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Hybrid Intelligence in Big Data Environment: Concepts, Architectures, and Applications of Intelligent Service

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Abstract: Based on the emerging concept of "Hybrid Intelligence," this paper aims to explore a new model of human–computer interaction, and deeply research on its development and application of Intelligent Service in the big data environment. It systematically explores the related academic concepts of hybrid intelligence, and establishes its architecture model. The development of hybrid intelligence is faced with cognitive differences, system fragmentation, human–machine digital divide, and other issues. Strengthening the interaction between cognition and perception can be the key to break through the bottleneck. The intelligent service system based on the hybrid intelligent architecture takes knowledge fusion as the core, and "cloud intelligent brain" is making it possible for the human–computer symbiosis driven by hybrid intelligence. The proposed advanced human–computer interaction mode constructs a hybrid intelligent architecture model, enriches the concept system of human–machine hybrid intelligence, and provides a new landing scheme for intelligent services based on complex scenes in the big data environment.

Keywords: human–machine hybrid Intelligence, human–machine interaction, artificial intelligence, knowledge fusion, intelligence service

1 Introduction

Against the background of the era of big data, and with the further development of science and technology, especially the development and application of the concept of deep learning, artificial intelligence (AI) has achieved the ability to surpass human beings in every single field. However, the current research is still in the "weak artificial intelligence" stage, but has not made breakthrough progress; on the other hand, in the organizational environment, the application scope and effect of using AI to solve complex business problems have great limitations.

At present, the efficiency of information transmission between human beings and machines is still very low, which is far from achieving the true human–machine collaboration. Compared with human intelligence, AI at the present stage is limited in input mode and fusion processing, and has innate deficiencies in emotion and philosophy. The "intelligence" of AI is embodied in the intelligence of digital logic and complex calculation, but it is not outstanding in the complex environment with emotion and intentionality. Therefore, the development trend of intelligent science will be the mixed intelligence of human and machine. In September 2016, the report "Artificial Intelligence and Life in 2030" (Stone et al.,2016) released by Stanford university comprehensively evaluated the progress, challenges, opportunities, and prospects of current AI, which mentioned that the future of AI is the fusion of human and computer intelligence, namely *human–machine hybrid intelligence*.

Hybrid intelligence (HI) is a new form of intelligence, which is different from human intelligence and machine intelligence, and is the next generation of intelligent scientific system that combines the attributes of different species (Li, Shi, Yang, & Bicchi, 2019). HI aims to make AI a deep extension of human intelligence through human–machine interaction and collaboration, which has profound scientific significance and huge industrial prospects.

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This paper attempts to clarify concepts related to HI through contrast analysis method, and the HI architecture model is constructed by combining the idea of human-in-loop and human–machine confrontation based on the dilemma in the current development of HI; it then accordingly puts forward a new idea of applying HI in intelligent service scenario under the big data environment. At present, the development of HI is faced with many problems, such as cognitive differences, system fragmentation, human–machine digital divide, and so on. In the big data environment, the core of data-driven intelligent services and applications lies in man–machine collaboration and interaction, which is an advantage of HI. In the foreseeable future, human–computer HI based on the combination of big data-driven and knowledge guidance will become the trend leading the intelligent era.

2 Related Works

As a new form of intelligence, HI is a new generation of intelligent science system with cross-species attributes. Guozhi Liu, director of the Science and Technology Commission of the CMC, believes that "Human–machine Hybrid Intelligence will be the highest form of future intelligence," and human–machine fusion, as a key direction of the development of hybrid enhanced intelligence, can play an important supporting role in many important fields in the future (Wang & Dai, 2018).

However, the current research on HI is still in the basic stage, and even the definition has not reached a complete consensus in the academic circles. As an interdisciplinary field, HI involves computer science, robot science, data science, neuroscience, philosophy, and other disciplines. Therefore, there are three mainstream cognitive viewpoints regarding HI in the current relevant researches, which are technology-driven, human-driven, and human–machine collaboration.

The technology-centric perspective claims that AI will surpass humans in an all-round way in the future. The so-called HI is actually the ultimate form of AI, and the "hybrid" here is more inclined to the technological integration of "human-like" behaviors such as machine recognition and autonomous learning. This view holds that HI is the theoretical and technical support for the human–machine intelligence system to achieve complex goals. It is mainly through the combination of traditional robotics technology and AI technology to improve the naturalness, security, and robustness of human–machine interaction and collaboration from the aspects of system modeling, perception interaction, collaborative control, and human loop optimization (Cheng et al., 2020). The aim is to make results more effective and efficient at the level of socio-technical systems by achieving previously unsolvable goals. In addition, technology-centrism doubts the fairness and effectiveness of human decision-making. For example, Kahneman (2011) shows that human decision-making may be seriously flawed, because human beings tend to use suboptimal heuristics and may produce biased results. Thus, the risks of artificially introduced biases are enormous, and HI must be technology-driven.

Experts in the human-centric perspective views have tried to make the role of people more prominent in the definition of HI, centering on the core topic of how moving toward automated labor will affect the human sense of accomplishment and meaning. They do not deny the role of technology, but they emphasize the integration of intelligent technologies under a "human-centered" system, because they foresee the possible negative effects of AI technology. The human-centric perspective views intelligence technology primarily as a tool for improving the performance, safety, and wellbeing of humans (Baum, 2017; Russell, Dewey, & Tegmark, 2015), but not one that will eventually replace humans. Current AI capabilities are expert and domain-specific in nature, causing their applicability to highly limited task domains and even situations, and limiting their adaptability to the degree of freedom considered in a given application (Winter & Dodou, 2014), and the HI of the future should be a combination of complementary heterogeneous intelligences (i.e., humans and artificial agents) to create a socio-technical integration that can overcome the limitations of current intelligence. Instead of focusing on automating simple tasks through machine learning, this approach emphasizes the role of human intelligence in the AI cycle.

From the perspective of human–machine collaboration, Farjam and Kirchkamp (2018) believe that HI is an advanced form of collective intelligence. The early researches on collective intelligence mainly focus on the philosophical level. With the emergence and promotion of computer and Web technology, collective intelligence begins to have more substantial contents, such as crowdsourcing and market prediction, and at this time, user-oriented machine intelligence becomes more advanced. By studying the development process of core AI technologies, Sobhani-Tehrani and Khorasani (2009) believed that AI had entered a stage of mixed intelligence composed of multiple intelligent technologies. And the so-called "hybrid" is the system that spontaneously combines the intelligent system with complementary performance, mainly using intelligent technology

including expert system, neural network, and fuzzy logic (Dellermann, Ebel, Söllner, & Leimeister, 2019). It can be seen that the network provides a medium for the collection of swarm intelligence, and the development of AI greatly promotes the research and application of collective intelligence, and will profoundly change the formation of collective intelligence.

