The Role of Resonance in the Development and Propagation of Memes

Muneo Kitajima*, Makoto Toyota† and Jérôme Dinet‡
* Nagaoka University of Technology, 1603-1 Kamitomioka Nagaoka, Niigata, Japan, Email: mkitajima@kjs.nagaokaut.ac.jp
† T-Method, Chiba, Japan, Email: pubmtoyota@me.com
‡ Université de Lorraine, 91 avenue de la Libération, 54000 Nancy, France, Email: jerome.dinet@univ-lorraine.fr

***Abstract*—Meme is a type of behavior that is passed from one member of a group to another, not through the genes but by other means. This paper claims that the concept of resonance should play an important role in the propagation of memes among group members and the development of meme in individual members. Dinet et al. pointed out that the concept of resonance originally issued from physics that has been successfully applied to cognitive processes for behavior selection; the Model Human Processor with Real-Time Constraints (MHP/RT) model proposed by Kitajima and Toyota is a unique model that incorporates a resonance mechanism to connect perceptual-cognitive-motor (PCM) processes that work synchronously, and memory processes that work asynchronously with the environment. This paper elaborates the resonance mechanism implemented in MHP/RT and its associated multi-dimensional memory frames from three perspectives: how resonance works in a single-action selection process; what types of memes can exist in multi-dimensional memory frames; how PCM processes and memory develop from birth to the end of adolescence in terms of the detailed workings of resonance. This paper concludes with the implications of the mechanistic understanding of the role of resonance, the effect of resonance malfunction and the effect of the existence of memory that does not resonate with the real environment.**

Keywords–Resonance; Meme; MHP/RT; Development.

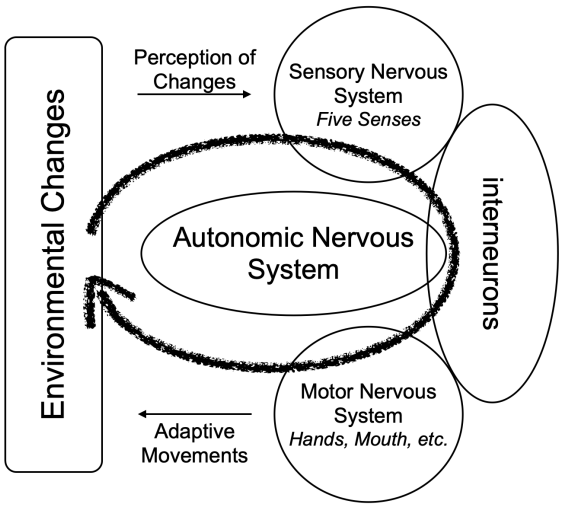

Figure 1. Continuous cyclic loop of perception and movement ([9, Figure 1]).

I. INTRODUCTION

At the 0-th order approximation, a person interacts with the environment by running an endless stream of perceptions involving the external and internal environments through the five senses, i.e., taste, sight, touch, smell, and sound, via sensory neurons as parallel processing, and acting in response to the external environment using body parts, e.g., limbs, eye balls, and so on, via motor neurons using serial processing (see Figure 1). As s/he perceives the results of movement of his/her body parts as well as the changes in the external environment with the passage of time, the next cycle of perceptual-motor processes occur. Interneurons between the sensory neurons and motor neurons convert the input patterns to the output patterns – this constitutes a Perceptual-Cognitive-Motor (PCM) process.

Starting from this basic cycle (see Figure 1), Kitajima and Toyota [3][4] constructed a comprehensive theory of action selection and memory, Model-Human Processor with Real-time Constraints (MHP/RT), that provides a basis for constructing any models for an acting person (see Figure 2). MHP/RT is an extension of Model Human Processor proposed by Card, Moran, and Newell [5] that can simulate routine goal-directed behaviors. The processes involved in action selection is a dynamic interaction that evolves in the irreversible time dimension. The purpose of MHP/RT is to explain the following three facts: 1) the fundamental processing mechanism of the brain is Parallel Distributed Processing (PDP) [6], which is referred to as Organic PDP (O-PDP) system in the development of MHP/RT; 2) human behavior emerges as a result of competition of the dual processes of System 1, fast *unconscious* processes for intuitive reaction with feedforward control that connect perception with motor movements, and System 2, slow *conscious* processes for deliberate reasoning with feedback control; this is called Two Minds [7]; 3) human behavior is organized under happiness goals [8].

