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The introduction of the brain-inspired systems

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Abstract– David Marr described three levels of information processing in the brain, that is, the computational level, the algorithmic level, and the implementation level. Many brain science and engineering researchers are ordering their study based on these levels. Note that the last level is not, for example, the process of making chips or devices but the study of how the neuronal networks in a brain actually implement an algorithm in the brain. The study of the brain-inspired systems (BrainIS) is based on Marr's three levels with the addition of implementation of the brain algorithm on chips or devices and the checking of whether the algorithm actually works in the real world. In the study of BrainIS, you draw the algorithm from the results of the brain science or hypothesize the putative brain algorithm, implement the algorithm on chips or devices, and check whether the brain algorithm works well in the real world using the platform rather than simply mimicking the brain's information processing. When you draw the algorithm from the results of neuroscience, you can make an inspired algorithm from the results. In BrainIS, you not only describe a simple brain function but also a whole inspired system consisting of brain functions for the information processing that is part of those functions. The inspired system autonomously moves, learns the environment, and behaves using an environment-system loop.

David Marr described in his book [1] that there are three levels that comprise a brains information processing system, that is, the computational level, the algorithmic level, and the implementation level. At the computational level, you have to study what a brain does and why a brain does what it does. At the algorithmic level, researchers study how a brain does what it does, specifically, what representations it uses and what processes it employs to build and manipulate the representations. At the implementation level, researchers study how the system is physically realized in a brain. Brain studies to date have occurred within the framework of these three levels.

At Marr's implementation level, neuroscientists have studied the neurons in a brain using a neurophysiological approach. Brain science is based on the neuron doctrine. The first proponent of the doctrine was the Spanish neuroanatomist Santiago Ramon y Cajal, who proposed that nerve cells in the brain are discrete entities and that they communicate with one another by means of specialized contacts, called synapses. Barlow proposed the sparse coding of the neurons to represent the environment [2]. That is, a single neuron or a few neurons in a brain represented the external world. In the results of firing of the neuron or neurons, we perceive the external world. Based on his doctrine, neuroscientists have tried to find the individual neurons that respond to external stimuli. In their famous work, Hubel and Wiesel found the orientation-tuned neurons and also found that the neurons with the same orientation are located near each other [3]. Recently, using a multi-electrode method, it has been clarified the characteristics of some more populations of neurons simultaneously.

In most cases, studies at Marr's three levels have been done independently, though some cases are exceptions. McCulloch and Pitts proposed the simple neuron model in 1943 [4]. Donald O. Hebb proposed that when a brain learns something, the synapse changes depending on the activity of the pre- and postsynaptic neurons [5]. He also said that the synaptic change was the basic phenomenon of cognition and memory. Rosenblatt proposed the machine perceptron using the McCulloch-Pitts neuron model and Hebb's learning rule [6]. The perceptron receives the input data and learns to classify the data depending on the teacher signal conveyed to the output unit. Marr [7] and Albus [8] proposed that the cerebellum in a brain had synaptic plasticity and worked with the same principle of the perceptron. Later, Masao Ito at Tokyo University demonstrated the plasticity at the synapse in the cerebellum by the neurophysiological method [9]. These are cases where the studies using Marr's three levels went well.

Other cases where the studies using Marr's three levels were successful are as follows. Neurophysiology clarified that there is a topological mapping represented by the neurons in the cerebral cortex [10]. Retinotopy on the visual cortex and the somatotopic mapping on the somatosensory cortex are examples of the mapping. Willshaw and Malsburg (1976) [11] clarified that the mapping was self-organized in a neural network model with Hebb's learning rule. Kohonen extended the concept of the topological mapping in a brain and interpreted it from the viewpoint of information processing, and proposed the concept of a self-organizing map (SOM) [12]. In addition, recently one of the authors (Furukawa) has generalized Kohonen's SOM and proposed the concept of a modular network SOM (mnSOM) [13]. The mnSOM is comprised of a set of modules that can process the information. When the modules are a neuronal network, the system looks like a brain. There is some possibility that a brain consists of some sets of mnSOM, but the evidence to support this has not yet been obtained neurophysiologically.

When one interprets the information processing of a brain, the studies at Marr's three levels are sufficient, but when the goal is to understand the information processing very well or when one is designing information processing machines or robots based on the brain information processing, Marr's three levels are not enough, because one doesn't know whether the computational theory or the algorithm really works in the real world.

To take Marr's model further, T. Yamakawa et al. at the Kyushu Institute of Technology have proposed the concept of the brain-inspired information technology (BrainIT). In BrainIT, researchers first paid attention to the results of brain science, which are at Marr's implementation level, by drawing the brain algorithm or computational theory, or hypothesizing the putative ones at the algorithmic and computational level. In addition, researchers made chips or devices based on the algorithm or the computational theory, and the chips or devices on which the algorithm is implemented on the platform robot to test whether the algorithm or the theory worked in the real world. K. Ishii at the Kyushu Institute of Technology developed the platform robot WITH, in which the brain algorithm can be implemented to check the algorithm [14]. There were many productions in Brain IT, including a chemical sensor array using the stochastic synchronization inspired by the taste bud of the tongue [15], a navigational system inspired by the dynamics of the brain's hippocampal neuronal network [16], a robot that has curiosity inspired by the conditioning learning observed in the amygdale of the brain [17], a mobile robot that merged new behaviors with the curiosities and internal rewards learned by reinforcement learning [18], a human gesture recognizing system inspired by the vision system in the brain [19], and a navigational system of a mobile robot based on mnSOM inspired by the topological mapping in the brain [20]. In BrainIT, one picked a single brain function and implemented it in a system. BrainIT has no integration algorithm or theory.

In the concept of the brain-inspired systems (BrainIS), which extends the capability of BrainIT, one also studies the integration theory or algorithm of a single brain function and tries to make a total inspired information processing machine like a brain. To do that, we have to design an inspired machine. The inspired machine that we imagine explores the environment autonomously, collects the necessary information about the environment, learns the information, and decides to choose its next behaviors depending on the external information and the internal state including emotion. As a result of the behavior, because the machine has a body, the machine affects the environment using its body, and the affected environment then becomes the new input for the machine. Thus the movement of the machine affects the environment, and the affected environment affects the machine again. We call the interaction between the environment and machine the environment-machine loop. The loop emerges with the autonomous movement of the inspired machine, and the loop is important in BrainIS. The key words we have in BrainIS at the present time are the dynamics of the brain, the embodiment, and the self-organization. While one used robots as the platform in BrainIT, in BrainIS one will use not only a robot but also an intelligent car, mobile phone, or other device. We hope that the concept of BrainIS adds to the present technology.

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