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Multi-dimensional memory frames and action generation in the MHP/RT cognitive architecture

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Abstract

The main theme of this paper is to provide a cognitive architecture, MHP/RT (Model Human Processor with Realtime Constraints), that is appropriate for describing the idea, "The agent would not be getting an informational input or a reinforcement, but the inputs would be better described as perturbations on a self-organizing complex systems", as stated in the call for the workshop, Enaction, Complex Systems and Cognitive Architectures. MHP/RT describes a cyclic process of *action selection* and *memorization* while one lives in the world, and the memory is gradually structured as multi-dimensional frames as one interacts with the environment. Behavioral processing constraints are imposed by conscious and unconscious processes, and behavior must be synchronized with the ever-changing external and internal environments. This paper provides a brief explanation of MHP/RT and multi-dimensional memory frames, followed by how memory is structured as one develops.

Keywords: MHP/RT, multi-dimensional memory frames, conscious and unconscious processes

1 Introduction

We have developed a cognitive architecture, MHP/RT, that is capable of simulating people's daily action selection processes [2]. It consists of the processes for generating behavior and multi-dimensional memory frames, MD-frames, that store the results of behavior and are used to generate next behavior. The behavior generation processes include the autonomous perceptual system associated with sensory neurons and the autonomous motor system associated with motor neurons. Between them are interneurons that process the input from the perceptual system with the conscious decision making process or the unconscious automatic action selection process. Each process in behavior generation is associated with an MD-frame. As such, the behavior generation processes and the MD-frames are intimately connected with each other and the amount of the contents stored in the MD-frames are accumulated incrementally as the time goes by and the stored entities are strongly influenced by the detailed experience each

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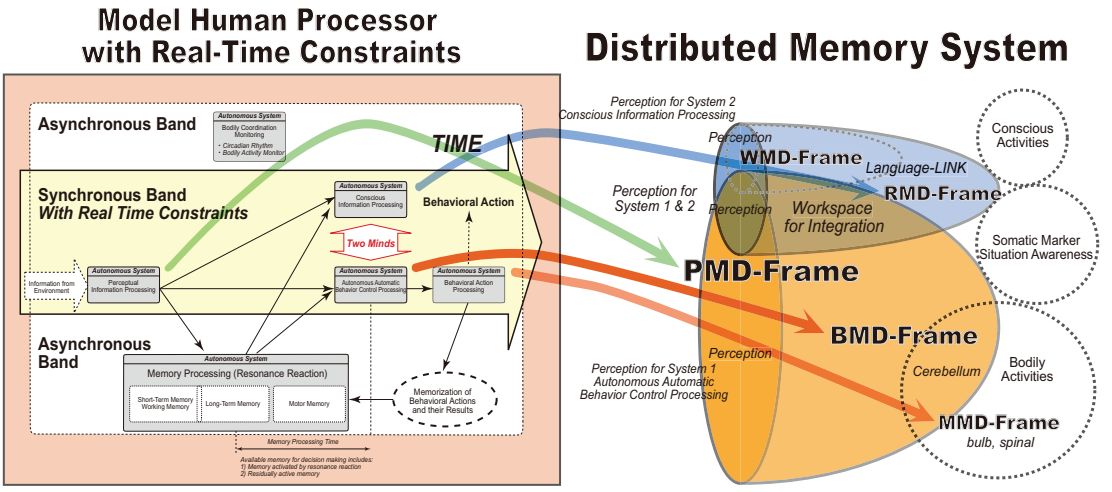

Figure 1: MHP/RT (Figure 3, [2]) and the distributed memory system.

individual has at each moment. In the following sections, this paper explains MHP/RT and MD-frames, followed by how memory is structured as one develops through repetitive cycles of generating actions using existing memory, and altering and structuring memories reflecting on the results of performing actions as one develops.

2 Action Selection by MHP/RT with MD-Frames

2.1 MHP/RT: Model Human Processor with Realtime Constraints

Model Human Processor with Real time Constraints (MHP/RT) simulates in situ human behavior by switching among four processing modes, conscious / unconscious activities for the future events, and conscious / unconscious activities for the past events [2]. It focuses on synchronization between unconscious process and conscious process, or System 1 and System 2, respectively, as Kahneman [1] called them in his Two Minds theory. The left portion of Figure 1 depicts the outline of MHP/RT. There are two distinctive information flows: System 1 and System 2 receive input from the Perceptual Information Processing System in one way, and from the Memory Processing System in another way. System 1 and System 2 work autonomously and synchronously without any superordinate-subordinate hierarchical relationships but interact with each other when necessary. In Figure 1, the dual-path from perception to memory and from perception to unconsciousness is associated with System 1 process, and the other from perception to memory and from perception to consciousness is associated with System 2 process. These two flows are synchronized before carrying out some behavior.

