# Machine Consciousness of Mind Model CAM

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**Abstract.** Mind model consciousness and memory (CAM) is a biologically inspired mind model, which is a general framework for human-level intelligent systems. Consciousness module plays very important role in mind model CAM. This paper presents architecture of machine consciousness containing awareness, attention, motivation, metacognition, introspective learning and global workspace modules. The proposed machine consciousness will be applied in cyborg intelligence for action planning.

**Keywords:** Intelligence science · Machine consciousness · Mind model CAM · Cyborg intelligence

## 1 Introduction

The theoretical and technical foundations of intelligence are derived from the study on brain-inspired computing. The study on intelligence is named as intelligence sciences, which is an interdisciplinary subject that dedicates to joint research on basic theory and technology of intelligence by brain science, cognitive science, artificial intelligence and others [16]. Intelligence Sciences is very important as it reveals the basic theory about the intelligence and gives explanations on the intelligent activities according to the intelligence theories. Furthermore, the intelligence science is the director that guides the development of brain-inspired computers and intelligent robots.

One of the main issues in intelligence science is mind modeling which tries to find ways to model the human mental activities, such as perception, learning, memory, thinking, consciousness etc. The mind refers to the aspects of intellect and consciousness involves the combination of the brain's conscious and unconscious cognitive processes including thought, perception, memory, emotion, will and imagination etc. The mind modeling is the process of building cognitive architectures which specify the underlying infrastructures for intelligent systems. It is also the foundation for creation and understanding of synthetic agents that support the same capabilities as humans. We have proposed a new mind model named Consciousness And Memory Model (CAM) for general framework of human-level intelligent systems [17]


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The outstanding characteristic of CAM is mainly based on consciousness and memory, which is different with previous cognitive models, such as Soar, ACT-R and so on. The origin and essence of consciousness is one of the most important scientific problems. From the view with intelligence science, consciousness is the experience integration with external world, one's own body and mental process.

Farber and Churchland discussed the consciousness concept from three levels in the article "Consciousness and the Neurosciences: Philosophical and Theoretical Issues" [10], that is, sense of awareness, high-level ability and consciousness state. In 2012, Baars and Edelman explained their natural view about consciousness in the article [3], and listed the 17 characteristics of the state of consciousness. So far a lot of consciousness theories are proposed, such as Global Workspace Theory (GWT) [2], reductionism [7], theory of neuronal group selection [9], quantum theory [6, 15], information integration theory [22]. In this paper we propose an architecture of machine consciousness in CAM from the view of intelligent system engineering.

Machine consciousness refers to attempts by those who design and analyse informational machines to apply their methods to various ways of understanding consciousness and to examine the possible role of consciousness in informational machines [1]. Franklin and Baars proposed a cognitive model LIDA with the functions of consciousness as identified by Baars' Global Workspace Theory [11]. Sensorimotor learning helps an agent properly interact with its environment using past experiences in LIDA [8].

The next section describes the CAM model and its relationship to the machine consciousness. Section 3 contains an overview of machine consciousness. The execution of machine consciousness is described in Sect. 4 in detail. Section 5 introduces the simulation of a specific cyborg maze search. Finally, the conclusions and future works are given.

## 2 The CAM Model

In the mind activities, memory and consciousness play an most important role. Memory stores various important information and knowledge; consciousness make human having the concept of self, according to the needs, preferences based goals, and do all kinds of cognitive activity according to memory information. Therefore, the main emphasis on mind model CAM are memory functions and consciousness functions [18]. Figure 1 shows the architecture of the mind model CAM.

CAM includes five main parts which are memory, consciousness, high level cognitive functions, perception and motor action. Each part plays a different role in cognitive process. Memory is responsible for storing cognitive information. Consciousness is a central controller which controls the interaction among memory components. Furthermore, consciousness reads and writes the information stored in memory to perform cognitive activities. Consciousness cooperated with memory to give the basic cognitive function supports to high level cognitive functions. High level cognitive functions perform high level cognitive activities such as video understanding, action planning, problem solving etc. These high level cognitive activities are the foundations realizing the cognitive based intelligent applications, such as automatic surveillance, game

