International Journal of Intelligence Science, **2011, 1, 8-16**
doi:10.4236/ijis.2011.11002 Published Online July 2011 (http://www.SciRP.org/journal/ijis)

Foundations of Intelligence Science*

Zhongzhi Shi
The Key Laboratory of Intelligent Information Processing, Institute of Computing Technology, Chinese Academy of Sciences, Beijing, China
E-mail: *shizz@ics.ict.ac.cn*
Received June 11, 2011; *revised July* 20, 2011; *accepted July* 25, 2011

Abstract

In order to make significant progress toward achievement of human level machine intelligence a paradigm shift is needed. More specifically, the natural intelligence and artificial intelligence should be closely interacted in Intelligence Science study, instead of separate from each other. In order to reach the paradigm, brain science, cognitive science, artificial intelligence and others should cross-research together. Brain science explores the essence of brain, research on the principle and model of natural intelligence in molecular, cell and behavior level. Cognitive science studies human mental activity, such as perception, learning, memory, thinking, consciousness etc. Artificial intelligence attempts simulation, extension and expansion of human intelligence using artificial methodology and technology. All together pursue to explore the mechanism and principle of intelligence which is the engine of advanced science and technology. The paper will give the definition of intelligence and discuss ten big issues of Intelligence Science. The conclusion and perspective will be given in last section.

Keywords: Intelligence, Intelligence Science, Machine Intelligence

1. Introduction

Since 1956 artificial intelligence is formally found and very impressive progress has been made in many areas over the past years. Its achievements and techniques are in the mainstream of computer science and at the core of so many systems. For example, the computer beats the world's chess champ, commercial systems are exploiting voice and speech capabilities, there are robots running around the surface of Mars. In well-known TV quiz show "Jeopardy" IBM super computer system Watson beats the best of the two bit of human champion Ken Jennings and Brad Rutter. But all these achievements are not in the realm of human level machine intelligence.

Humans are the best example of human-level intelligence. McCarthy declared the long-term goal of AI is human level AI [1]. Recent works in multiple disciplines of cognitive and neuroscience motivate new computational approaches to achieving human level AI. In the book On Intelligence, Hawkins proposed machine intelligence meets neuroscience [2]. Granger presented a framework for integrating the benefits of parallel neural hardware with more serial and symbolic processing which motivated by recent discoveries in neuroscience [3]. Langley proposed a cognitive architecture ICARUS which uses means-ends analysis to direct learning and stores complex skills in a hierarchical manner [4]. Sycara proposed the multi-agent systems framework which one develops distinct modules for different facets of an intelligent system [5]. Cassimatis and his colleagues investigate Polyscheme which is a cognitive architecture designed to model and achieve human-level intelligence by integrating multiple methods of representation, reasoning and problem solving [6]. Based on the LIDA cognitive architecture, Franklin *et al.* proposed an underlying computational software framework for Artificial General Intelligence [7].

To make significant progress toward achievement of human level machine intelligence a paradigm shift is needed. Artificial intelligence should change the research paradigm and learn from natural intelligence. The interdisciplinary subject entitled Intelligence Science is promoted. In 2002 the special Web site called Intelligence Science has been appeared on Internet [8], which is con-

*This paper is supported by National Basic Research Programme (2007CB311004), Key projects of National Natural Science Foundation of China (No. 61035003, 60933004,), National Natural Science Foundation of China (No. 61072085, 60970088, 60903141).

structed by Intelligence Science Lab of Institute of Computing Technology, Chinese Academy of Sciences. A special bibliography entitled Intelligence Science written by author was published by Tsinghua University Press in 2006 [9]. The book shows a framework of intelligence science and points out research topics in related subject. The English version of the book Intelligence Science is published by World Scientific Publishers in 2011.

Intelligence Science is an interdisciplinary subject which dedicates to joint research on basic theory and technology of intelligence by brain science, cognitive science, artificial intelligence and others. Brain science explores the essence of brain, research on the principle and model of natural intelligence in molecular, cell and behavior level. Cognitive science studies human mental activity, such as perception, learning, memory, thinking, consciousness etc. In order to implement machine intelligence, artificial intelligence attempts simulation, extension and expansion of human intelligence using artificial methodology and technology.

Next section will define what is intelligence. The basic issues of Intelligence Science are listed in Section 3. Finally, conclusion and perspective will be given.

2. What Is Intelligence

Intelligence is a very hot word. At the present it is a new development trend to intellectualize technology, product, equipment, such as intelligent computer, intelligent robot, intelligent database, intelligent management, intelligent control, intelligent CAD, intelligent network, intelligent engineering and so on [10]. Intelligence is most widely studied in humans, but has also been observed in animals and plants. Numerous definitions of intelligence have been proposed with no consensus reached by scholars. Intelligence has been defined in different ways, including the abilities for abstract thought, understanding, communication, reasoning, learning, planning, emotional intelligence and problem solving.

