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Heading toward Artificial Intelligence 2.0

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A B S T R A C T

With the popularization of the Internet, permeation of sensor networks, emergence of big data, increase in size of the information community, and interlinking and fusion of data and information throughout human society, physical space, and cyberspace, the information environment related to the current development of artificial intelligence (AI) has profoundly changed. AI faces important adjustments, and scientific foundations are confronted with new breakthroughs, as AI enters a new stage: AI 2.0. This paper briefly reviews the 60-year developmental history of AI, analyzes the external environment promoting the formation of AI 2.0 along with changes in goals, and describes both the beginning of the technology and the core idea behind AI 2.0 development. Furthermore, based on combined social demands and the information environment that exists in relation to Chinese development, suggestions on the development of AI 2.0 are given.

1. Introduction

In recent years, industry, the media, and political organizations have shown strong interest in artificial intelligence (AI), with AI-related research and applications rapidly increasing at home and abroad. Industry is interested in potential uses of AI. According to a report [1] issued by the venture capital corporation CB Insights in the US in July 2016, Google, Microsoft, Twitter, Intel, Apple, and other information technology giants have acquired about 140 entrepreneurial firms in the field of AI since 2011. During the first six months of 2016, investment in AI exceeded that realized throughout 2015, and 200 AI-related companies have raised 1.5 billion dollars in the stock market.

A large number of mergers and acquisitions, along with the influx of capital, are accelerating the integration of AI technology with applications, thereby increasing the already rapid transformation of the related economy. For example, Google caused an uproar when it offered to purchase the neural network company DNNresearch, which was comprised of a few members and founded by Professor Geoffrey Hinton from the University of Toronto, at a high price in 2013. The deep-learning method is currently the hottest technology in industrial circles and has helped Google improve the accuracy of picture searches. This technology has also become a core technology associated with Google Glass, unmanned ground vehicles, and other projects. Google boasts about itself that it is developing from "mobile first" toward "AI first."

The integration of AI with industrial demands has forced significant changes in modes of service. For example, the chatting robot Xiaobing that was developed by Microsoft is guiding a transformation from a traditional graphical interface to an interactive interface with natural-language and emotional understanding. In June 2016, Microsoft acquired the social-networking site LinkedIn and prepared to reconstruct the Internet community using AI technology. In addition, the Watson system [2] developed by IBM has been operationally utilized in hospitals to rapidly screen millions of patient records for histories of cancer treatment in order to provide suggestions for diagnosing leukemia and providing therapeutic schedules; thereby changing the paradigm of oncotherapy and clinical diagnosis. Furthermore, Baidu was designated as the "smartest corporation" due to its development of machine translation, natural-language understanding, and smart vehicles.

Notable breakthroughs have also promoted expectations for

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AI technology. Google DeepMind recently developed AlphaGo, a game-playing program that combines policy-based and value networks with deep-reinforcement learning, and which trains itself using self-game strategies to learn and apply knowledge about Go by means of a Monte Carlo tree search [3]. In March 2016, this system defeated the world Go champion, Sedol Lee, with a 4:1 score. The ability of the system to exceed human intelligence shocked much of the media and attracted a new wave of global attention. In newspapers, several famous scientists stated that the complete development of AI "could spell the end of the human race" [4] and that "computers will overtake humans with AI at some point within the next 100 years" [5].

In June 2016, a special report [6] entitled "The Rise of AI" was published in *Scientific American*, with the subheading "Artificial intelligence, once discarded as a has-been technology, is now undergoing a vigorous resurgence." This article proposed that this superficial recovery is indicative of a technical leap in AI technology.

2. The 60-year developmental history of AI

Since it first began, AI has experienced 60 years of continuous development, with both abundant advancements and setbacks. Reviewing the lessons learned should enable an assessment of the developmental tendencies associated with AI.