In the current research on HI, most of its wide application scenarios are discussed. Analyzing the human–computer interaction (HCI) patterns and methods involved in autonomous driving, Koopman and Wagner (2017) proposed an interactive cognitive program from the perspective of human–computer mixed intelligence, which solved the problem of interaction barriers in autonomous driving. Liang, Zhao, Li and Ding (2019) integrated human decision-making into intelligent algorithm, further improved force tracking performance through iterative learning to compensate position tracking error, and applied it in the field of HCI where environmental parameters are unknown. Zou, Wang and Zou (2019) put forward a new method of big data and man–machine conversation that must cover all the words: generate a large amount of speech big data through human–machine interaction and cooperation, and compare, query, or reuse these words or terms through machine learning and man–machine interaction. Li, Cui, Yan and Xu (2019) proposed a long-term adaptive information path planning algorithm for scalar field monitoring, and used the cross entropy method to obtain the local optimal path segment, integrating human intentions into the intelligent algorithm and breaking through the limitations of AI technology, so as to achieve machine intelligence close to human intelligence level in learning and thinking.

To sum up, the current research on mixed intelligence mainly focuses on the theoretical elaboration and simple application of mixed intelligence. Theoretical research tries to explain the nature and characteristics of HI from different perspectives, which is similar to the research on AI. At present, a technology-centered, human-centered, and human–machine collaborative school has been formed. It can be found that human–machine HI, as an advanced mode of human–machine interaction and collaboration, has many similarities with the concepts of human intelligence and AI, but it has not given a clear definition and distinction of concepts. The application research focuses on the fusion mode of intelligent system, and gives the possible application paradigm of mixed intelligence, but there are some problems such as the one-sided understanding of the concept of HI and a single application scene. Undeniably, the just emerging intelligent human–computer fusion concept, related theory, and technology application are still in their infancy, and the advanced intelligent model itself is still far from us; the spontaneous idea itself from the people moving to machine intelligence implementation difficulty is immense, so this paper does not carry out research on the related issues of hybrid intelligent comprehensive analysis and interpretation, only on the basis of the study, emphasis on the concept and definition, and the architectures and application prospect of three problems. The research value and innovation points of this paper are mainly reflected in the following three aspects:

① Using the comparative research method to define the similar concepts of HI and systematically sort out the similarities and differences between human intelligence, AI, and HI;
② Focusing on the current development dilemma of HI, exploring the core breakthrough points of its future development in big data environment, and constructing the structure model of HI system;
③ Finding that related application research in view of the present understanding of HI only stay on the problem of intelligent system integration, this paper gives a concrete application of the hybrid intelligent scene and pattern based on intelligent service scenarios, and highlights the depth interaction ability which has situational awareness and a complex scene.

3 HI and Its Related Concepts

3.1 From Human Intelligence to AI

According to Gottfredson (1997), intelligence is defined as the ability to accomplish complex goals, learn, reason, and execute effective actions adaptively in an environment. As a new form of intelligence, human–machine HI is a new generation of intelligent science system with cross-species attributes. Clearly, HI is not a complete new concept, but a model of advanced intelligence born with the continuous development of AI. It has many intersections with the concept connotation of human intelligence and AI.

Human intelligence refers to the learning and reasoning abilities of human beings, such as cognition, prediction, and decision-making. It covers the ability to learn, reason, and perform effective actions in the environment based on existing knowledge. Human society is the result of human intelligence, and the combination of human learning ability and environmental receptivity promotes the evolution of human intelligence. With

consciousness, human beings can have free cognition of the objective world and make summary and analysis of experience to obtain discrete approximate science. However, human rationality is based on reason with the perceptual cognition as the bottom layer, which is not only the fundamental difference between human beings and machines, but also the fundamental reason that human beings cannot be as completely rational as machines. Kahneman's two-system thinking model (Figure 1) explains to some extent the characteristics of human intelligence: preference intuition and bounded rationality. System 1 represents intuition, which is often dominated by habits, experiences, and stereotypes, and is therefore difficult to control or correct. System 2 is in conscious control, but slow and resource-intensive. A large number of experiments have proved that people prefer to use intuition for judgment and decision making, which is the root of human decision-making bias. In theory, System 2 monitors the activity of System 1 and corrects the errors that result from it, but this adjustment itself is insufficient, which is called decision-bounded rationality. Human intelligence is centered in the brain, which relies on complex living systems. However, the human cognitive reasoning ability and parallel transaction processing ability are limited. Based on this, one view holds that the development of AI is based on the deep understanding of a human's unique intelligence, which is the further simulation of human intelligence. In the big data environment, the human's computing speed and ability to process big data are limited, and the evolution of human intelligence has reached a bottleneck.

Empirical knowledge and fragmented logic constitute the complex human intelligence, while AI is the reflection of the conceptualization, systematization, and programming of human intelligence. The development of AI is based on the deep understanding of humans' own intelligence, which is the further simulation of human intelligence. It can be said that human–machine interaction provides application requirements and research ideas for AI, and AI also drives the development and reform of HCI technology. In the process of development of AI, *Connectionism* imitates the connection mechanism of the cerebral cortex neural network and advocates the intellectualization of the deep learning algorithm that has gradually formed; *actionism* is based on bionics and control behavior; and *symbolism* is represented by the physical symbol system and finite rationality. However, these three schools all have some defects. The development of connectionism benefits from the deep learning algorithm. However, the deep learning algorithm is not interpretable and its application effect in the open dynamic environment is not

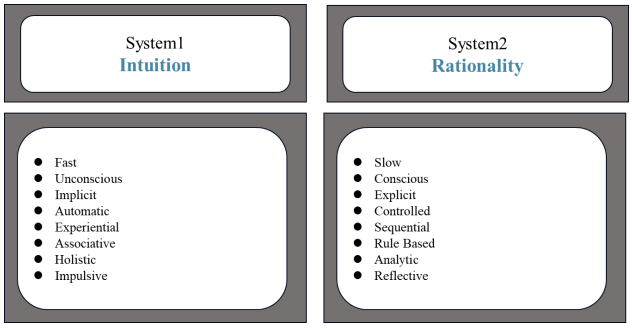

Figure 1. Kahneman's two-system model

so good. Behaviorism realizes the characteristics of output planning through reinforcement learning and feedback. However, this theory oversimplifies the psychological and behavioral characteristics of human beings and ignores the importance of human self-awareness. Socialism is one of the symbols of the a priori knowledge extracted from the rules of knowledge map and is introduced as a constraint condition of the complex model, although the nature of knowledge map construction is to make the machine have the cognitive ability to "understand" the world; however, because of common sense, to extract and questioned by the other schools, in addition, the symbolic thinking essence of the said knowledge greatly reduces the efficiency of bots.

