Neural Informatics

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INTRODUCTION

The development of classical and contemporary informatics, the cross fertilization between computer science, systems science, cybernetics, computer/software engineering, cognitive science, neuropsychology, knowledge engineering, and life science, has led to a new research field known as Cognitive Informatics (Wang, 2002a/2003a/2003b/2004/2006a/2007b; Wang, Johnston, & Smith, 2002; Wang & Kinsner, 2006). An important branch of cognitive informatics is neural informatics (Wang, 2007b), which reduces cognitive informatics theories and the studies on the internal information processing mechanisms of the brain onto the neuron and physiological level.

Definition 1

Neural informatics is a new interdisciplinary enquiry of the biological and physiological representation of information and knowledge in the brain at the neuron level and their abstract mathematical models.

In neural informatics, memory is recognized as the foundation and platform of any natural or machine intelligence based on the Object-Attribute-Relation (OAR) model (Wang, 2007c; Wang & Wang, 2006) of information/knowledge representation. The cognitive models of human memory (Wang & Wang, 2006), particularly the sensory buffer memory (SBM), short-term memory (STM), long-term memory (LTM), action-buffer memory (ABM), and their mapping onto the physiological organs of the brain reveals the fundamental mechanisms of neural informatics.

FUNDAMENTAL MODELS OF NEURAL INFORMATICS

The theories of neural informatics explain a number of important questions in the study of natural intelligence. Enlightening findings in neural informatics are such as (a) LTM establishment is a subconscious process; (b) The long-term memory is established during sleeping; (c) The major mechanism for LTM establishment is by sleeping; (d) The general acquisition cycle of LTM is equal to or longer than 24 hours; (e) The mechanism of LTM establishment is to update the entire memory of information represented as an OAR model in the brain (Wang, 2007c); and (f) Eye movement and dreams play an important role in LTM creation.

Neural Informatics Models of Memory

In neural informatics, the taxonomy of memory is categorized into four forms, as given in the following cognitive model of memory.

Definition 2

The Cognitive Models of Memory (CMM) states that the architecture of human memory is parallel configured by SBM, STM, LTM, and ABM, where the ABM is newly identified in Wang and Wang (2006).

The major organ that accommodate memories in the brain is the cerebrum or the cerebral cortex. In particular, the association and premotor cortex in the frontal lobe, the temporal lobe, sensory cortex in the frontal lobe, visual cortex in the occipital lobe, primary motor cortex in the frontal lobe, supplementary motor area in the frontal lobe, and procedural memory in cerebellum (Wang & Wang, 2006; Wilson & Keil, 2001). The CMM model and the mapping of the four types of human memory onto the physiological organs in the brain reveal a set of fundamental mechanisms of neural informatics (Wang, 2007b).

Definition 3

The functional model of LTM can be described as a Hierarchical Neural Cluster (HNC) model with partially connected neurons via synapses.

The HNC model of LTM consists of dynamic and partially interconnected neural networks. In the HNC model, a physiological connection between a pair of neurons via a synapse represents a logical relation between two abstract objects or concepts. The hierarchical and partially connected neural clusters are the foundation for information and knowledge representation in LTM.

Conventionally, LTM is perceived as static and fixed in adult brains (Baddeley, 1990; James, 1890; Rosenzmeig, Leiman, & Breedlove, 1999; Smith, 1993; Sternberg, 1998). This was based on the observation that the capacity of adult brains has already reached a stable state and would not grow continuously. However, recent discoveries in neuroscience and cognitive informatics indicate that LTM is dynamically reconfiguring, particularly at the lower levels of the neural clusters (Gabrieli, 1998; Rosenzmeig et al., 1999; Squire, Knowlton, & Musen, 1993; Wang, 2007c; Wang & Wang, 2006). Otherwise, the mechanisms of memory establishment, enhancement, and evolution that are functioning everyday in the brain cannot be explained. Actually, the two perceptions are not contradictory. The former observes that the macronumber of neurons will not change significantly in an adult brain. The latter reveals that information and knowledge are physically and physiologically retained in LTM via newly created synapses between neurons rather than the neurons themselves.

Therefore, there is a need to seek a new model rather than the conventional container model to explain how information and knowledge are represented and retained in the brain. For this purpose, a relational model of human memory is developed as described.

Definition 4

The relational model of memory is a logical memory model that states information is represented and retained in the memory by relations, which is embodied by the synaptic connections among neurons.

In contrary to the conventional container metaphor, the relational metaphor indicates that the brain does not create new neurons to represent newly acquired information; instead, it generates new synapses between the existing neurons in order to represent new information.

The reconfigurable neural clusters of STM cohere and connect related objects such as images, data, and concepts, and their attributes by synapses in order to form contexts and threads of thinking. Therefore, the main function of STM may be analogized to an index memory connecting to other memories, particularly LTM. STM is the working memory of the brain. The capacity of STM is much smaller than that of LTM, but it is a hundred times greater than 7±2 digits as Miller proposed (Miller, 1956). Limited by the temporal space of STM, one has to write complicated things on paper or other types of external memories in order to compensate the required working memory space in a thinking process.

Theorem 1

The dynamic neural cluster model states that the LTM is dynamic. New neurons (to represent objects or attributes) are assigning, and new connections (to represent relations) are creating and reconfiguring all the time in the brain.

Neural Informatics Models of Internal Knowledge Representation–OAR

To rigorously explain the hierarchical and dynamic neural cluster model of memory at physiological level, a logical model of memory is needed, as given in Definition 5, known as the Object-Attribute-Relation (OAR) model (Wang, 2007c).

Definition 5

The OAR model of LTM can be described as a triple, that is:

$$OAR \triangleq (O, A, R) \quad (1)$$

where O is a finite set of objects identified by unique symbolic names, that is:

$$O = \{o_1, o_2, \ldots, o_i, \ldots, o_n\} \quad (2)$$

For each given $o_i \in O$, $1 \leq i \leq n$, A_i is a finite set of attributes for characterizing the object, that is:

$$A_i = \{A_{i1}, A_{i2}, \ldots, A_{ij}, \ldots, A_{im}\} \quad (3)$$

where each o_i O or A_{ij} A_i, $1 \leq i \leq n$, $1 \leq j \leq m$, is physiologically implemented by a neuron in the brain.

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