2.1. The birth of AI

In 1956, Professor J. McCarthy at Stanford University, Professor M. L. Minsky at the Massachusetts Institute of Technology, and Professors H. Simon and A. Newell at Carnegie Mellon University (all four of whom were awarded the Turing Award), along with C. E. Shannon (also known as "the father of information theory") at Bell Labs, N. Rochester at IBM, and other scholars, first established the concept of "artificial intelligence" at Dartmouth College in the US [7]. Their definition of AI referred to the ability of machines to understand, think, and learn in a similar way to human beings, indicating the possibility of using computers to simulate human intelligence.

Since the 1970s, AI has expanded into research fields, including mechanical theorem proving, machine translation, expert systems, game theory, pattern recognition, machine learning, robotics, and intelligent control. The exploratory processes related to these fields have led to the development of many technologies and to the formation of various schools of symbolism, connectionism, and behaviorism.

2.2. Three setbacks to AI development

AI development was never simple, and experienced three major setbacks over the course of 60 years. The first occurred in 1973, accompanied by a report by James Lighthill that was published in England [8]. The report discussed the concept of the automaton, robots, and the central nervous system as areas of fundamental AI research, and made the following conclusions: Research on the automaton and central nervous system had value, but the development was disappointing; and research on the robot had no value, and the development was a spectacular disappointment—and should therefore be cancelled. In fact, AI was still in its infancy at the time of this report.

The second setback concerned the failed development of an intelligent computer by Japan. In 1982, the Ministry of International Trade and Industry of Japan began the project of a fifth-generation computer in the hope of creating something possessing the ability to infer and process knowledge. The goal of the project was to construct a parallel-inference machine with 1000 processing units capable of incorporating 1 billion information groups, so as to develop listening and speaking ability. By 1992, the project had expended 850 million dollars, with no breakthroughs in key technological problems. This failure provided insights indicating that AI development should be primarily driven by innovation and software, with hardware used to support the operation.

The third setback occurred in 1984, when Stanford University attempted to manually construct an encyclopedia of knowledge (Cyc) [9] that contained all human common-sense knowledge. The expectation was to attain human-level inferential capability. Although Cyc incorporated a considerable amount of data and knowledge, the capabilities of the Internet and big data possessed more power due to the rise of the search engine. Cyc development began to decline by the end of the 1990s and, despite its ability to link to external knowledge bases such as DBpedia [10], Freebase [11], and the Central Intelligence Agency (CIA) World Factbook [12], its decline continued to a point beyond retrieval. The lesson was that it is infeasible to learn massive amounts of knowledge from human exports. Instead, knowledge should be gained from the environment automatically.

3. Artificial intelligence 2.0

Reviewing the setbacks in AI development makes it evident that the failures were consistently caused by AI incompatibility with variations in the information environment. The development of AI is driven both by research and by the information environment, with its accompanying social goals. Although both are very important, the latter always has the stronger driving force.

With the current popularization of the Internet, universal existence of sensors, emergence of big data, development of e-commerce, rise of the information community, and interconnection and fusion of data and knowledge in society, physical space, and cyberspace, the information environment surrounding AI development has changed profoundly, leading to a new evolutionary stage: AI 2.0. The emergence of new technologies also promotes AI to a new stage.

3.1. External dynamic forces promoting AI 2.0

External forces promoting the formation of AI 2.0 originated from changes in four areas. First, the information environment in the 21st century has changed greatly along with the popularity of mobile terminals, the Internet, sensor networks, vehicular networking, and wearable devices. Sensing devices are extensively distributed throughout cities, and the unprecedented rapid expansion of networks connecting individuals and groups throughout the world continues to reflect and aggregate demands, knowledge, and capabilities. Moreover, the world has evolved from a binary space (physics and human society, or PH) to a ternary space (cyber, physics, and human society, or CPH). CPH interactions form new computing paradigms, including perception fusion, "man-in-the-loop," augmented reality, and cross-media computing.

Second, social demands for AI are rapidly expanding, resulting in rapid changes in AI research, which is shifting from being driven by academic curiosity to being driven by demands that are focused outside of academia. The new goals and problems in intelligent cities, medicine, transportation, logistics, manufacturing, and smart products, as well as driverless automobiles and smartphones, all require AI development. Therefore, many enterprises have actively promoted new AI research.