Legg and Hutter list 70 odd definitions of intelligence from collective definitions, psychologist definitions and AI researcher definitions [11]. They pull out commonly occurring features and find that intelligence has following features:

1) A property that an individual agent has as it interacts with its environment or environments.

2) Is related to the agent's ability to succeed or profit with respect to some goal or objective.

3) Depends on how able to agent is to adapt to different objectives and environments.

According to above features they give the informal definition of intelligence as "Intelligence measures an agent's ability to achieve goals in a wide range of environments." [11]

We think that intelligence is a comprehensive ability to use one's existing knowledge or experience to adapt new situations or solve new problems [10]. Since 1956, traditional artificial intelligence adopts reasoning to do problem solving. Most of expert systems are implemented through deductive reasoning. Inductive reasoning is applied in machine learning and data mining. Artificial neural networks are massively parallel, adaptive, dynamical systems modeled on the general features of biological networks. Through trial and error, the network literally teaches itself how to do the task. In terms of situatedness, embodiment, intelligence and emergency behavior-based artificial intelligence has built more powerful autonomous mobile robots. It is a good idea that symbolic, connectionist and behaviorist mechanism are combined together to develop intelligent systems.

Humans have many remarkable capabilities: first the capability to reason, converse and make rational decisions in the real world of imprecision, uncertainly, incompleteness of information; and second, the capability to perform a wide variety of physical and mental tasks. Machine intelligence should learn from natural intelligence and more closely interacted in Intelligence Science study.

3. Basic Issues of Intelligence Science

3.1. How Do Brain Neural Circuits Work?

The brain is a collection of about 10 billion interconnected neurons. Neurons are electrically excitable cells in the nervous system that process and transmit information. A neuron's dendrites' tree is connected to a thousand neighboring neurons [12]. When one of those neurons fire, a positive or negative charge is received by one of the dendrites. The strengths of all the received charges are added together through the processes of spatial and temporal summation. The aggregate input is then passed to the soma (cell body). The soma and the enclosed nucleus don't play a significant role in the processing of incoming and outgoing data. Their primary function is to perform the continuous maintenance required to keep the neuron functional. The output strength is unaffected by the many divisions in the axon; it reaches each terminal button with the same intensity it had at the axon hillock.

Each terminal button is connected to other neurons across a small gap called synapse. The physical and neurochemical characteristics of each synapse determines the strength and polarity of the new input signal. This is where the brain is the most flexible, and the most vulnerable. In molecular level neuron signal generation, transmission and neurotransmitters are basic problems attracted research scientists to engage investigation in brain science.

One of the greatest challenges in neuroscience is to determine how synaptic plasticity and learning and memory are linked. Two broad classes of models of synaptic plasticity can be described by Phenomenological models and Biophysical models [13].

Phenomenological models are characterized by treating the process governing synaptic plasticity as a black box. The black box takes in as input a set of variables, and produces as output a change in synaptic efficacy. No explicit modeling of the biochemistry and physiology leading to synaptic plasticity is implemented. Two different classes of phenomenological models, rate based and spike based, have been proposed.

Biophysical models, in contrast to phenomenological models, concentrate on modeling the biochemical and physiological processes that lead to the induction and expression of synaptic plasticity. However, since it is not possible to implement precisely every portion of the physiological and biochemical networks leading to synaptic plasticity, even the biophysical models rely on many simplifications and abstractions. Different cortical regions, such as Hippocampus and Visual cortex have somewhat different forms of synaptic plasticity.

Some important questions about human brain structure and function remain a puzzle to us. What functions happen in the left-right and front-back division of cerebral cortex and how to link each other? Many regions of the -brain come together to form a dynamic and intricate biological structure that holds many puzzles for us to unravel.

3.2. What Is Perceptual Representation and Theory of Perception?

The perceptual systems are primarily visual, auditory and kinesthetic, that is, pictures, sounds and feelings. There is also olfactory and gustatory, *i.e.* smell and taste. The perceptual representation is a modeling approach that highlights the constructive, or generative function of perception, or how perceptual processes construct a complete volumetric spatial world, complete with a copy of our own body at the center of that world. The representational strategy used by the brain is an analogical one; that is, objects and surfaces are represented in the brain not by an abstract symbolic code, or in the activation of individual cells or groups of cells representing particular features detected in the visual field. Instead, objects are represented in the brain by constructing full spatial effigies of them that appear to us for all the world like the objects themselves or at least so it seems to us only because we have never seen those objects in their raw form, but only through our perceptual representations of them.