MHP/RT suggests that at a particular time *before the event*, one engages in conscious processes and unconscious processes concerning the event. At a particular time *after the event*, one engages in conscious processes and unconscious processes. "After modes" are for updating the contents of memory and/or the structure of existing memory. "Before modes" are for using existing memory for preparing for an event to come in the near future consciously, and for executing actions for the immediate event unconsciously.

2.2 MD-Frames: Multi-Dimensional Memory Frames

MHP/RT starts action selection processes by *object cognition*. It occurs as follows [2]: collecting information from the environment via perceptual sensors; integrating and segmenting the collected information, centering on visually collected objects; and continuing these processes until the necessary objects to live in the environment are obtained. These objects are then used independently in Systems 1 and System 2 of Two Minds, and memorized after integrating related entities associated with each system.

Due to the limitation of the brain's processing capability, the range of integration is limited; therefore, System 1 memory and System 2 memory should differ. However, they could share objects originating from perceptual sensors. The types of information to be memorized are not the 4-dimensional values of objects but a set of differential features of objects associated with strong variations, phase change points, or boundaries, and mutual relationships among them. Such quantities as time and distance, direct derivatives of the 4-dimensional values of the objects, are reconstructed from the memory when the memory of the objects are needed in such a way that they are consistent with the environmental conditions at that time. *What* people would do in a specified situation is dictated by the contents stored in the MD-frames and *how* people would do is determined by the behavior generation processes of MHP/RT.

When objects, that are the result of the just-finished integration and segmentation process, are processed in the next cycle, representation of the objects may serve as the common elements to combine the System 1 memory and the System 2 memory to form an inter-system memory. We call this memory the Multi-Dimensional (MD) -frames. They should result in a distributed layered memory structure because of the multiplicity of multi-dimensional perceptions and multi-dimensional motor activities. And then activations in the memory network always go down from perceptual memory to the rest of the memory structure. Multi-dimensionality in both perceptual and motor processing works as a kind of filter to prune ineffective connections.

2.3 Integration of MHP/RT's definition of memory with neuronal activities

Figure 1 illustrates how each MD-frame is created as the result of working of autonomous processes in MHP/RT and how MD-frames are mutually interrelated. There are five kinds of MD-frames, which are defines as follows:

> *PMD (Perceptual Multi-Dimensional) -frame* constitutes perceptual memory as a relational matrix structure. It collects information from external objects followed by separating it into a variety of perceptual information, and re-collects the same information in the other situations, accumulating the information from the objects via a variety of different processes. PMD-frame incrementally grows as it creates memory from the input information and matches it against the past memory in parallel.

> *MMD (Motion Multi-Dimensional) -frame* constitutes behavioral memory as a matrix structure. The behavioral action processing starts when unconscious autonomous behavior shows after one's birth. It gathers a variety of perceptual information as well to connect muscles with nerves using spinals as a reflection point. In accordance with one's physical growth, it widens the range of activities the behavioral action processing can cover autonomously.

> *BMD (Behavior Multi-Dimensional) -frame* is the memory structure associated with the autonomous automatic behavior control processing. It combines a set of MMD-frames into a