The AI research has shown that machines have incomparable advantages in search, computation, storage and optimization, etc., but they cannot match human intelligence in perception, reasoning, induction, and learning. As a result, the role of people is introduced into the calculation of the circuits of the AI system, which can solve the problem of fuzzy and uncertain analysis and response to advanced cognitive mechanism and machine intelligence system tight coupling, leading to adapt to each other, work together, form a two-way exchange of information and control, make the person's perception, cognitive ability, and computer combination of powerful computing and storage capacity, and enhance intelligence to form real meaning, namely, the human–machine HI.

The so-called HI points to combining human and AI to achieve a superior complex ability individually and through mutual learning to improve the results of Liu (2017), Dellermann, Calma, Lipusch, Weber and Ebel (2019) who combine the advantage of machine intelligence and human intelligence and their performance to a more intelligent form. The comparison of human intelligence, AI, and HI is shown in Table 1.

Thus it can be seen that the tasks that are easily done by artificial and human intelligence are quite divergent. This fact is known as Moravec's paradox. At present, the

Table 1
Comparison of the Connotation Characteristics of Human Intelligence, AI, and HI

	Human intelligence	Artificial intelligence	Hybrid intelligence
Basic definition	The learning and reasoning abilities of human beings, such as cognition, prediction, and decision-making	The reflection of the conceptualization, systematization, and programming of human intelligence	Combining the advantages of machine intelligence and human intelligence and performance of the more intelligent form
Essential attributes	Sociability	Naturalness	Compatibility
Typical characteristics	Flexibility and transfer, empathy and creativity Common sense	Pattern recognition, probabilistic, speed and efficiency	Continuous learning, information transmission channel, depth of situational awareness
Evolutionary path	Combination of natural evolution and thought evolution	Pure physical evolution	The evolution of thinking driven by the evolution of matter
Material bearer	Brain	Integrated circuit	Brain–machine interface
Function body	Human	Machine	Collective intelligence, human–machine
Thinking characteristics	Intuition, creativity	Reason, imitation	Deep perception, cognitive interaction

understanding between humans and machines is shallow, and the relationship in the future should be two-way. Machine is a "partner," it has the ability of perception, learning, reasoning, and decision-making, which should not only obey human beings, but also human decisions will be largely influenced by machines. Therefore, man–machine HI is a combination of the subjective and objective, a combination of flexible intentionality and precise formalization, and a harmonious end state of the man–machine symbiosis.

3.2 From Brain–machine Interface to Brain–machine Fusion

Brain–computer interfaces (BCIs) are two-way channels of information interaction between the brain and the computer, used to record neuronal signals and interpret brain intentions (Sasaki, Eguchi, & Suzuki, 2015). BCI technology promotes mutual learning and adaptation between the human and the machine. With the help of BCI technology, the operation mechanism of biological intelligence can be further explored, so that AI can get rid of the limitation of pure machine intelligence and gradually transition to HI. Yu (2016) believed that the hybrid intelligent system is an inevitable trend in the development of BCI technology and also a new way to realize intelligent enhancement. However, the core of the brain–machine Interface technology lies in the reading and writing of brain waves, how to read brain signals smoothly, be understood by machines and feed back to the brain, and how to achieve engineering and pass clinical detection of products, all of which are extremely challenging.

With the development of AI and neuroscience, the BCI, which relies on one-way transmission of intelligent devices, began to transform to brain–computer interaction and even brain–machine fusion. Brain–machine fusion is a high-level brain–machine interaction form in which BCI changes from the unidirectional open-loop to bidirectional closed-loop. Through two-way communication between the brain and the machine, two-way information perception and deep understanding of the brain–machine and machine–brain can be realized, and a hybrid intelligent system can be built to form a multilevel intelligent model of brain–machine fusion. From this perspective, consider that HI is a new mode of the integration of biological intelligence and machine intelligence, can make biological sense of the basic unit, and the machine function unit calculates the hierarchical deep integration of multiple perspectives, so as to establish both a biotic environment perception, information integration, learning and memory, and movement ability of the new hybrid intelligent systems.

3.3 From HCI to Symbiosis

As an interdisciplinary field, HI is closely related to HCI and human–computer collaboration. However, from different

cognitive and research perspectives, the understanding of HI is different.

From the development history of HCI, Liao (2019) believes that HCI in the era of AI has practically entered the stage of practical application from the level of theoretical concept, and human-computer HI plays a key role in exploring the deep cooperation between biological intelligence and AI. In the advanced stage of the development of machine intelligence, "human" as an intelligent individual will participate in the solution of complex tasks at the same time as "machine," and machines have gradually begun to participate in human activities as intelligent individuals. Led by AI and supercomputing technology, HCI, cross-media perception, and intelligent services have a bright future. By sorting out the development history of HCI and AI, Fan, X., Fan, J., Tian and Dai (2019) thought that HCI and AI are mutually promoted and driven, and will further integrate and develop together, and human–computer mixed intelligence is the mainstream development direction in the future.

From the cognitive perspective of human–machine collaboration, Kamar (2016) believed that hybrid intelligence, as an efficient collaborative mode, essentially provides complex decision support for intelligent science through the organic unity of the human–machine. Although AI has more efficient advantages over humans in search, computing, storage, and optimization, its advanced cognitive functions, such as perception and reasoning, are far inferior to those of the human brain. Current AI systems at different levels are dependent on a large number of samples of training completed "supervised learning," and the true general intelligence would be on the basis of the experience and knowledge accumulation for complete and efficient "unsupervised learning," this is the director of human intelligence. Machine intelligence is short, so the two together must constitute a more advanced hybrid intelligent system, to solve more complex tasks.

In addition, the concept of human–computer symbiosis (HCS) is often mentioned in conjunction with HI. *Two different organisms live together in close cooperation and even form close alliances* – this pattern of cooperation is called symbiosis (Licklider, 1960). Therefore, human–machine symbiosis no longer emphasizes the main role of human or machine, but enables human and computer to make high-level decisions and control complex situations without relying on predetermined programs. In the expected symbiotic partnership, humans will set goals, make assumptions, determine standards, and evaluate. Computers will do routine work, preparing humans for insights and decisions about technology and scientific thinking. From this point of view, HI is the technical manifestation of human–machine symbiosis, and the purpose of the both is nearly the same.