Objects of perception are the entities we attend to when we perceive the world. Perception lies at the root of all our empirical knowledge. So far there are 3 theories of perception mainly, that is, direct realism [14], indirect realism, Gestalt principles [15]. The fundamental question we shall consider concerns the objects of perception: what is it we attend to when we perceive the world?

As you know that the binding problem is an important problem across many disciplines, including psychology, neuroscience, computational modeling, and even philosophy. Feature binding is the process how a large collection of coupled neurons combines external data with internal memories into coherent patterns of meaning. According to neural synchronization theory, feature binding is achieved via neural synchronization. When external stimuli come into the brain, neurons corresponding to the features of the same object will form a dynamic neural assembly by temporal synchronous neural oscillation, and the dynamic neural assembly, as an internal representation in the brain, codes the object in the external world.

In 1990, Eckhorn and coworkers proposed a Linking Field Network according to the synchronized neural oscillation in the visual cortex of cat [16]. Linking Field Network can synchronize stimuli evoked oscillations at different regions in the visual cortex if the regions have similar local coding properties. Referred to noisy neural model, Bayesian method and competition mechanism a computational model for feature binding has been proposed [17].

3.3. How Are Memories Stored and Retrieved?

Memory can be defined as a lasting representation that is reflected in thought, experience or behavior. Based on operation time memory can be categorized as sensory memory, working memory or short-term memory, long-term memory. Sensory memory is memory from our immediate sensory. Sensory memory preserves accurate representation of the physical features of sensory stimuli for a few seconds or less. Working memory holds information temporarily in the order of seconds to minutes. Long-term memory can be considered a warehouse of all experiences, events, skills, words, rules, emotions, and judgments that have been attained from sensory and short-term memory.

In terms of the types of information stored long-term memory can be classified into declarative and non-declarative memories. Declarative memory can be further divided into episodic and semantic memory, while non-declarative memory consists of procedural memory and conditioning memory.

Understanding how memories are stored in the brain is an essential step toward understanding ourselves. Since the 1970s, work on isolated chunks of nervous-system tissue has identified a host of molecular players in memory formation. Many of the same molecules have been implicated in both declarative and non-declarative memory. A key insight from this work has been that short-term memory involves chemical modifications that strengthen existing connections, called synapses, between neurons, whereas long-term memory requires protein synthesis and probably the construction of new synapses [18].

A brain has distributed memory system, that is, each part of brain has several types of memories that work in somewhat different ways, to suit particular purposes. According to the stored time of contents memory can be divided into long term memory, short term memory and working memory. Research topics in memory exist coding, extract and retrieval of information. Current working memory attracts more researchers to involve.

Working memory will provides temporal space and enough information for complex tasks, such as understanding speech, learning, reasoning and attention. There are memory and reasoning functions in the working memory. It consists of three components: that is, central nervous performance system, video space primary processing and phonetic circuit [19].

Memory phenomena have also been categorized as explicit or implicit. Explicit memories involve the hippocampus-medial temporal lobe system. The most common current view of the memorial functions of the hippocampal system is the declarative memory. There are a lot of research issues that are waiting for us to resolve. What is the readout system from the hippocampal system to behavioral expression of learning in declarative memory? Where are the long-term declarative memories stored after the hippocampal system? What are the mechanisms of time-limited memory storage in hippocampus and storage of permanent memories in extra-hippocampal structures?

Implicit memory involves the cerebellum, amygdale, and other systems [20]. The cerebellum is necessary for classical conditioning of discrete behavioral responses under all condition. It is learning to make specific behavioral responses. The amygdales system is learning fear and associated autonomic responses to deal with the situation.

3.4. What Is the Neural Basis of Language?

Language is fundamentally a means for social communication. Language is also often held to be the mirror of the mind. Chomsky developed transformational grammar that cognitivism replaced behaviorism in linguistics [21].

Through language we organize our sensory experience and express our thoughts, feelings, and expectations. Language is particular interesting from cognitive informatics point of view because its specific and localized organization can explore the functional architecture of the dominant hemisphere of the brain.

Recent studies of human brain show that the written word is transferred from the retina to the lateral geniculate nucleus, and from there to the primary visual cortex. The information then travels to a higher-order center, where it is conveyed first to the angular gyrus of the parietal-temporal-occipital association cortex, and then to Wernicke's area, where the visual information is transformed into a phonetic representation of the word. For spoken word the auditory information is processed by primary auditory cortex. Then the information input to higher-order auditory cortex, before it is conveyed to a specific region of the parietal-temporal-occipital association cortex, the angular gyrus, which is concerned with the association of incoming auditory, visual, and tactile information. From here the information is projected to Wernicke's area and Broca's area. In Broca's area the perception of language is translated into the grammatical structure of a phrase and the memory for word articulation is stored [22].