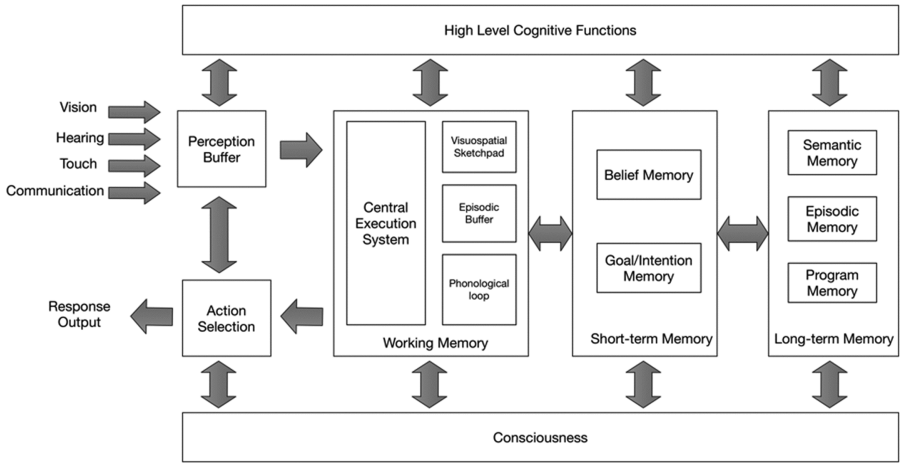


**Fig. 1.** Architecture of mind model CAM

playing, robotic house keeper etc. A brief introductions to each part of CAM are given in the following.

Memory is one of the basic human brain functions. It stores the common knowledge about the world, reflects the things took place in the past and keeps the learned behaviors that help human to interact with the environment. Because of the existence of memory, human can reason logically through common knowledge, make present reactions on the basis of the past, and evolve from the past experiences which lead the reflections of environment deeper and more comprehensive. The information stored in Memory can be categorized into difference classes, for example common knowledge based information, past experience information, state belief information, and observation based information. In CAM, three memory components are proposed to store different types of information. These components are Long term memory, short term memory and working memory.

## 3 Architecture of Machine Consciousness in CAM

Figure 2 shows the machine consciousness in CAM. It consists of global workspace, awareness, attention, motivation, metacognition, introspective learning modules.

### 3.1 Awareness Module

Awareness module begins with the input of external stimuli, and the primary features of the sensing system are activated. The output signal is sent to the sensory memory, where a higher level of functional detectors are used for more abstract entities, such as objects, categories, actions, events, etc. The resulting perception is sent to the workspace, where local connections short episodic memory and declarative memory will mark thread. These local associations are combined with perception to produce the current

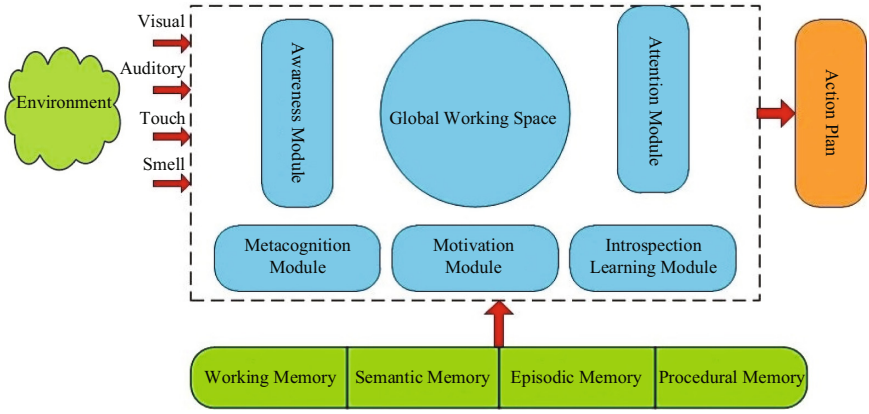


**Fig. 2.** Architecture of machine consciousness in CAM

situation model, which is used to represent the understanding of the current events that are happening.

In CAM, awareness is basically a perception combination of detect sensation. Agents work effectively in complex environments, and a subset of these combinations must be selected as the value of perception.

### 3.2 Attention Module

Detection of new events is an important feature of any signal classification method. Because we are not able to train all the data that may be encountered in the machine learning system, it becomes very important to distinguish known and unknown object information in the test. Novelty detection is a very challenging task, which can be found in a complex, dynamic environment of the novel, interesting events. Novelty detection is an essential requirement for a good classification or recognition system, because sometimes the information contained in the test data is not known when the training model information is included. The novelty of awareness is related to cognition, and the novelty of cognition is related to knowledge. Based on a fixed set of training samples from a fixed number of categories, novelty detection is a dual decision task for each test sample to determine whether it belongs to a known classification or not.