From simple interaction to fusion symbiosis, it reveals the subtle changes in the role and status of human–computer on one hand, and on the other hand implies that HI will become the main technology mode leading intelligent services in the near future.

In conclusion, we can see the concept diagram of HI as shown in Figure 2.

From this, we can conclude the following:

① HI is an advanced form of intelligence that integrates the advantages of machine and human. Different from the collective intelligence that emphasizes the use of collective function to enhance machine intelligence, HI pays more attention to the simultaneous solution of complex problems by both of them, which is a more advanced interaction and collaboration.

② Although both HCI and human–computer collaboration involve human–machine participation, their participation degree and status are different. "Interaction" reflects two-way information transmission and is machine-driven, while "collaboration" reflects the joint decision-making, which is dominated by human beings.

③ BCI is the beginning of the symbiosis between biological intelligence and machine intelligence. Brain–machine fusion further promotes the mutual learning and adaptation of brain–machine, and is a new means of intelligent interconnection.

④ As a possible terminal form of AI, HI represents the ideal possibility of human–machine symbiosis.

4 Construction of Hybrid Intelligent Architecture Model

4.1 The Form of Hybrid Intelligence

4.1.1 Simple Form Based on Human-in-Loop

As mentioned before, human beings are more dependent on *intuition*, and therefore have the disadvantage of bounded rationality; machines are better at *analysis*, but they do not have strong cognitive and comprehension abilities. Therefore, we propose an enhanced intelligence model of human-in-loop (Figure 3).

Human-in-loop hybrid enhanced intelligence is defined as an intelligence model that requires human

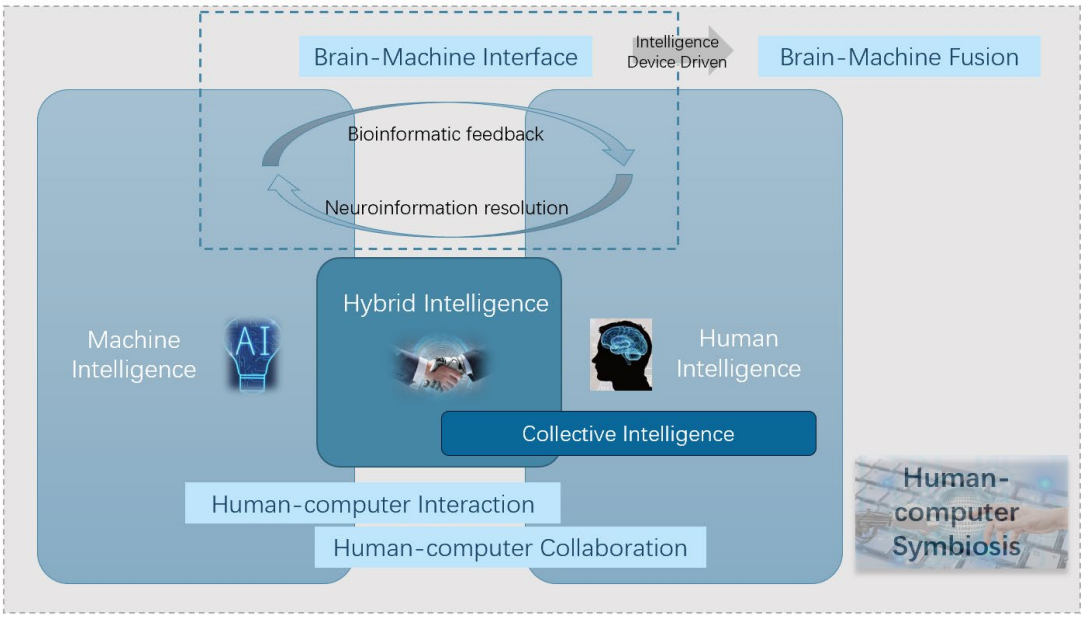

Figure 2. Conceptual integration of hybrid intelligence

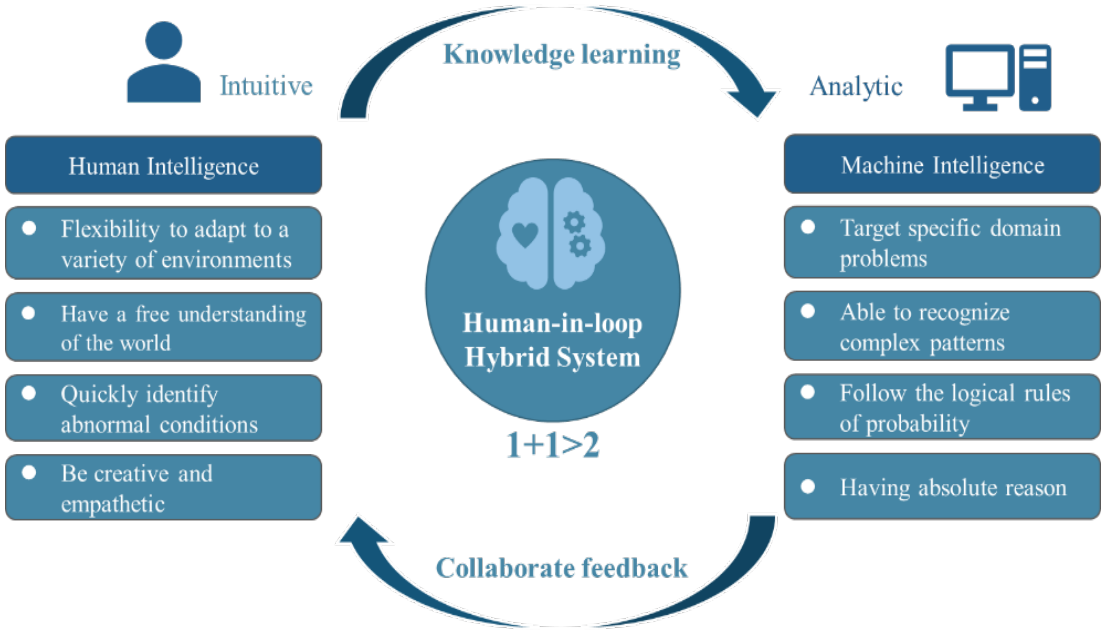

Figure 3. Human-in-loop hybrid system model

interaction (Zheng et al., 2017). This model no longer only emphasizes AI. In fact, we believe that AI cannot compete with human intelligence in perception, reasoning, induction, and learning for a very long time. This requires introduction of the human role or human cognitive model into the AI system to combine a mixed form of enhanced intelligence, in an attempt to achieve the effect of 1 + 1 > 2.