Third, the goals of AI have undergone great changes, transforming from the pursuit of "using a computer to simulate human intelligence" to: ① enhanced hybrid intelligence systems combining machines and humans; ② new crowd intelligence systems organized by machines, humans, and networks; and ③ more complex intelligence systems, such as intelligent cities combining humans, societies, physics, and cyber systems.

Fourth, data resources related to AI are changing. AI relies upon data-driven algorithms, and gives rise to a new information environment. These calculations will be driven by the increasing amount of big data, sensors and networks, and cross-media information. Therefore, the development of AI related to big data, sensors and networks, and cross-media, with a perceptive and fused intelligence, is an inevitable trend. However, the traditional approach of the Turing test [13] for machine intelligence based on symbols will be challenged.

These environmental changes will promote significant advancements in AI technology.

3.2. Emergence of new technologies driving AI 2.0

In the new external environment, several technological advances have arisen and continue to drive AI development.

3.2.1. Big-data-based AI

AlphaGo, developed by DeepMind, is an example of transforming big data into knowledge. In contrast to traditional games, AlphaGo learns and develops capabilities, including an "intuitive sense (i.e., of what the next step is)," "inference related to the chessboard (i.e., what the chance of complete victory is)," and a play strategy that a human player would be unable to use that enables the memorization of the human chessboard with the aggregation of the self-play chessboard. Software developed by DeepMind also controls 120 variables, including the refrigeration system, fans, and windows, of the Google data center. It improved power efficiency by 15% and has saved hundreds of billions of dollars over the years [14]. Many data centers in China require similar technology, with their total energy consumption currently equivalent to the generated energy of the Three Gorges electric power station. Deep-learning technology is very important; however, deep models are hard to explain and generalize. To solve these problems, new technologies for the transformation of big data into useful knowledge must be undertaken.

3.2.2. Internet crowd intelligence

Internet crowd intelligence technologies have recently advanced. A recent paper [15] divided crowds into three types according to difficulty level: ① crowdsourcing used to realize task allocation, ② complex workflows, and ③ problem-solving ecosystems. Large-scale crowds exhibit extraordinarily intelligent capabilities through the participation and interaction of individuals on the Internet, which constitutes a new type of intelligent system. The EyeWire game [16] developed by the Connectome Project at Princeton University can determine single cell and neural connections using a similar methodology, with a total of 165 000 citizen scientists from 145 countries participating in the game to describe with colors how nervous tissue in mammalian retinas detects structure-function relationships involving motion [17]. Other examples include Wikipedia, Baidu Q&A, and Zhihu Q&A. Internet crowd intelligence computing can greatly enhance the knowledge base available to human society, and has extensive and important applications. The related theory and technology currently remain in the preliminary stages; however, the development of Internet crowd intelligence computing will result in unprecedented levels of AI.

3.2.3. Cross-media intelligence

An important characteristic of human intelligence involves the comprehensive utilization of information attained from various forms of perception, including vision, language, and auditory sense, to enable recognition, inference, design, creation, and prediction. In this regard, Chinese scientists proposed the concept of "cross-media computing" [18]. In 2013, a paper in *Nature* entitled "2020 vision" [19] discussed the term "cross-media" as describing the integration of text, images, voice, and video. In 2014, Lazer et al. [20] suggested that the fusion and intelligent analysis of multiple sources of information were the characteristics associated with knowledge and system evolution and were the necessary means of solving "big data hubris." In addition, Yao et al. [21,22] proposed a series of methods for generating text descriptions from video. Furthermore, the game Pokemon Go [23] utilizes augmented-reality technology related to cross-media concepts by organically combining 3D graphics with real-time video on mobile phones. With the continuous development of computer networks and mobile terminals, global multimedia data have exhibited explosive growth. Cross-media intelligence represents a cornerstone of AI, in that it allows machines to recognize their external environment. In the semantic connection between language, vision, and auditory sense, this will be the key to realizing intelligent behavior, such as the association, design, and creation of knowledge. Cross-media intelligence currently remains in its early stages of development; however, it is expected to form an important field of AI in future.

