that feature to intelligent system.

(b) Synaptic pruning and plasticity

Current neural network could adjust the weight in each node but could not adjust the efficacy of the connection between two nodes. In biological nervous system, we could see the phenomenon of LTP (long-term potentiation) and LTD (long-term depression), which the synapse will be strengthen or weaken for a long time depending on the stimulus it received. Also, in our brain, the synapse continues to growth and remove, which cause a structural change. We could incorporate LTP and LTD, the growth and removal of the connection between each node in the neural network and decide which stimulus will trigger those happen.

(c) Brain specialization

The intelligent system tends to establish a uniform, principal algorithm as the corner stone, yet the brain functions in an extremely complex and detailed way. For example, different layers and currents in the brain have different credit assignments, pattern of information processing in one brain region differs from another region. Since specialized algorithms are important for solving computational problems effectively, the brain is made powerful for using such specialization.

(d) Neural Development

In prenatal development stage, when a neuron in fetus brain wants to make connections with other neurons, it stretches out its growth cones to receive the chemical signals such as netrin, semaphoring and ephrin, which act as guidance. As a mimicry to such phenomenon, we could create an algorithm to guide one node to make connection with another.

Also, in the brain, the cost function changes over time, in order to better cope the accumulation of experience of a growing human. Many A.I. now have the ability of self-evolve. For example, the famous AlphaGo Zero had played millions set of game by itself and had continued to evolve its algorithm with the accumulation of experience.

3.2.2 Realization of a Specific Biological Performance

When it is impossible to directly analyze the basic principles from the study of basic factors for the time being, one of the important research directions of bionics is the performance of imitating organisms. For example, the study of bird-like flight cannot analyze the material and composition of basic elements such as feathers, muscles and bones for the time being, nor consider how birds obtain thrust, but only consider the gliding principle of birds when they spread their wings, i.e. the principle of wings not moving. The principle of buoyancy in fluid is enough to invent the wing of an airplane, and so is brain-like research. When I study the visual system in the human brain, I have obtained a series of effective machine vision motion control principles by simulating the motion control nervous system of the human eye and the dynamic response of various eyeballs, which have been successfully applied to 3D automatic photography system, on-line calibration of binocular cameras and other products. Artificial Intelligence (AI) algorithm only simulates the hierarchical processing mechanism of information and the basic topological structure of neural network in cat visual cortex pathway, and constructs convolutional neural network, which has promoted the great progress of AI.

4. Prospects for the Integration of Neuroscience and Artificial Intelligence Technology

4.1 Generating New Ways of Information Exchange

Just as airplanes fly higher, faster and farther than birds, it is inevitable that AI surpasses human intelligence in many ways. Otherwise, the practical value of AI will be greatly reduced, such technologies as big data computing, cloud computing, Internet of Things, block chains and so on are very suitable for integrating AI, while human brain is more difficult to integrate these technologies directly. The information and function of life and the information exchange between human brain are still staying in the communication between keyboard, screen, microphone and speaker and other extracerebral organs such as fingers, eyes, mouth, ear, etc. It is not as easy as the artificial intelligence system to achieve the degree of "you have me, I have you", which is also the bottleneck and limitation of the further development of human brain intelligence level.

Although brain-computer interface is a hotspot of current research, it is hard to imagine that the human brain can easily connect with the above network system and achieve information fusion like a terminal computer. This is also why the human brain will become the new old brain (the brain of lower animals before the emergence of the brain and cerebellum), and the artificial intelligence system will become the reason for the higher brain. Visual, auditory, tactile and AI communication methods, but through the brain-computer interface to more directly operate the new "super brain" of AI system.

4.2 Impact on Human Society

Whether artificial intelligence will pose a threat to human beings is a topic that has been accompanied by the birth of the term "artificial intelligence". When human beings lost to artificial intelligence in Weiqi, the most complex chess game invented by themselves, and today famous scientists and technological entrepreneurs such as Hawking Musk also issued warnings about the development of artificial intelligence, this topic is even more noticeable.

Before expressing my personal opinion on this issue, I would like to discuss the nature of the brain first. The old brain of organisms does not disappear after the emergence of the brain and cerebellum. The primitive brain such as brain stem, thalamus, hippocampus and even hormones controlling body development are still the soul of organisms. All the brain's thinking is for these primitive desires and physiological needs, including the so-called. This is why once a person is addicted to drugs, no good brain can enable him to complete the task of detoxification independently. The brain will constantly defend and serve desire. For example, the brain, like the hands and feet of human beings, is only subordinate to the host (the purpose/need/instinct that exists in the body).) The same is true of tools and artificial intelligence: [Human beings will eventually regard the AI system as their own external brain, which is as faithful to the old brain as the new brain and brain in the biological world].

No matter how excellent the learning performance of AI system is, it needs a rule of reward and punishment to guide its learning and training process. Without rules, there is no way to learn and train. Intelligence cannot be formed naturally. This rule is designed by the human who made it. Of course, when AI is developed enough, can we set rules and use them to transform ourselves or others? Cultivating the next generation of AI is a problem of sci-fi AI. It's too early to consider it at present.

Human intelligence has not only the learning process from small to large, but also the evolutionary mechanism of eliminating small and weak individuals in competition. A series of steps, such as interchange (male-female mating), new individual production (fertility), competition and elimination (war), cooperation between individuals (culture), etc.

5. Conclusion

It is an indisputable fact that AI will bring epoch-making influence to human society. In the fields of driverless vehicles, ships, airplanes, industry, agriculture, shopping, leisure, food, transportation and other intelligent cities, in the fields of cultural entertainment, such as virtual reality and mixed reality, and even in the fields of security and national defense, AI will be introduced. A great subversive revolution will surely surpass any previous industrial revolution and have a far-reaching impact on human society, national destiny and family life.

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