4.1.2 Advanced Form Based on Confrontation.

As an interdisciplinary field, HI covers such concepts as human–machine interaction, human–machine collaboration, human–machine confrontation, collective intelligence, situational awareness, and self-organizing learning.

It should be pointed out that human–machine confrontation cannot be simply understood as the competition between human and machine, and its ultimate goal is still to achieve a harmonious steady state of human–machine symbiosis. Therefore, we think human–machine confrontation is another form of HI.

Different from the enhanced intelligence form under the simple human–machine cooperation, human–machine confrontation usually focuses on more complex cognitive intelligence such as temporal decision making, and its process modeling is a highly complex problem. Therefore, cognitive decision modeling is the core key link in the whole man–machine confrontation. The decision-making process of man–machine confrontation in a strong confrontation environment includes perception, reasoning, decision-making, and control. The key technologies of human–machine confrontation are summarized into four parts: spatial representation and modeling of confrontation, situation assessment and reasoning, strategy generation and optimization, and action coordination and control (Winograd, 2006). By means of situation interpretation and understanding of confrontation, cognitive prediction, strategy decision, and action implementation, the local whole is continuously iterated and strengthened.

4.2 The Dilemma of HI

Although human-in-loop and human–machine confrontation are defined as the two forms of HI, they still expose some problems, such as cognitive differences, separation of each other, human–machine digital divide, and so on. How to realize the high-speed and effective transmission of information and introduce human cognitive model into machine intelligence so that it can reach the level of advanced human-like intelligence in reasoning, decision making, memory, etc., is still a dilemma faced by the HI system in the current development.

4.2.1 Cognitive Difference

One of the most important difficulties in the development of HI is the difference in human–computer cognition. According to Liu (2019), the main reason that human–machine intelligence is difficult to integrate is due to the inconsistency between space-time and cognition. First, the cognition and learning of machines have a specific scope of time and space and are not malleable, while the cognition of human beings is subjective and arbitrary. From the perspective of cognitive thinking, there is a space to be extended. Second, machines' cognition of time and space is formal and specific, while human beings have subjective cognition and expectation, and will adapt to the environment.

The fundamental of cognition is abstraction and representation. The high abstraction ability of humans corresponds to the high representational ability of machine knowledge. For machines, information abstraction and knowledge extraction capacity determine the degree of human–computer cognition difference. How to introduce the human cognitive model into AI so that it can reach the level of human-like intelligence in reasoning, decision-making, memory, and other aspects is a research hotspot, and is also the core problem of human–computer hybrid intelligence.

4.2.2 System Fragmentation

In the current AI system or related products, the role of the human is limited, and the system composed of human, machine, and environment does not have the ability for efficient cooperation and interactive operation. In order for an intelligent system to function efficiently, its internal components and operating mechanisms must inherently have the ability to attract and repel each other, to combine, and to separate. Intentionality in human–machine fusion intelligence is a bridge connecting facts and values. The organic combination of logic and abstraction, intuition, and rationality rather than system separation is an important research direction to solve the human–machine fusion intelligence output.

As an interactive system of information integration, HI should be highly coordinated between man and machine and highly unified among human, machine, and environment. On one hand, humans can increase their acceptance and trust in machines. On the other hand, machines can play a more important role in the system and improve the efficiency of the system.

At present, the system composed of human, machine, and environment does not have the ability for efficient cooperation and interactive operation. The interaction between human–machine and environment involves two basic processes: "assimilation" and "adaptation." In order for an intelligent system to operate efficiently, its internal components and operating mechanism must have the ability to adapt and integrate with each other in nature. Only in this way can a set of *human–machine-environment integrated cognitive chain* (Figure 4) from depth to state

space, to trend, to sensation, and finally to perception be constructed, and a cycle and transition from depth perception to depth relearning be realized.

4.2.3 Human–Machine Digital Divide

Big data and AI are inseparable in the positive cycle. AI relies on the existence and accumulation of big data and helps to release the potential of data storage. However, big data supports the progress and development of AI, but also limits the ideas of AI transformation. The new "digital divide" caused by the monopoly of AI technology has become an important issue in the development of intelligent technology.

In the big data environment, human perception and cognition of big data is particularly important. Human intelligence needs not only to understand the complex theories brought about by the big models of machine thinking supported by big data, but also to discover the essence of things and solve big problems by relying on big models. The human–computer "digital divide" problem arises when humans fail to develop the ability to perceive and process complex information in the face of massive amounts of data generated by machines.

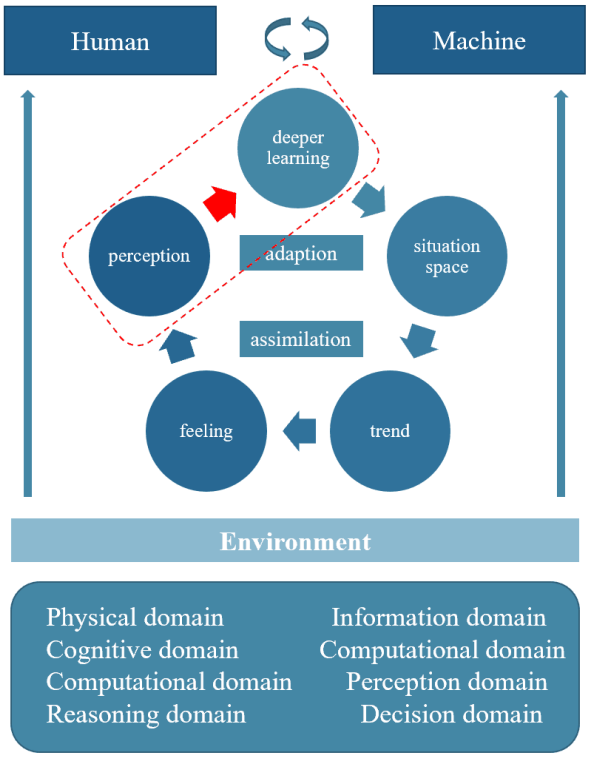

Figure 4. Human–machine–environment integrated cognitive chain

4.3 The Key to the Development of HI

The above dilemma reflects the high complexity of agreeing on cognitive and behavioral levels of brain and machine. For this reason, we believe that a complete HI should be able to have two core characteristics: enhancement of cognitive and perceptual differences.

4.3.1 Augmented Cognition

At the moment, human–machine fusion in the application stage has a clear division of labor between human and machine, which does not produce an effective contract effect. The process of human understanding in the world is essentially the process of using concepts, attributes, and relations to perceive the world. Machines cannot relate things of different properties, but people can relate seemingly unrelated things. Nowadays, people have relatively little understanding of the principles and mechanisms of cognitive nerve, and the real cognitive process is more complex, such as learning and memory. However, exploring the complementarity and integration of machine intelligence and human intelligence is the only possible way to break through the cognitive limitations.