3.2.4. Human-machine hybrid-augmented intelligence

People often question whether machine intelligence will surpass human intelligence. This is possible in specialized fields; for general intelligence, however, it is unlikely to occur in the next 60 years.

Human intelligence constitutes a form of natural biological intelligence that is different from that of AI. The simulation of human intelligence by a computer is important; in contrast to such simulation, hybrid intelligence systems are formed by cooperation between computer and humans so as to form an augmented intelligence of "1 + 1 > 2". To date, wearable devices, intelligent-driving vehicles, exoskeleton devices, and human-machine collaborative surgeries have been developed, indicating that the human-machine hybrid-augmented intelligence system has vast potential for future development.

3.2.5. Autonomous-intelligent systems

Since the birth of AI, robotics development has been a focused target, with bionics as an important developmental direction. Over the past 60 years, however, most bionic robots that were developed failed upon application. For example, after an initial trial of the "mechanical mule," which was capable of walking using four legs, the US military is returning to the development of unmanned combat vehicles. Other well-known examples include unmanned aircraft and vehicles, which have developed rapidly and which far surpass the advances in robotics.

Advancements in developing automated intelligent mechanical equipment are more effective, easy, and economical. Therefore, autonomous-intelligence systems will be an important developmental direction for future generations of AI. It will be particularly important for the Chinese manufacturing industry to grasp this trend.

3.3. Core ideas related to AI 2.0

In conclusion, AI 2.0 can be preliminarily defined as the new generation of AI, based on the new information environment and new development goals. The new information environment includes the Internet, mobile devices, networked community, sensor networks, and big data. New development goals are defined by the demands of society, from the macrocosm to the microcosm, and include the development of intelligent cities, digital economies, intelligent manufacturing, intelligent medicine, smart homes, and smart vehicles. New technologies that are expected to be upgraded include the areas of big-data-based intelligence, Internet crowd intelligence, cross-media intelligence, autonomous intelligence, and human-machine hybrid-augmented intelligence.

AI 2.0 technology will possess distinguishing features, such as the process of combining data-driven and knowledge guidance into autonomous machine learning that is both explainable and more general. In addition, there will be a move away from the processing of categorical data—such as visual, auditory, and written data—and toward cross-media cognition, learning, and inference. Furthermore, there will be a move toward new forms of hybrid-augmented intelligence, from the pursuit of an intelligent machine to high-level human-machine collaboration and fusion. Another area will involve the formation of technologies and platforms to promote crowd-based intelligence built on individual intelligence in order to form a higher level of community intelligence that is based on the Internet. Finally, there will be an extension from research involving robotics to more expansively autonomous-intelligent systems focused on developing intelligent machinery and products.

AI 2.0 is a new stage of AI research that is different from that of the past 60 years. It focuses on current advances in technology, with the goal of pursuing breakthroughs in AI by combining internal and external driving forces. In comparison with other points in history, AI 2.0 will integrate natural intelligence and artificial intelligence in order to enhance human intellectual activity, and will be closely integrated into human life (cross-media and autonomous systems) to the point of being a part of the human body (hybrid-augmented intelligence). It will potentially be capable of reading, managing, and recombining human knowledge (computational knowledge engine) in order to make suggestions for social problems, including daily life, production, resource usage, and the environment (intelligent cities and intelligent medicine). From the standpoint of recognition, control, translation, and prediction in some specialized fields, AI is currently comparable to or exceeds human levels.

With the assistance of AI 2.0, humans will be able to obtain better insight and effective management to interact with complex macroscopic systems involving urban development, ecological protection, economic management, and financial risk. AI 2.0 will also be conducive to solving specific problems, such as medical treatment, product design, safe driving, and energy conservation.

4. China should promote AI 2.0

4.1. Demands and possibilities for developing AI 2.0 in China

China is involved with the cutting edge of industrialization, urbanization, expansion of the information age, agricultural modernization, and environmental protection. Therefore, it is imperative to develop AI technology to improve daily life and enhance social productivity by optimizing urban development, increasing the efficient use of resources, and supporting sustainable development, through the acceleration of our ability to solve pressing issues in education, medicine, poverty, the environment, and natural resources.