3.5. How Does the Brain Learn?

Learning is the basic cognitive activity and accumulation procedure of experience and knowledge. Through learning the system performance will be improved. Perceptual learning, cognitive learning, implicit learning are active research topics in the learning area.

Perceptual learning should be considered as an active process that embeds particular abstraction, reformulation and approximation within the Abstraction framework. The active process refers to the fact that the search for a correct data representation is performed through several steps. A key point is that perceptual learning focuses on low-level abstraction mechanism instead of trying to rely on more complex algorithm. In fact, from the machine learning point off view, perceptual learning can be seen as a particular abstraction that may help to simplify complex problem thanks to a computable representation. Indeed, the baseline of Abstraction, *i.e.* choosing the relevant data to ease the learning task, is that many problems in machine learning cannot be solve because of the complexity of the representation and is not related to the learning algorithm, which is referred to as the phase transition problem. Within the abstraction framework, we use the term perceptual learning to refer to specific learning task that rely on iterative representation changes and that deals with real-world data which human can perceive.

In contrast with perceptual learning cognitive leaning is a leap in the process of cognition and generate knowledge through clustering, classification, conceptualization and so on. In general, there are inductive learning, analogical learning, case-based learning, explanation learning, evolutional learning connectionist learning.

The core issue of cognitive learning is self-organizing principles. Kohonen has proposed a self-organizing maps which is a famous neural network model. Babloyantz applied chaotic dynamics to study brain activity. Haken has proposed a synergetic approach to brain activity, behavior and cognition.

Introspective learning is an inside learning of brain, which means without input information from outside environment. We have proposed a model for introspecttive learning which employs case-based reasoning and ontology-based knowledge [23].

The term implicit learning was coined by Reber to refer to the way people could learn structure in a domain without being able to say what they had learnt [24]. Reber first proposed artificial grammars to study implicit learning for unconscious knowledge acquisition. It will help us to understand the learning mechanism without consciousness. Since middle of 1980's implicit learning become an active research area in psychology.

3.6. How to Think in Human Brain?

Thought is a reflection of essential attributes and internal laws of objective reality in conscious, indirect and generalization by human brain with consciousness [25]. In recent years, there has been a noteworthy shift of interest in cognitive science. Cognitive process rises man's sense perceptions and impressions to logical knowledge. According to abstraction degree of cognitive process, human thought can be divided into three levels: perception thought, image thought and abstraction thought. A hierarchical model of thought which illustrates the characteristics and correlations of thought levels has been proposed and shown in **Figure 1** [10,26].

Perception thought is the lowest level of thought. Behavior is the objective of research in perception thought. Reflection is a function of stimulus. Perception thought emphasizes stimulus-reflection schema or perception-action schema. The thought of animal and infant usually belong to perception thought because they can not introspect, and also can not declare empirical consciousness. In perception thought, intelligent behavior takes place without representation and reasoning.

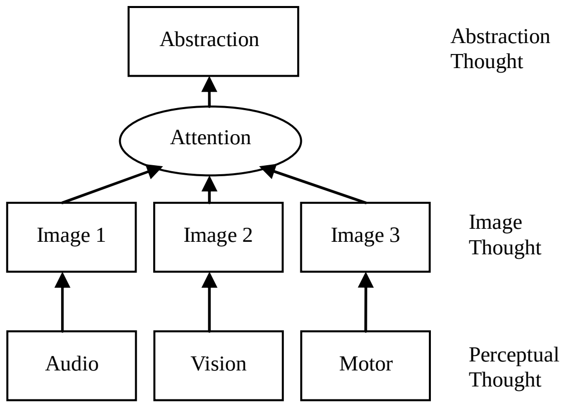

Figure 1. Hierarchical thought model of brain.

Behavior-based artificial intelligence has produced the models of intelligence which study intelligence from the bottom up, concentrating on physical systems, situated in the world, autonomously carrying out tasks of various sorts. They claim that the simple things to do with perception and mobility in a dynamic environment took evolution much longer to perfect. Intelligence in human have been taking place for only a very small fraction of our evolutionary lineage. Machine intelligence can take evolution by the dynamics of interaction with the world.

Image thought adopts intuitive imagery as thinking element. Intuitive imagery is one kind of information which acquires through processing perceptual representtation, but does not yet generate concepts of language. Typical image thought is pattern recognition which can deal with pattern information, such as character, image, speech, classification and recognition of objects, and so on [10,25].

Based on perceptual knowledge, the process which reflects the common properties and exposes internal relations of distinct objects through concepts, judgment and inference is called abstraction thought. Concepts are no longer the phenomena, the separate aspects and the external relations, while reflect the essences and internal relations of objects. Judgment represents the certain relations between conceptions. Inference acquires new knowledge from existing knowledge. There are existing deductive reasoning, inductive reasoning, and abductive reasoning currently. By means of judgment and inference one is able to draw logical conclusions. Logical knowledge is capable of grasping the development of the surrounding world in its totality, the internal relations of all its aspects.