In hybrid intelligent systems, both human and machine can develop together through enhanced cognition and achieve outstanding results at the system level. By enhancing cognition, HI can flexibly coordinate various contradictions and paradoxes in human–machine fusion intelligence. In the process of man–machine data, fusion processing of unstructured information architecture (such as natural language) will have some gradient that is structured, and structured data of the machine according to the syntax will focus on unstructured cognition and interpretation. In this kind of a semi-structured situation, not only to use reasoning based on justice, but in combination with non-public rational reasoning, makes the whole process of cognitive inference more rigorous and reasonable, in order to achieve the ultimate goal of cognitive enhancement.

At the application level, Campbell, Egerstedt, How and Murray (2010) made an in-depth analysis of various HCI modes and methods involved in autonomous driving. Taking the human brain as the carrier, they proposed a cognitive enhancement scheme from the perspective of human–computer HI, which solved the problem of

interaction barriers in autonomous driving and started the era of human–car intelligent integration.

In the big data environment, a simple computing power has made breakthrough progress, less likely to have future fusion "cognitive" should be considered in calculation of position, for a state of equilibrium, so that the person of thinking disorder and the calculation order of the computer, the person's mood perceptual and rational organic mixed by computer program, so as to achieve efficient and flexible real enhancement "smart."

4.3.2 Cognitive Interaction

Another key to HI is that humans can understand how machines see the world and make effective decisions by relying on their thinking and expression. Therefore, in the process of interaction, transfixion of human–machine thinking mode is the core. HCI fusion in thinking not only requires machine perception and understanding of human behavior, but also human understanding of data-driven machine thinking. Only when perceptual interaction is achieved can intelligent fusion in a real sense be realized.

Humans have the ability to cross domains, but machines do not. Therefore, the establishment of two-way interaction between human and machine is the breakthrough to realize real intelligence. On one hand, the machine itself can make use of the mutual cooperation between the machines and the feedback mechanism provided by the machine to "perceive," and strengthen the machine's intelligence through game, so as to realize the self-evolution of machine intelligence. On the other hand, with the improvement of machine intelligence, people can also be inspired by the feedback from machines, so as to enrich their own experience and knowledge, and improve their perception and cognitive value.

The performance of the hybrid intelligent system can be measured not only by the excellent results of the whole social technology system, but also by the perceived collaborative efficiency of man–machine. The perceptual interaction takes humans as the perceptual node, through the fusion of human intelligence, to improve the traditional perception ability based on machine equipment, realize the complementary advantages of man and machine, and achieve the purpose of improving the perceptual efficiency.

At present, some studies attempt to connect the bottom layer of the cerebral cortex between machine and human (Kamar,2016), so as to achieve real brain–machine perception interaction and two-way communication. However, as the research of BCI to realize the underlying fusion and interaction involves multiple disciplines such as intelligent technology, neuroscience and brain science, it is still in its infancy.

4.4 Hybrid Intelligent System Architecture Model

Based on the above problems and the key to the development of HI, an HI system architecture model is proposed on the basis of previous studies, which is shown in Figure 5.

The main body of a human–computer hybrid intelligent system includes both human and computer. The internal execution and operation of the system are composed of data source layer, data transmission layer, data processing layer, and application layer. In addition, the whole system also contains an external environment. The machine intelligence represented by the computer can achieve a rational, accurate, and efficient state for the transmission and utilization of objective data, and can learn from the data of the surrounding environment. Some features that are not yet understood by human beings and extract and correlate them are that the human-oriented human intelligence generates knowledge through the perception of the environment, relies on experience, and then transmits the knowledge to the machine, so as to help the machine better learn and perceive the environment. In the process of HCI and collaboration, the continuous interactive learning between the two in the external environment enables the system to have the ability of cognitive enhancement and perceptual interaction, thus producing a more perfect result than the decision made by machines or humans alone.

Against the background of the big data era, the combination of data-driven and knowledge-guided method should be a way of continuous learning and common progress of the man–machine system. On one hand, data-driven intelligent machines need to understand human subjective experience and perceptual thinking. On the other hand, knowledge-driven human thinking also needs to understand the objective characteristics and rational calculation of machines. At the data source layer, human beings can contribute high-quality swarm intelligence perception data with characteristics of multi-mode, rich content, spatiotemporal, human nature, etc., and form high-quality data sources through the exchange of objective network data (Guo, Zhai, Yu, & Zhou, 2017). At the data transmission layer, in the environment of swarm intelligence perception, the transmission delay of perception data can be reduced by interacting with the