### 3.3 Global Workspace Module

The global workspace module is in the working memory area, in which different systems can perform their activities. Global means that the symbols in this memory are distributed and passed through a large number of processors. Of course, each processor may have a number of local variables and run. But it is very sensitive to the symbol of the overall situation, and the information can be made in a timely manner. When faced with new and different things that are different from the habit, our senses will produce an orienting reaction. At the same time, all kinds of intelligent processors will display their

new things on the cognitive analysis scheme by way of cooperation or competition in the global workspace, until you get the best results. It is in this process that we have a sense of new things. The global workspace can be seen as a blackboard system of information sharing, through the use of the blackboard, each processor tries to spread the information of the global situation, the joint establishment of the problem solving approach.

The internal structure of the work area is constituted by a variety of input buffer and three main modules: current scenario mode, register and the queue of awareness contents. The current scenario model is a structure that stores the current internal and external events that represent the reality. The construction encoder is responsible for creating the structure of the elements in each seed model using the work area. Register in the auxiliary space, in here construction encoder can construct possible structure, and then transfer them to the scenario mode. The queue of the consciousness content stores the contents of the continuous broadcast, which makes the CAM model understand and operate the concepts related to time.

The competition of the global working space selects the most outstanding, the most relevant, the most important and the most urgent affair, their content becomes the content of consciousness. Then, the contents of the consciousness are broadcasted to the whole space, and the action selection phase is initiated.

### 3.4 Motivation Module

Motivation could be represented as a 3-tuples {N, G, I}, where N means needs, G is goal, I means the motivation intensity. A motivation is activated by motivational rules which structure has following format:

$$R = (P,D,\text{Strength}(P|D))$$

where, P indicates the conditions of rule activation; D is a set of actions for the motivation; Strength(P|D) is a value within interval [0,1].

At present CAM is going to apply to animal robot which is a brain-computer integration system. All behaviors of brain-computer integration stem from a fixed and finite number of needs. According to characteristics and requirements of brain-computer integration there are 3 types of needs, that is perception, adaptation and cooperation:

(1) Perception needs: Acquire environment information through vision, audition, touch, taste, smell.
(2) Adaptation needs: Adapt environment condition and optimize impaction of action.
(3) Cooperation needs: Promise to reward a cooperation action between brain and machine.

### 3.5 Metacognition Module

In mind model CAM, metacognition provides the cognition and monitoring of thinking activity and learning activity of the agent, which the core is knowledge about cognition and control of cognition. Metacognition module has the function of metacognitive

knowledge, metacognitive self-regulation control and metacognitive experience. Metacognitive knowledge includes knowledge about the subject, the knowledge of the task, and the knowledge of the strategy. Metacognitive experience refers to the experience of their own cognitive process. In cognitive process, through the metacognitive self-regulation control, select the appropriate strategy to realize the use of strategy, the comparison of process and goal, the adjustment of the strategy and so on.

### 3.6 Introspective Learning Module

Knowledge base construction of introspective learning module uses ontology technology based on the general introspective learning model. The classification problem of failure is an important problem in introspective learning. The classification of failure is the basis of the diagnostic task, and it provides important clues to explain the failure and to construct the correct learning objectives. Two important factors of failure classification should be considered, one is the granularity of failure classification, the other is the relationship between failure classification, failure explanation and introspective learning goals. Ontology based knowledge base is the combination of ontology based knowledge representation and expert system knowledge base, which has the advantages of conceptual, formal, semantic, and sharing. By using the method of ontology based knowledge base to solve the failure classification problem of introspective learning, the failure classification will be clearer and retrieval process more effective.

## 4 Execution of Machine Consciousness

In mind model CAM the execution of machine consciousness can be divided 3 phases: awareness, motivation and action plan. Awareness phase is the process of attaining perception or understanding of the environment by organizing and interpreting sensory information. Using the incoming percept and the residual contents of working memory, as cues, local associations are automatically retrieved from transient episodic memory and from declarative memory. Motivation phase focuses on learners' beliefs, expectations, and needs for order and understanding. According to the impact factors of motivation, such as proportional activation, opportunism, contiguity of action, persistence, interruption, combination of preference we construct a motivation subsystem. Action plan will compose a group of actions through action selection, planning to reach the end goal.

### 4.1 Awareness

Awareness is the state or ability to perceive, to feel, or to be conscious of events, objects or sensory patterns. In this level of consciousness, sense data can be confirmed by an observer without necessarily implying understanding. More broadly, it is the state or quality of being aware of something. In biological psychology, awareness is defined as a human's or an animal's perception and cognitive reaction to a condition or event.

Awareness is commonly viewed as an information path connecting to the environment and understanding outside situations. We have proposed a conditional random fields based feature binding computational model [19], coding and combining features model [20], deep convolutional generative stochastic model [12] and so on. All these methods try to find what these objects are and where locate in from environment scenario.