Attention focuses consciousness to produce greater vividness and limits the number of thoughts that can be entertained at one time. Attention forces human thinking process from parallel to sequential in terms of leaping from image thought to abstraction thought.

3.7. What Is the Procedure of Intelligence Development?

From pregnant with, born to the adult's coursing human cerebral cortex passed perception and effectors with external environment that mutual and plasticity development takes place, cause corresponding intelligence and cognitive ability to reach maturity progressively. The first theory of intelligence development which is a comprehensive theory about the nature and development of human intelligence developed by Jean Piaget. It is primarily known as a developmental stage theory. Jean Piaget proposes that there are four distinct, increasingly sophisticated stages of mental representation that children pass through on their way to an adult level of intelligence [27].

1) From birth to 2 years old is the sensorimotor stage.

2) From 2 years old to 7 years old is pre-operation stage. The Preoperational Stage can be further broken down into the Pre-conceptual stage and the Intuitive stage.

3) Concrete operational stage is between the ages of 7 and 11 years. This stage is characterized by the appropriate use of internalized, reversible, conservative and logical actions.

4) Formal operational stage is between the ages of 12 and 15 years. In this stage, individuals move beyond concrete experiences and begin to think abstractly, reason logically and draw conclusions from the information available, as well as apply all these processes to hypothetical situations.

Soviet psychologist Vygotsky's most important contribution concerns the inter-relationship of language development and thought. This concept, explored in Vygotsky's book *Thought and Language*, establishes the explicit and profound connection between speech, and the development of mental concepts and cognitive awareness [28].

In recent years, biological mechanism, computational theory and cognitive applications of intelligence development have obtained very great development. Studying on Independent motivation and utility system in cognitive computation, internal representation and development mechanism based on the basis of sensory perception and action effection, getting nonspecific study and characteristics of popularization and application, and development structure of cognitive computation scholars have made the abundant achievements. Through the study of intelligence development the mankind can expand physical limit greatly.

3.8. What Is the Nature of Emotion?

The mental perception of some fact excites the mental affection called the emotion, and that this latter state of mind gives rise to the bodily expression. Emotion is a complex psychophysical process that arises spontaneously, rather than through conscious effort, and evokes either a positive or negative psychological response and physical expressions. Research on emotion at varying levels of abstraction, using different computational methods, addressing different emotional phenomena, and basing their models on different theories of affect.

Since the early 1990s emotional intelligence is systematically studied [29]. Scientific articles suggested that there existed an unrecognized but important human mental ability to reason about emotions and to use emotions to enhance thought. Emotional intelligence refers to an ability to recognize the meanings of emotion and their relationships, and to reason and problem solve on the basis of them. Emotional intelligence is involved in the capacity to perceive emotions, assimilate emotion-related feelings, understand the information of those emotions, and manage them.

Emotional state refers to one's internal dynamics when one has an emotion. Emotional states influence available information in working memory, subjective utility of alternative choices and style of processing. There are five models on emotion have been proposed, that is, Ortony Clore Collins cognitive model [30], Roseman's cognitive appraisal model [31], three-layer architecture [32], six-layer architecture [33], four elicitors for emotion synthesis [34]. However, till today, there is no model that can completely represent the human emotional system. One of the key problems is how to map emotional states to behaviors.

Another problem is the possible emotional circuitry in the brain. The process of emotion engages parts of the cortex, in particular the frontal cortex. The frontal cortex communicates with the limbic system and impacts decision-making.

3.9. What Is the Nature of Consciousness?

The most important scientific discovery of the present era will come to answer how exactly do neurobiological processes in the brain cause consciousness? The question "What is the biological basis of consciousness?" is selected as one of 125 questions, a fitting number for Science's 125th anniversary. Recent scientifically oriented accounts of consciousness emerging from the properties and organization of neurons in the brain. Consciousness is the notions of mind and soul.

The physical basis of consciousness appears to be the most singular challenge to the scientific, reductionist world view. Francis Crick's book 'The astonishing Hypothesis' is an effort to chart the way forward in the investigation of consciousness [35]. Crick has proposed the basic ideas of researching consciousness:

1) It seems probable, however, that at any one moment some active neuronal processes in your head correlate with consciousness, while others do not. What are the differences between them?

2) All the different aspect of consciousness, for example pain and visual awareness, employ a basic common mechanism or perhaps a few such mechanisms. If we could understand the mechanisms for one aspect, then we hope we will have gone most of the way to understanding them all.