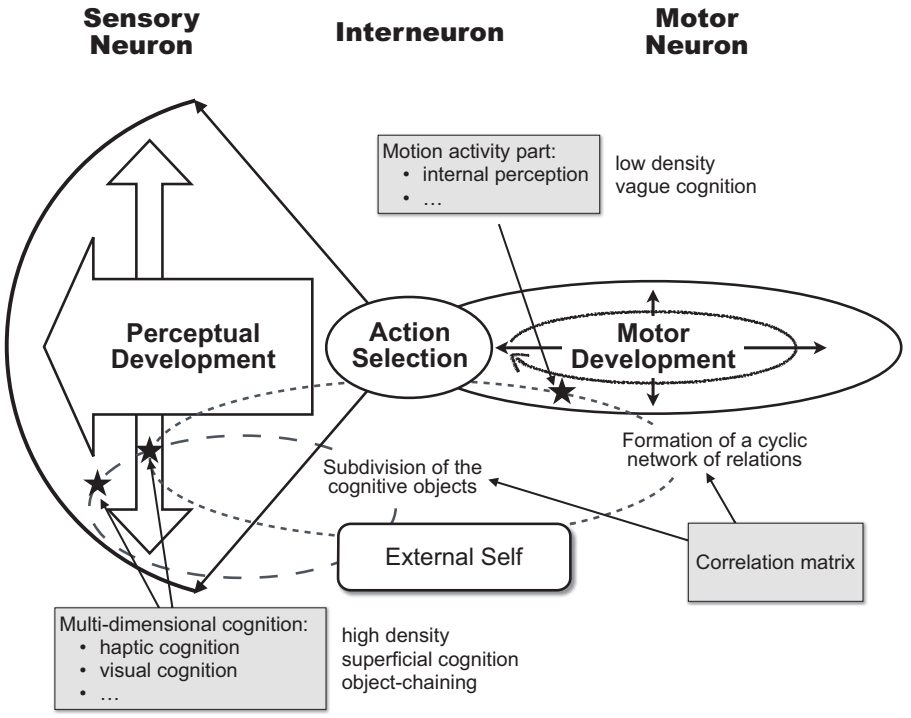

Figure 2: Development of the sensory nervous system and the somatic nervous system, and interneurons connecting them with action selection process.

manipulable unit.

> *RMD (Relation Multi-Dimensional) -frame* is the memory structure associated with the conscious information processing. It combines a set of BMD-frames into a manipulable unit. The role BMD-frames play for RMD-frame is equivalent to the role MMD-frames play for BMD-frame.

> *WMD (Word Multi-Dimensional) -frame* is the memory structure for language. It is constructed on a very simple one-dimensional array.

3 Evolution of the "MHP/RT + MD-Frames" system

As Swanson [4] explains, cross-networks of neurons in the brain develop in a systematic way to show three-layered structure of interneurons system (Figure 2). Interneurons intervene the sensory nervous system that is responsible for processing sensory information and the somatic nervous system, associated with the voluntary control of body movements via skeletal muscles to form complex paired structure of perception and motion. They consist of direct feedforward connections from perception to motion, and more complex connections with feedback loops

using the interneurons to form three distinguishable layers.

Body movement is constructed by selecting executable motions and sequencing them in such a way that it adapts to the current environmental under environmental constraints. A motion is executable when it is exerted with stable postures, which are realized as a musculoskeletal system that has been formed via the developmental and experiential processes according to DNA's body plan. A body movement could be associated with multiple different purposes. Therefore, a meaning of particular body movement is given *consciously* as a compound social ecology. In this way, PDP (Parallel Distributed Processing) [3] is naturally integrated with evolutional view described by Swanson [4].

4 Summary: Individual Development

With the cyclic processes of action selection and memorization, one develops his/her memory and shows distinct behavioral characteristics as one grows. This section summarizes them according to several age ranges.

There are two layers in the autonomous automatic behavior control processing, both of which are controlled by feedforward loops.

- *Level-1:* The first layer is associated with reactive activities carried out by the spinal nerves characterized by automatic and simple reflexive movements.

- *Level-2:* The second layer is associated with reactive activities carried out by the bulb or the cerebellum characterized by automatic complex reflexive movements.

One layer is associated with the conscious information processing, controlled by feedback loops and the back propagation mechanism.

- *Level-3:* The third layer is associated with activities carried out by the frontal lobe and the cerebrum characterized by deliberate movements.

The following explains the developmental paths of the neural networks as human beings grow as the function of their ages.

- **Early stage ($0 \sim 6$):** In $0 \sim 6$ years of age, feedforward loops are the dominant control mechanism and they establish fundamental relationships between the layers by means of "uplink." In the first half of this period, $0 \sim 3$ years of age, human beings establish inter-connections between Layer-1 and Layer-2 as integrated movements of bodily actions on the basis of the relationships between the input from the perceptual system and the output expressed as reflexive movements, for example, simple utterances. In the latter half of this period, $4 \sim 6$ years of age, human beings acquire the skill of behaving in relation with the other persons and the methods for conversing with others such as explanation formation via simple syntax.

- **Middle stage ($7 \sim 12$):** Later, in $7 \sim 12$ years of age, human beings acquire the skill of logical thinking by means of the first order logic by using letters or symbols and that of cooperation with the other persons. These activities facilitate the development of interconnections among the three layers, resulting in very complex networks. The key is the existence of symbols that intervene various connections between input and output.

- **Later stage** ($13 \sim 18$)**:** Lastly, in $13 \sim 18$ years of age, feedback loops come into play, which are used to form language processing circuits in a single layer, Layer 3, by means of the learning mechanism such as the back propagation.

  In $13 \sim 18$ years of age, the interconnections of the neural networks evolve among the three layers. In this period, the ability of logical writing by using an ordinary language affects significantly the evolving process. Without language, structural recognition is formed dominantly via visual information. On the other hand, when accompanied with language, it makes possible to represent the visual information in a highly logical way, the vision-based structural recognition is significantly augmented to become a structure that can be dealt with a language-based logic system.

- **Final stage** ($18 \sim$)**:** Finally, in $18 \sim$ years of age, feedback loops become dominant, which make possible to form a compound language processing circuits by means of the learning mechanism such as the back propagation mechanism.

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