MHP/RT consists of two parts. The first part comprises

TABLE I. NEWELL'S TIME SCALE OF HUMAN ACTION. (ADAPTED FROM NEWELL [10, PAGE 122, FIG. 3-3]).

Scale (sec)	Time Units	System	World (Theory)
10^7	months		
10^6	weeks		SOCIAL
10^5	days		BAND
10^4	hours	Task	
10^3	10min	Task	RATIONAL
10^2	minutes	Task	BAND
10^1	10sec	Unit Task	
10^0	1sec	Operations	COGNITIVE
10^{-1}	100ms	Deliberate Act	BAND
10^{-2}	10ms	Neural Circuit	
10^{-3}	1ms	Neuron	BIOLOGICAL
10^{-4}	100μsec	Organelle	BAND

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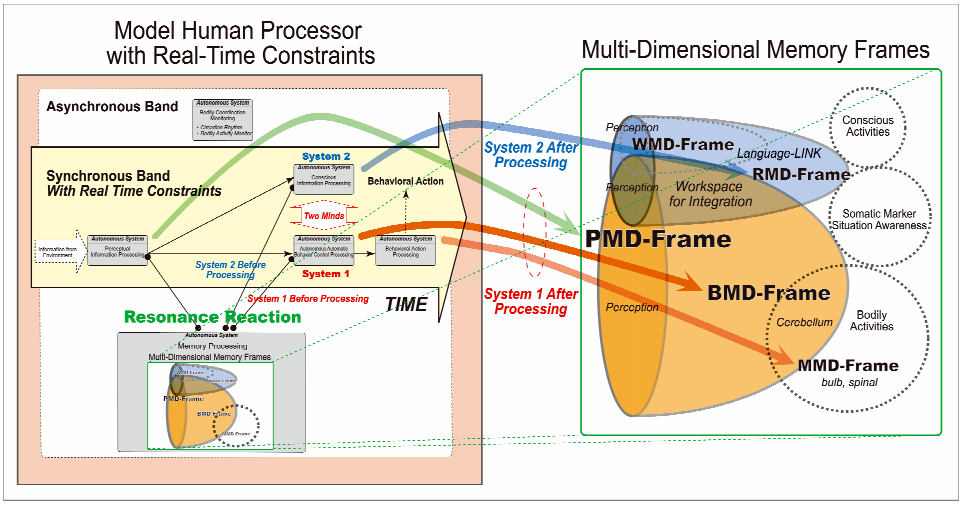

WMD (Word MD)-frame is the memory structure for language. It is constructed on a very simple one-dimensional array.
RMD (Relation MD)-frame is the memory structure associated with the conscious information processing. It combines a set of BMD-frames into a manipulable unit.
BMD (Behavior MD)-frame is the memory structure associated with the autonomous automatic behavior control processing. It combines a set of MMD-frames into a manipulable unit.
PMD (Perceptual MD)-frame constitutes perceptual memory as a relational matrix structure. It incrementally grows as it creates memory from the input information and matches it against the past memory in parallel.
MMD (Motion MD)-frame constitutes behavioral memory as a matrix structure. 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.

Figure 2. MHP/RT and the distributed memory system implemented as multi-dimensional memory frames (modified from [4, Figure 3]).

cyclic PCM processes (see Figure 2, left), in which PDP for these processes is implemented in hierarchically organized bands with characteristic times for operations by associating relative times (not absolute) to the PCM processes that carry out a series of events *in synchronous with* changes in the external environment. Table I shows the bands, i.e., biological, cognitive, rational, and social bands, as defined by Newell [10]. It should be noted that there is a gap between two adjacent bands; these two bands are non-linearly connected and therefore it is inappropriate to understand the phenomena that happen across these bands by constructing a linear model. The phenomena occur by connecting what happens in a band to what happens in its adjacent band non-linearly. A mechanism is required to connect the phenomena; MHP/RT suggests that this connection is provided by the resonance mechanism.