Bernard Baars has proposed Global Workspace Theory (GWT) which integrates conscious contents with unconscious distributed expertise in the brain [36]. A theatre metaphor for GWT is a useful approximation. Unconscious processors in the theatre audience receive broadcasts from a conscious bright spot on the stage. Control of the bright spot corresponds to selective attention. Backstage, unconscious contextual systems operate to shape and direct conscious contents.

Chalmers suggests the problem of consciousness can be broken down into several separate questions. The major question is the neuronal correlate of consciousness (NCC) which focuses on specific processes that correlate with the current content of consciousness [37]. The NCC is the minimal set of neurons, most likely distributed throughout certain cortical and subcortical areas, whose firing directly correlates with the perception of the subject at the time. Discovering the NCC and its properties will mark a major milestone in any scientific theory of consciousness. Several other questions need to be answered about the NCC. What type of activity corresponds to the NCC? What causes the NCC to occur? And, finally, what effect does the NCC have on postsynaptic structures, including motor output.

3.10. How to Build Mind Model?

Mind could be defined as: “That which thinks, reasons, perceives, wills, and feels. The mind now appears in no way separate from the brain. In neuroscience, there is no duality between the mind and body. They are one.” in Medical Dictionary [38]. A mind model is intended to be an explanation of how some aspect of cognition is accomplished by a set of primitive computational processes. A model performs a specific cognitive task or class of tasks and produces behavior that constitutes a set of predictions that can be compared to data from human performance. Task domains that have received considerable attention include problem solving, language comprehension, memory tasks, and human-device interaction.

Researchers try to construct mind model to illustrate how brains do. Anderson and colleagues have demonstrated that a production rule analysis of cognitive skill, along with the learning mechanisms posited in the ACT-R model, provide detailed and explanatory accounts of a range of regularities in cognitive skill acquisition in complex domains such as learning to program Lisp [39]. ACT-R also provides accounts of many phenomena surrounding the recognition and recall of verbal material, and regularities in problem solving strategies [40-42].

In the early 1980’s, SOAR was developed to be a system that could support multiple problem solving methods for many different problems [43]. In the mid 1980’s, Newell and many of his students began working on SOAR as a candidate of unified theories of cognition. SOAR is a learning architecture that has been applied to domains ranging from rapid, immediate tasks such as typing and video game interaction to long stretches of problem solving behavior [44]. SOAR has also served as the foundation for a detailed theory of sentence processing, which models both the rapid on-line effects of semantics and context, as well as subtle effects of syntactic structure on processing difficulty across several typologically distinct languages.

Stan Franklin *et al.* have proposed a mind model called LIDA [45,46] which is grounded in the LIDA cognitive cycle. Each cognitive cycle the LIDA agent first makes sense of its current situation as best as it can. It then decides what portion of this situation is most in need of attention. Broadcasting this portion, the current contents of consciousness, enables the agent to finally chose an appropriate action and execute it.

A new mind model called Consciousness and Memory (CAM) is proposed by Intelligence Science Laboratory of Institute of Computing Technology [47]. **Figure 2** shows you the architecture of CAM model which consists of three main parts, which are consciousness, mem-

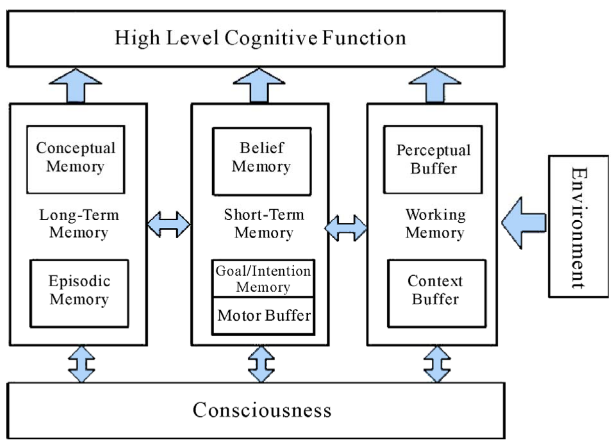

Figure 2. Architecture of CAM.

ory and high level cognitive functions. The consciousness possesses a set of planning schemes which arrange the components of CAM to accomplish different cognitive tasks. The memory part contains three types of memory which are long term memory, short term memory and working memory. The high level cognitive function part includes a class of high level cognitive functions such as event detection, action execution etc.

In CAM model, for episodic memory we employ case-based system to retrieve the episode according to the cues; while for semantic memory we adopt dynamic description logic to represent concepts and reasoning. Also we develop the cognitive cycle consists of awareness, intension, action composition which will be discussed in another paper.

4. Conclusions and Perspective

Intelligence Science is a new paradigm and interdisciplinary subject. Ten basic issues of Intelligence Science have been explored in the paper. These problems will constitute foundation of Intelligence Science and waiting for scientist to study.