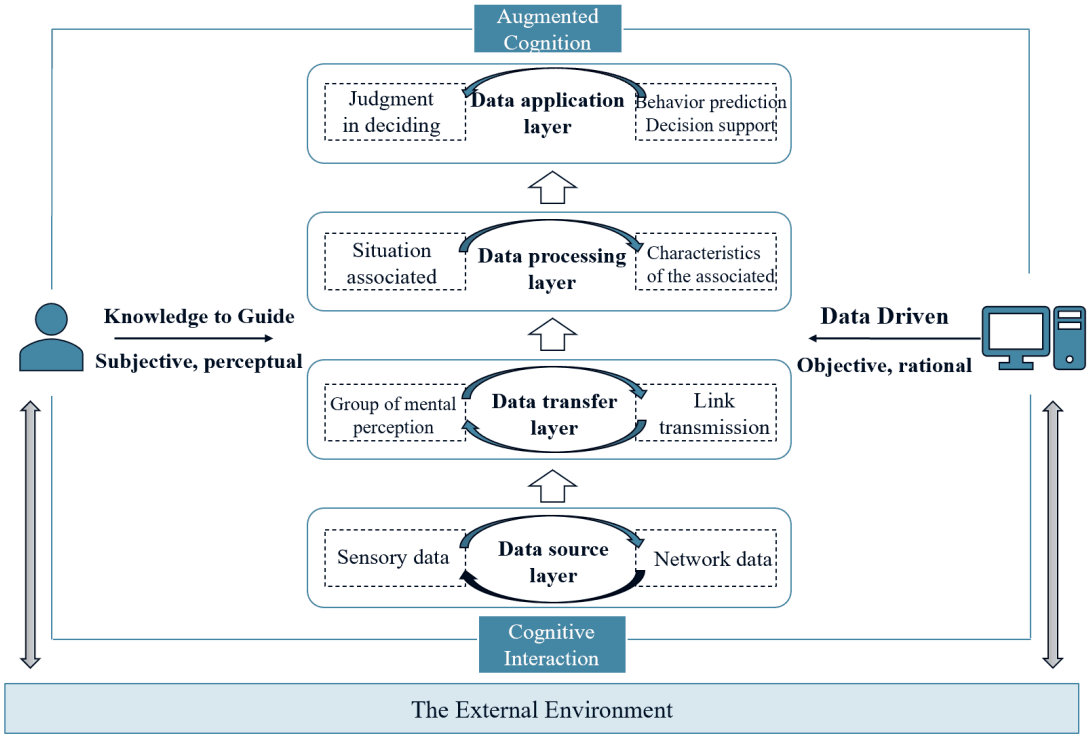

Figure 5. Architecture model of HI system

computer network. In the data processing layer, human cognitive ability and expert experience can assist the machine to more efficiently and accurately complete the data association, fusion, and understanding. Especially in the case that some tasks cannot be solved by existing machine intelligence technology, the man–machine collaborative computing becomes the key for data processing. In the application layer, based on the previous man–machine collaborative processing, the machine can have a strong perception and judgment ability, and its ultimate purpose is to provide the support of prediction and decision, and cooperate with human beings to complete the final decision. The accuracy of the final decision result is largely determined by the comprehensive judgment ability of human beings, while the machine makes indirect evaluation of the result "interperception" obtained by calculation. This unique decision process combining intuition with "interperception" is a major feature of the human–machine fusion intelligent output.

In addition, HI is a product of the interaction and cooperation between human, machine, and environmental systems, and it is an equilibrium state generated by the superposition of the changing states of the three, so how to maintain the coordination and stability of the three is the key. The people in the system represent the group intelligence, the machine not only includes the machine equipment but also involves the mechanism, and the two also relate the natural and social environments, the real and the virtual environment.

5 Intelligent Services Based on HI Architecture

5.1 The Connotation Characteristics of Intelligent Service

With the rapid increase of the number of science and technology intelligence users, the concept of intelligent services has emerged. Intelligence is not only the tool, but also the content of service. The traditional knowledge service begins to change according to the intelligent active service mode. The co-creation of HI services between humans and intelligent agents might create a sense of psychological ownership and, thus, increase acceptance and trust.

As a typical human–machine collaborative application scenario, intelligent service aims to build a truly efficient and intelligent production system of "social perception & data fusion & collaborative production &intelligent service" to meet the needs of users for precision. Real-

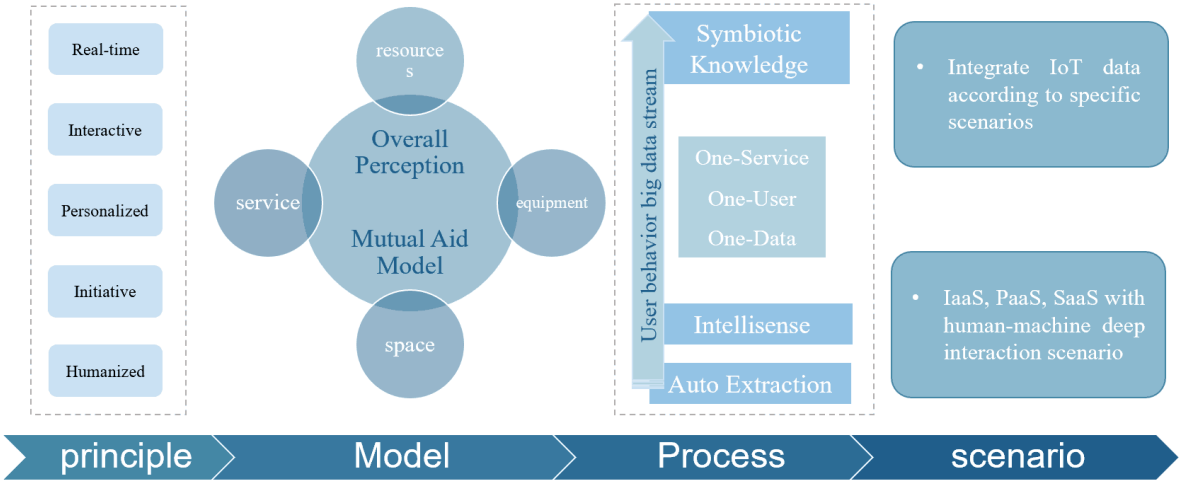

Figure 6. Principles, models, processes, and scenarios of intelligence service

time performance and interactivity are two important principles of data-driven intelligence service. The current mainstream technology cloud service platform satisfies users' needs through interactive intelligence service consultation and real-time interactive retrieval of the semantic Web knowledge base. So, intelligent services follow the RIPIH principle, which includes five basic principles including Real-time, Interactive, Personalized, Initiative, and Humanized (Chen, 2012).

Figure 6 shows the principles, models, processes, and scenarios for intelligent services. It can be seen that intelligent services use core knowledge of organizational integration to improve service pertinence, such as intelligent perception, automatic extraction, and relevance discovery. In the process of service, we comprehensively perceive resources, equipment, space and services, and form a mutual assistance mode. By deeply penetrating the mixed intelligence, we can improve the intelligent management efficiency and service level of each link, thus forming a complete symbiotic knowledge and wisdom system. The concept of data center mentioned in the industry is actually, to some extent, a smart service driven by big data. One-Data integrates low-level data collection and storage, One-User completes user-oriented data transformation and scheduling based on deep mining and perceptive interaction, and One-Service is an application-oriented integrated optimization service system. In this process, it is the key to collaborative management and knowledge service to perceive users' depth needs through human–machine hybrid intelligence.

5.2 Intelligent Services Based on Knowledge Fusion

In the process of the development of the information system, people have never really integrated into these systems. The intermediary between them is the human–computer interface (HCI), and what is transmitted through the machine is only the bitstream without emotion, while the so-called "human-computer collaboration" is only the control dominated by people. Management software and collaboration systems, represented by UC&C, are essentially work and work management systems that integrate people into them, focusing on the coordination of people and information. HI is the key to collaborative management and service. Researchers investigating this HI "explore how people and computers can be connected so that—collectively—they act more intelligently than any person, group, or computer has ever done before. (Malone, 2018)" The connection and interoperation between people, things, and information, the compatible integration of information workflow and knowledge workflow become the only way, and the core process of enterprise operation and management automation and intelligence.

Traditional knowledge service is based on the search and query of professional knowledge content and Internet information to provide users with useful information and knowledge. In the era of big data, AI empowers knowledge services to improve service efficiency to a certain extent and meet the basic needs of users. However, due to the fact that human–machine collaboration remains on the surface, it fails to realize the effective fusion of knowledge.