The bottom left and middle portions of Figure 2 show the autonomous memory system consisting of multi-dimensional memory frames of perception, motion, behavior, relation, and word. These memory frames store information associated with the corresponding autonomous processes defined in the PCM processes. The middle portion of Figure 2 shows the five memory frames and their relationship with the PCM processes. The right portion of Figure 2 provides brief explanations of the respective memory frames. The important feature of the memory system is that it works *asynchronously* with the external environment. MHP/RT assumes that the *synchronous* PCM processes, including the perceptual system, System 1, System 2, and the motor system, and the asynchronous memory system communicate with each other through a resonance mechanism. The concept of resonance has been borrowed from physics to describe the linkage between the asynchronous memory system and the synchronous PCM processes. As Dinet et al. [1] suggested, apprehension of psychological phenomena using concepts issued from physics is useful because the majority of the interactions, including psychological interactions, between humans and the environment (social or physical environment) can be derived from physical processes.

The PCM process cycle in a human being continues from his or her birth until death in the ecological system that consists of the self and the environment. The linkage between the memory system and the PCM processes through resonance supports the development of the PCM processes. At the same time, the PCM processes are accompanied by changes in the connections of neurons that constitute the multi-dimensional memory frames. The purpose of this paper is to understand the development process from the viewpoint of the memory-PCM linkage through resonance.

This paper is organized as follows. Section II focuses on the role of resonance in the use of memory and its relationship with the changes in memory when a human being interacts with the environment. Section III extends the snap-shot view of resonance explored in the previous section in the time dimension to understand the nature of external objects that generate sustainable resonance. We define these sustainable objects as "memes" and this section describes how memes propagate over time and space. Section IV describes the development of the PCM processes and the multi-dimensional memory frames from birth to the end of adolescence. Section V concludes the paper by summarizing the contents and pointing out implications derived from the considerations of the role of resonance described in this paper.

II. Memorizing the Results of Resonance

The network of sensory neurons, motor neurons, and interneurons shown in Figure 1 develop as a human being interacts with the external environment in time. This section starts by describing a general feature of the development process in Section II-A, followed by the descriptions of what is memorized in Section II-B, and how the resonance mechanism relates to memory usage and memory formation in Section II-C.

A. Forming an O-PDP System

Life emerges in a preexisting structure, which is the global environment that surrounds the human being who is born, and exists as a system that operates under the mechanism of PDP.

Life has evolved through adaptation to the global environments, which are characterized by the following preexisting structures:

- **Atmosphere:** fluctuates at the meteorological scales showing chaotic behavior,
- **Sea:** has tidal currents and the surface layer is affected by the atmosphere showing chaotic behavior,
- **Periodic circular structures:** stable periods of rotation and revolution around the sun with a close-circular orbit as a planet of the solar system,
- **Gravity:** upper vs. lower directions, defined by the earth's gravity, and
- **Energy:** future vs. past directions, defined by the direction of energy flow as the dissipative structure of the earth.

Life is formed under these preexisting structures and the direction of the evolution of life is determined by the pressure caused by these structures. Under the dissipative structural space, i.e., the earth, the fundamental structural pressure is a prerequisite to life, which is born and active in it, and prescribes the direction of life evolution. Life is formed as an adaptive body with the functional and structural features that work most efficiently in the environment having the features best conceived by the four concepts of Goals, Operators, Methods, and Selection rules (GOMS) [5].

In the global environment before life occurred, there existed multiple-layered structures equipped with means of communicating information in a multi-dimensional space, including such physical and chemical entities as light, sound, heat, ion, etc. Under these preexisting conditions, life emerged. Life interacts with the multi-dimensional environment by using perception and motion as interfaces to it. Assuming the size of dimension of perception and that of motor to be M and N, respectively, the function of interface is represented as mappings in the $M \otimes N$ space. Specific numbers of M and N reflect the preexisting conditions of the environment.