Intelligence Science will let the human dream be reality to replace human brain work by machine intelligence The incremental efforts in neuroscience and cognitive science provide us exciting solid foundation to explore brain model and intelligent behavior. We should research on neocortical column, population coding, mind model, consciousness etc. for the human-level intelligence [48]. We believe that intelligence science will make great progress and new breakthroughs in the coming years. It is a good opportunity to contribute our intellect and ability to promote the development of intelligence science and become a bright spot of human civilization in 21 century.

5. Acknowledgements

The author would like to thank to Prof. J. R. Anderson, Prof. Loft A. Zadeh, Prof. Nils J. Nilsson, Prof. P. Rosenbloom and Prof. Yixin Zhong for their valuable discussions. I also acknowledge my colleagues at the Intelligence Science Laboratory for their contributions.

6. References

[1] J. McCarthy, "The Future of AI-A Manifesto," *AI Magazine*, Vol. 26, No. 4, 2005, p. 39.

[2] H. Jeff and S. Blakeslee, "On Intelligence, Times Books," Henry Holt and Company, New York City, 2004.

[3] R. Granger, "Engines of the Brain," *AI Magazine*, Vol. 27, No. 2, 2006, pp. 15-31.

[4] P. Langley, "Cognitive Architectures and General Intelligent Systems," *AI Magazine*, Vol. 27, No. 2, 2006, pp. 33-44,

[5] K. Sycara, "Multi-Agent Systems," *AI Magazine*, Vol. 19, No. 2, 1998, pp. 79-93.

[6] N. Cassimatis, "A Cognitive Substrate for Achieving Human-Level Intelligence," *AI Magazine*, Vol. 27, No. 2, 2006, pp. 45-56.

[7] J. Snaider, R. McCall, S. Franklin, "The LIDA Framework as a General Tool for AGI," AGI2011. (To be appeared).

[8] Intelligence Science Web http://www.intsci.ac.cn/.

[9] Z. Z. Shi, "Intelligence Science," in Chinese, Tsinghua University Press, Beijing, 2006.

[10] Z. Z. Shi, "Artificial Thought and Intelligent Systems," AI Summer School'94, Beijing, 1994.

[11] S. Legg and M. Hutter, "A Collection of Definitions of Intelligence," 2006. www.vetta.org/shane/intelligence.html.

[12] M. F. Bear, B. Connors, M. Paradiso, M. F. Bear, B. W. Connors and M. A. Neuroscience, "Exploring the Brain," 2nd Edition, Lippincott Williams & Wilkins, Philadelphia 2002.

[13] H. Z. Shouval, "Models of Synaptic Plasticity," *Scholarpedia*, Vol. 2, No. 7, 2007, p. 1605. doi:10.4249/scholarpedia.1605

[14] J. J. Gibson, "The Ecological Approach to Visual Perception" Houghton Mifflin, Boston, 1979.

[15] D. Chang, K. V. Nesbitt and K. Wilkins, "The Gestalt Principle of Continuation Applies to Both the Haptic and Visual Grouping of Elements," *WHC '07 Proceedings of the Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, 2007, pp. 15-20. doi:10.1109/WHC.2007.113

[16] R. Eckhorn, H. J. Reitboeck, M. Arndt and P. W. Dicke, "Feature Linking via Synchronization among Distributed Assemblies: Simulation of Results from Cat Cortex," *Neural Computation*, Vol. 2, No. 3, 1990, pp. 293-307. doi:10.1162/neco.1990.2.3.293

[17] Z. W. Shi, Z. Z. Shi, X. Liu and Z. P. Shi, "A Computational Model for Feature Binding," *Science in China, Series C: Life Science*, Vol. 51, No. 5, 2009, pp. 470-478. doi:10.1007/s11427-008-0063-3

[18] G. Miller, "How Are Memories Stored and Retrieved?" *Science*, Vol. 309, No. 5731 2005, p. 92. doi:10.1126/science.309.5731.92

[19] M. J. Dehn, "Working Memory and Academic Learning: Assessment and Intervention," Wiley, New York, 2008.

[20] M. Tarsia and E. Sanavio, "Implicit and Explicit Memory Biases in Mixed Anxiety-Depression," *Journal of Affective Disorders*, Vol. 77, No. 03, 2003, pp. 213-225. doi:10.1016/S0165-0327(02)00119-2

[21] N. Chomsky, "Syntactic Structures," Mouton, The Hague,

1957.

[22] R. Mayeux and E. R. Kandel, "Disorders of Language: The Aphasias," In: E. R. Kandel, J. H. Schwarz and T. M. Jessell Eds., *Principles of Neural Science*, 3rd Edition, Elsevier, Amsterdam, 1991, pp. 840-851.