In recent years, the Chinese Academy of Engineering has acknowledged the importance of AI by expanding research into intelligent cities, big data, intelligent manufacturing, innovative design, the digital creative industry, and the engineering knowledge center. Moreover, market and social demands for AI in China have rapidly expanded. In 2014, the market scale of search engines reached around 60 billion yuan [24], and the market scale of Chinese intelligent voice was estimated at 4.68 billion yuan in 2015 [25]. In addition, the sale of industrial robots increased by 54%, reaching 56 000 in 2014 [26]. There are more than 330 cities currently engaged in constructing an intelligent city, with market sizes of over 80 billion yuan throughout the country [27]. In 2014, the United Nations Educational, Scientific and Cultural Organization (UNESCO) set up the International Knowledge Center for Engineering Science and Technology (IKCEST) at the Chinese Academy of Engineering in Beijing; thereby forming the first international cooperation center related to big data and knowledge services.

Because of this, China should promote new ideas, make contributions, conduct prospective studies, and plan and implement strategies as soon as possible. The implementation of AI 2.0 needs to be based on previous developmental achievements, such as e-government affairs, e-commerce, express logistics, intelligent communities, smartphones, televisions, and household appliances, as well as on upgrades to the manufacturing industry and urbanization. Previous ideas or technological achievements, including innovative design, cross-media computing, image coding, Chinese character recognition, knowledge centers, intelligent cities, and intelligent libraries, should also be incorporated.

4.2. Suggestions for developing AI 2.0

Suggested research directions for AI 2.0 in China include the following aspects.

4.2.1. Big-data-based intelligence

Research into the use of big data and its transformation into usable knowledge, and from knowledge into intelligent behavior, connects data from various fields and supports the fusion of and innovative services between different areas in order to develop new technology and operations. Therefore, research is needed to define this new system of knowledge and its role in the CPH space in order to link its relationship and behavior. It will also be necessary to investigate forms of knowledge mining that combine data with other technologies to promote new methods and software-enabling knowledge computing, including autonomic learning and dynamic evolution. The resulting methods should be applied to develop intelligent medicine, the intelligent economy, and intelligent cities.

4.2.2. Internet crowd intelligence

Research into crowd-based intelligence related to the Internet requires theory development, management methods, and organizational technologies, as well as the defining of the mechanisms and platforms capable of collaboration, order, safety, evolution, and learning. Future applications for this technology include scientific research and economic development.

4.2.3. Cross-media intelligence

Research into cross-media intelligence includes research on perception, learning, inference, and the creation of cross-media technology platforms, as well as on mechanisms related to synthesis inference and image recognition. By means of semantics, cross-media technology can be used for analysis, inference, analogies, and association in order to establish new intelligent technologies that can “see and hear better” and study and understand comprehensively. This development will incorporate the establishment of theories and models of the perceptual analysis of multimedia involving language, vision, graphical interfaces, and the auditory sense in order to develop methods to enable cross-media autonomic learning and inferencing. Potential applications include intelligent security, innovative design, and digital creativity.

4.2.4. Human-machine hybrid-augmented intelligence

Research into human-machine hybrid intelligence requires the integration and cooperativity of biological-intelligence systems with machine-intelligence systems, resulting in higher levels of intelligence. This development will potentially lead to enhanced problem-solving and decision-making abilities due to collaboration between humans and machines. Potential applications include wearable devices, robotics, aided education, and products related to human-machine integration.

4.2.5. Autonomous-intelligence systems

Research into autonomous-intelligence systems includes the development of autonomous machinery, intelligent manufacturing, and smart vehicles. It also involves a focus on technology, architecture, platforms, and design standards. The potential applications include unmanned vehicles, service equipment, robotics, aided education, and intelligent factories.

4.3. Suggestions on ways to promote international cooperation involving AI 2.0 research

In view of the significant influence of AI 2.0 on human development, the promotion of cooperation between international scientists and think tanks is suggested in order to collaborate in the appropriate development of AI technology.

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