### 4.2 Motivation

Motivation is defined by psychologists as an internal process that activates, guides, and maintains behavior over time. Mook [14] defined motivation as "the cause of action" briefly. Maslow proposed hierarchy of needs which was one of first unified motivation theories [13]. Since it introduced to the public, the Maslow's hierarchy of needs theory has been made a significant impact to the every life aspect in people's life. Maslow actually was a humanistic psychologist who believed in the human potential that human can struggle to reach the success and look for the creativity in order to reach the highest wisdom and also the logic think. Bach has proposed a framework for an extensible motivational system of cognitive agents, based on research in psychology [4]. They developed a version of the model which has been successfully evaluated against human performance in problem solving games [5].

In CAM the structure of motivation module is shown in Fig. 3, which consists of 7 components: environment, internal context, motivation, motivation base, goal, action selection and action composition. Their main functions are explained as follows:

(1) Environment provides the external information through sensory devices or other agents.
(2) Internal context represents the homeostatic internal state of the agent and evolves according to the effects of actions.
(3) Motivation is an abstraction corresponding to tendency to behave in particular ways according to environmental information. Motivations set goals for the agent in order to satisfy internal context.
(4) Motivation base contains a set of motivations and motivation knowledge with defined format.
(5) Goal is a desired result for a person or an organization. It used to define a sequence of actions to reach specific goals. A goal list consists of a number of goals which can be described formally:

$$G_t = \{G_1^t, G_2^t, \ldots, G_n^t\}$$

(6) Actions selection is used to perform motivated action that can satisfy one or several motivations.
(7) Action composition is the process of constructing a complex composite action from atomic actions to achieve a specific task.

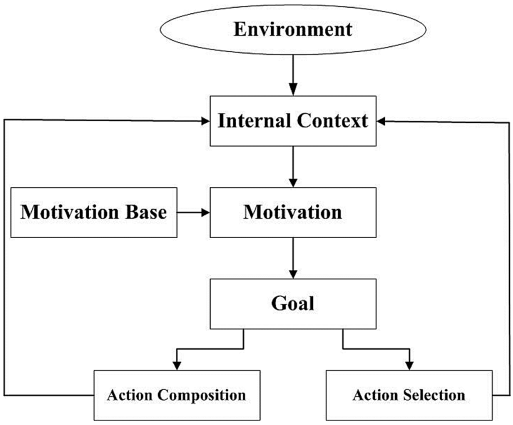


**Fig. 3.** The structure of motivation module

## 5 Experiment

An actual simulation application in the cyborg rat-robot maze search in Fig. 4 will be provided here in order to significantly demonstrate the feasibility and validity of machine consciousness [21]. The following will mainly represent the actual design of the rat-robot agent with machine consciousness.

The Cyborg sensory inputs (here mainly visual information) constantly trigger the awareness module, and convert those environment information into the unified internal motivation signal which are transferred to action plan module. Then the action plan module will select proper actions to response the environment.

The task of the rat-robot agent with machine consciousness is to start moving at the maze entrance, and finally reach the maze exit denoted as a red flag depended on all guideposts in Fig. 3. In order to fulfil the maze search task, the rat-robot agent should implement all the three basic modules, <Awareness>, <Motivation>, <Action Plan>. In the rat-robot maze search experiment, the rat-robot agent is designed to have 4 basic motivation behaviors moving on, moving back, turning left and turning right in the maze. We construct a sub-MNIST dataset extracting 4 types of handwritten digits with flag'0' denoting moving on,'1' moving back,'2' turning left and'3' turning right from the original MNIST dataset.

When rat-robot agent moves on the path, its sensory inputs constantly drive awareness module and generate the motivation signal. In the experiment, there are four motivation signals, moving on, moving back, turning left and turning right. Which means the agent can response four types of action plans.


**Fig. 4.** Cyborg intelligence for action planning in rat-robot maze search

## 6 Conclusions and Future Work

Mind model CAM is a biologically inspired cognitive model, which is a general framework for human-level intelligent systems. Consciousness subsystem plays very important role in mind model CAM. This paper presented the architecture of machine consciousness, which contains awareness, attention, motivation, metacognition, introspective learning and global workspace. Most of above modules have been designed and implemented. The proposed machine consciousness has been applied in cyborg intelligence for action planning. In final, the simulation of cyborg rat-robot maze search was demonstrated.

We are going to develop other modules of machine consciousness in CAM. The global workspace theory will guide action selections and chose the most outstanding, the most relevant, the most important and the most urgent affair for execution. Explore

the global workspace theory and connecting with attention. Metacognition is also interested in topic, which performs self-regulation control, selects the appropriate strategy to realize. We try to apply machine consciousness in robots, automatic car, unmanned plane in the future.

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