[23] Q. Dong and Z. Z. Shi, "A Research on Introspective Learning Based on CBR," *International Journal of Advanced Intelligence*, Vol. 3, No. 1, 2011. pp. 147-157.

[24] A. S. Reber, "Implicit Learning and Artificial Grammer," *Journal of Verbal Learning and Verbal Behavior*, Vol. 6, No. 6, 1967, pp. 855-863. doi:10.1016/S0022-5371(67)80149-X

[25] Z. Z. Shi, "Cognitive Science," Press of USTC, Anhui, 2008.

[26] Z. Z. Shi, "Advanced Artificial Intelligence," Science Press of China, Beijing, 2006.

[27] J. Piaget, "Piaget's Theory," In: P. Mussen, Ed. *Handbook of Child Psychology*, 4th Edition, Wiley, New York, 1983.

[28] J. Santrock, "A Topical Approach to Life-Span Development. Chapter 6 Cognitive Development Approaches (200 - 225)," McGraw-Hill, New York, 2004.

[29] D. A. Norman, "Emotion and Design: Attractive Things Work Better," *Interactions Magazine*, Vol. 4, No. 4, 2002.

[30] Ortony, G. L. Clore and A. Collins, "The Cognitive Structure of Emotions," Cambridge University Press, Cambridge, 1988. doi:10.1017/CBO9780511571299

[31] McCarthy, O. L. Mejia, H. T. Liu and A. C. Durham, "Cognitive Appraisal Theory: A Psychoeducational Model for Connecting Thoughts and Feelings," *The Annual Convention of the American Psychological Association*, San Francisco, 14-18 August 1998.

[32] A. Sloman, "Review of Affective Computing," *AI Magazine*, Vol. 20, No. 1, 1999, pp. 127-133.

[33] M. Minsky, "The Emotion Machine," Simon and Schuster, New York City, 2006.

[34] J. Velasquez, P. Maes, "Cathexis: A Computational Model of Emotions," *Proceedings of the First International Conference on Autonomous Agents*, Marina del Rey, 05 - 08 February 1997.

[35] F. Crick, "The Astonishing Hypothesis," Scribner, Humboldt, 1995.

[36] B. J. Baars and S. Franklin, "An Architectural Model of Conscious and Unconscious Brain Functions: Global Workspace Theory and IDA," *Neural Networks*, Vol. 20 No. 9, 2007, pp. 955-961. doi:10.1016/j.neunet.2007.09.013

[37] D. Chalmers, "The Conscious Mind: In Search of a Fundamental Theory," Oxford University Press, Oxford, 1995.

[38] Medical dictionary Website: http://www.medterms.com/script/main/hp.asp.

[39] J. R. Anderson, "The Adaptive Character of Thought," Erlbaum, Hillsdale, 1993.

[40] J. R. Anderson and Y. Qin, "Using Brain Imaging to Extract the Structure of Complex Events at the Rational Time Band," *Journal of Cognitive Neuroscience*, Vol. 20, No. 9, 2008, pp. 1624-1636. doi:10.1162/jocn.2008.20108

[41] J. R. Anderson, "Using Neural Imaging to Inform the Instruction of Mathematics," N. Zhong, K. C. Li, S. F. Lu and L. Chen, Eds., *Brain Informatics*, *International Conference*: *Lecture Notes in Computer Science*, Toronto, 28-30 August 2010.

[42] J. R. Anderson, S. A. Betts, J. L. Ferris and J. M. Fincham, "Neural Imaging to Track Mental States While Using an Intelligent Tutoring System," *Proceedings of the National Academy of Science*, Vol. 107, No. 15, 2010, pp. 7018-7023. doi:10.1073/pnas.1000942107

[43] J. Laird, A. Newell and P. Rosenbloom, "SOAR: An Architecture for General Intelligence," *Artificial Intelligence*, Vol. 33, No. 1, 1987, pp. 1-64. doi:10.1016/0004-3702(87)90050-6

[44] A. Newell, "Unified Theories of Cognition," Harvard University Press, Cambridge, 1990.

[45] J. Baars and S. Franklin, "How Conscious Experience and Working Memory Interact," *Trends in Cognitive Science*, Vol. 7, No. 4, 2003, pp. 166-172. doi:10.1016/S1364-6613(03)00056-1

[46] D. Friedlander and S. Franklin, "LIDA and a Theory of Mind," IOS Press, Amsterdam, pp. 137-148.

[47] Z. Z. Shi and X. F. Wang, "A Mind Model CAM in Intelligence Science," *International Journal of Advanced Intelligence*, Vol. 3, No. 1, 2011, pp. 119-129.

[48] Z. Z. Shi, "Research on Brain-Like Computer," *Computer Science*, Vol. 5820, 2009, p. 5. doi:10.1007/978-3-642-04875-3_5