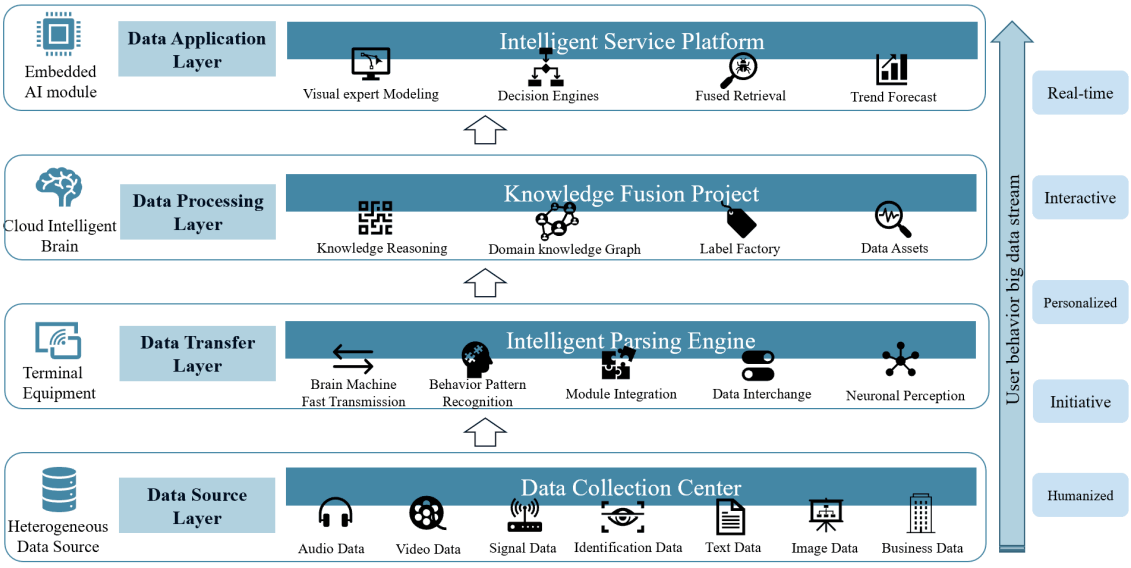

Figure 7. Intelligent services system based on HI architecture

Knowledge fusion is a key link in intelligent services. The advantage of HI is that it can generate new knowledge in complex fields, enabling humans to learn from AI and transfer implicit knowledge from experienced experts to novices (Kamar, Hacker, & Horvitz, 2012). Mellers et al. (2015) introduced knowledge into the data-driven intelligent machine and integrated knowledge into the machine. Adding human choice judgment and action management in the operation process of knowledge fusion system is the key to make information fusion intelligence achieve qualitative changes in the field of advanced perception in observation, judgment, analysis, and decision-making.

5.3 Hybrid Intelligent Service System

Through the analysis in Section 5.2, we can know that brain–machine knowledge fusion is the core of intelligent services for complex scenes, and also a key link of hybrid intelligent systems. In the early stage, through the effective integration and transmission of multisource heterogeneous data, the intelligent analysis and exchange of data are completed. On this basis, the automatic extraction technology of knowledge, knowledge reasoning technology, and the intervention of domain experts are also needed. The whole process reflects the characteristics of human–computer deep perception and interaction, and the completion of knowledge fusion marks the completion of "cloud brain" representing human–computer intelligence. Figure 7 is a complete framework of the hybrid intelligent service system. From data discovery to application landing, each level reflects the joint exploration of domain experts and AI represented by machines.

The intelligent service for complex scenes has the characteristics of "application traction, hybrid intelligent drive, platform enabling, terminal extension." The data source layer mainly relies on the large-scale data perception and integration ability of machine intelligence to form a data aggregation center; the data transmission layer relies on the alternate transmission of neuron signal and electrical signal to complete the rapid transmission and analysis of data; and forms the intelligent data processing layer, which is the core link for building the cloud brain as the main goal. This process takes the knowledge fusion project as the main body, and it is the link that truly reflects the value of hybrid intelligence. Finally, in the application layer, the embedded module is used as the intelligent center and core carrier. After the knowledge is processed by the cloud brain, the services formed are integrated into various businesses through the platform, so as to realize the landing of human–computer deep cooperation in complex scenes.

In this process, there are three main roles: experts in various industries and scenarios, knowledge services, and users of AI represented by machines. Experts empower the machine with knowledge, and the machine improves the user's experience through the way of knowledge service and intelligent products. In this process, users will also feedback their personalized needs, and then feed back to the machine. The machine will assist experts to improve

their potential and efficiency. The closed loop formed between the three helps in the development of intelligent services.

6 Conclusion

At present, a new round of scientific and technological revolution and industrial transformation is emerging. The application of big data and the innovation of theoretical algorithm are promoting the development of intelligence. Technologies such as 5G and cloud intelligence are driving the development of distributed AI to a new stage, making it possible for data to generate knowledge through learning in the cloud. Thus, with the cooperation of machine intelligence, human–machine fusion has become the ultimate goal of intelligence development, that is, human intelligence and machine intelligence adapt to each other, support each other, promote each other, and realize the common evolution and optimization of intelligence.

In the big data environment, the success of the AI paradigm based on the big data model requires us to establish a new way of thinking. As the volume of data has exploded, it has become a reality that pure human intelligence has lagged behind AI in every single field. The human brain gradually needs to adapt to big data and integrate with machine intelligence to build large models to understand complex environments and handle complex affairs.

Being an organic integration system of human, machine, and environment, HI can assimilate multisource heterogeneous information more quickly and efficiently. In the process of intelligent data processing, machine data computation and human information cognition are integrated to build a unique understanding approach, and adapt to external changes through cognitive enhancement and perceptual interaction. Therefore, HI is a highly convergent combination of rationality and sensibility, intuition and logic, memory and storage, and calculation and calculation, which represents the future development direction of intelligent technology.

The intelligent service system based on HI has been widely concerned by the academia and the industry. The key is to build a real "cloud intelligent brain" by using knowledge fusion theory and technology. This paper attempts to provide a feasible solution for the application service of HI in complex scenarios by constructing the hybrid intelligent service architecture. Thus, based on the hybrid intelligent architecture, guided by business experts, driven by the core technology engine, and supported by big data fuel, it can realize intelligent social service. It can be predicted that human–machine HI will bring the level of human applied intelligence to a new realm.

Authors' contribution: Liu Zhenghao put forward the research ideas and designed the research framework. Zeng Xi was responsible for writing and revising the English language of the paper.

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