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Hierarchical structure of human action selection – An update of Newell's time scale of human action

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Abstract
What we observe as each individual's physical behavior is the results of a multiple processing with a PDP system, not with a single unified system. This PDP system is organized evolutionally, and realized as a neural network system, including the brain, the spinal nerves, and the peripheral nerves. This paper illustrates a matrix representation of the relationships between the hierarchical structure of cognition under Two Minds and the hierarchical structure of the neural network system under PDP.

Keywords: Two Minds, Newell's time scale of human action, PDP

1 Introduction

In quest of general intelligence, Newell [6] observed that human activity can be classified by different levels of processing, grouped by time scales at twelve different orders of magnitude, starting with the organelle level of the order of 10^{-4} seconds extending through social activity level of the order of 10^{7} seconds. He grouped these into four bands, biological, cognitive, rational, and social, each of which is a place where regularities would be found. In [3], we proposed a cognitive architecture, MHP/RT, that is capable of simulating our daily decision making and action selection, by integrating Two Minds [2] with Newell's time scale of human action. The purpose of this paper is to reconsider the linearly ordered Newell's time scale of human action in light of the dual processing mechanism of Kahneman's Two Minds in order to show the reality of human behavior, observed as a sequence of decision making and action selection, with the basis of MHP/RT and our recent development [5, 4]. MHP/RT [3] dealt with synchronization of System 1 (fast and automatic unconscious process) and System 2 (slow and deliberate conscious process), locating at the different levels of processing of Newell's bands, for understanding our daily behavior, working under a parallel distributed processing system [5]. This system is organized evolutionally, and realized as a neural network system, including the brain, the spinal nerves, and the peripheral nerves. This paper illustrates a matrix

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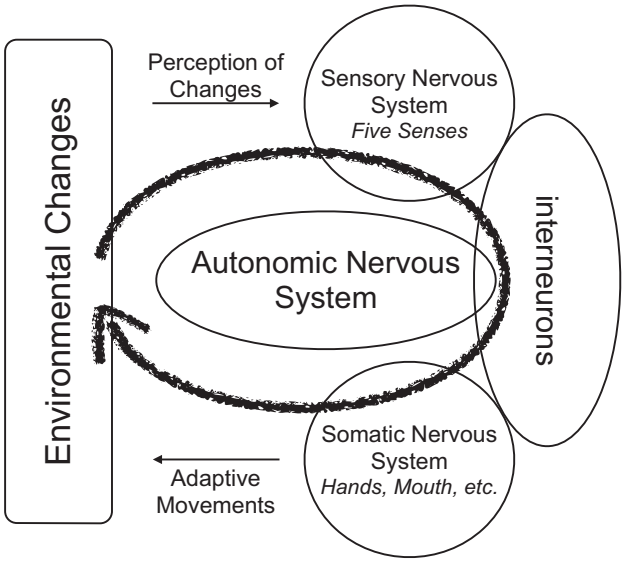

Figure 1: Continuous cyclic loop of perception and movement.

representation of the relationships between the hierarchical structure of cognition under Two Minds and the hierarchical structure of the neural network system under PDP.

2 An evolutional view of PDP system

2.1 Continuous cyclic loop of perception and movement

What we observe as each individual's physical behavior is the results of a multiple processing with a PDP system, not with a single unified system. This PDP system is organized evolutionally, and realized as a neural network system, including the brain, the spinal nerves, and the peripheral nerves.

According to [1], a vertebrate animal develops its neural network system in the following way. It starts with the development of the paired structure consisting of the sense of touch and reflexive movements associated with it. Then the sense of smell and the sense of taste, and finally, the sense of seeing and the sense of hearing develop their associations with reflexive movements. From the beginning, the perceptual stimuli from the five senses form a paired structure with their associated reflexive movements. In addition, the association tends to become bidirectional for the purpose of establishing selective sensing, which is a paired structure with feedback between perception and movement. For example, the sense of hearing and the sense of vocalization establish a feedback loop between them immediately after one acquires the function of voicing.

In summary, the neural network system forms at first the autonomic nervous system of respective autonomous organs as a genetic fundamental structure, then crosses it with the somatic nervous system that controls reflexive movements associated with the perceptual stimuli from the five senses, and develops the feedback loops with a system of interneurons that connect these systems. Figure 1 depicts this loop schematically.

2.2 Three-layered structure of interneurons system

Interneurons intervene the sensory nervous system that is responsible for processing sensory information and the somatic nervous system that is associated with the voluntary control of body movements via skeletal muscles to form complex paired structure of perception and motion. It consists of direct feedforward connections from perception to motion, and more complex connections with feedback loops using the interneurons to form three distinguishable layers. Table 1 summarizes the points.

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.

2.3 Formation process

This subsection explains the developmental paths of the neural networks as human beings grow as the function of their ages.

2.3.1 Early stage: $0 \sim 6$ years of age

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.

2.3.2 Middle stage: $7 \sim 12$ years of age

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.

Table 1: Relationships between the hierarchical structure of cognitive mechanism and that of neural networks.

Hierarchical Structure of Neural Networks	***Hierarchical Structure of Cognitive Mechanism***		
	System 1 of Two Minds		*System 2*
	Level-1	*Level-2*	*Level-3*
	Multi-dimensional perception	*Vision-oriented structural multi-dimensional perception*	*Language, one-dimensional sequence of sound, and non-verbal symbols*
Architecture for Processing	autonomous automatic behavior control	autonomous automatic behavior control + conscious information processing when needed	Conscious information processing; natural formation of grammar; perceptron
Formation Process	genetic	genetic + epigenetic	epigenetic (meme)
Number Sense	multi-valued stimuli	voluntarily formed perceptron using visual patterns; comparative cognition	mathematics; deliberate consideration
Contents	any changes around the self	three-dimensional space recognition, linear continuous change, visual + auditory information	representation of procedural knowledge; continuity under non-linear links; structural decomposition and reconstruction; grammar and notation
Acquisition	experience	imitation of bodily movement	learning of formality + confirmation of the results of experience and procedural understanding; not systematic understanding; uncertain in reproduction
Role of Cognition	for individual; intuitive understanding; used for adaptive reaction	for individual and society; behavior-ecological understanding; used for habitual behavior	for society; conceptual understanding; used for sense making

2.3.3 Later stage: 13∼18 years of age

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.

2.3.4 Final stage: 18 ∼ years of age

Finally, in 18 ∼ 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.

3 Conclusion

This paper attempted to expand what we observe in our daily activities characterized by Kahneman's Two Minds and Newell's time scale of human action along our developmental paths, starting from forming interconnections between input perceptual stimuli and corresponding output movement, followed by intervening connections using language manipulated by System 2 of Two Minds and the Rational Band of the time scale of human action. In the beginning, feedforward loops are dominant to establish fundamental relationships between the layers. Later, feedback loops start to join to form language processing circuits, then become dominant to form a very complex language processing circuits.

It is important to notice that the "language" each individual is doomed to use should affect the course of development of the individual. There are obvious differences in the syntax of languages among, for example, Japanese, English, French, and so on. Therefore, Japanese people, for example, tend to acquire the skill of visual perception to compensate for the weakness of their language. It is because their language is not good at representing logical relationships. Conscious processing of System 2 comes at the later stage of the one's life. However, it poses strong constraints on the individual's developmental path, because it is language-bound. This consideration provides a new light on how the hierarchy of the neural networks should develop in the circumstances where we live.

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