B. Interneurons to memorize effective $M \otimes N$ mappings

Table I shows that human actions are hierarchically organized in four bands. In general, in-band closed processes are executed in feedforward. Processes carried out in the upper bands provide feedback to the processes carried out in the lower bands. Life activities perform mappings of M-dimensional perceptual input (Biological band) to N-dimensional motor output (Biological band) by the system of interneurons that belongs to the Cognitive band. Activities at an upper band emerge, each of which is associated with a part of the entire sequence of activities, i.e., a sub-sequence, performed at a lower band. The action sequence belonging to the lower band is segmented into sub-sequences, each of which corresponds to one of activities in the upper band; due to the fluctuations in processing times of the upper-band activities, relativization of processing times and functionalization of sub-sequences occur. It is possible to establish an association between the processing in the upper band activity (Cognitive band) with an effective sequence of $M \otimes N$ mappings in the lower band (Biological band) to form a hard-wired circuit of interneurons that is characteristic of this processing, which is the process of memory formation and development. Once the memory is formed, life activities perform mappings of M-dimensional perceptual input to N-dimensional motor output by using the memory stored in the system of interneurons.

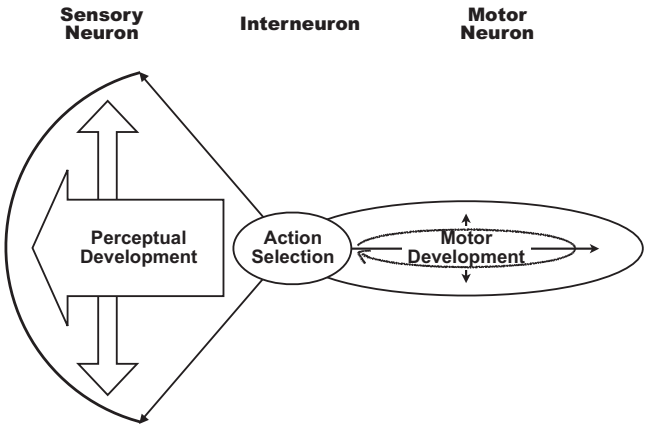

Figure 3. Development of the sensory nervous system and the motor nervous system, and interneurons connecting them with action selection process. ([11, Figure 1]).

In addition, trajectories of the life activities fluctuate, which provides opportunities to the O-PDP system to develop by adaptation.

The genealogy of DNA of vertebrates suggests that Perception, Interneuron, and Motion as the basis for development. Figure 3 shows that PIM is the basis of the formation of the concept of the body based on neural circuits and the whole is formed as PIM develops. Perception (P) captures various kinds of environmental changes via the sensors with different properties (*M*-dimension). Motor movement (M) is carried out continuously and cyclically from one's birth with gradual development via the accuracy and strength (*N*-dimension). Interneurons (I) memorize effective interlocked relationships between P and M to form neural circuits naturally in the form of feedforward (System 1) and more complex feedback to increase the effectiveness of reactions (System 2). PIM develops by expanding behavioral-ecological bandwidth. Behavioral ecological categories of vertebrates such as acquiring food, raising children, and so on, are almost identical and within a limited range. Everyday human life is performed cyclically in a behavioral ecological band, which is expanded by performing new actions to realize a goal within the limited behavioral ecological categories and adding these to the existing band.

Actions are realized as an *ad hoc* adaptive combination of various elements of the O-PDP system each time. Quasi-stable relationships between elements are generated by local relativization of the time relationship between the participating elements and added to the existing band. Since each process of performing actions is autonomous, it is possible for multiple processes to be initiated in a certain environment, resulting in *coincidental* parallel activities. Even if the timing of the execution of two or more parallel processes changes, it is possible for all of the processes to be completed within a certain time range with or without any relationships in the results. If the overall results are good, behavior selection in the future might be changed by this memory associated with rewards. Arbitrarily activated processes through conscious System 2 thinking, which may or may not be directly related to the current on-going external situation, can become a part of these expanded memories. Conscious thinking facilitates the expansion of memory.

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C. Conscious/Unconscious Processes Before/After an Event

MHP/RT maps $M \otimes N$ with the help of memory (Figure 2, left). It assumes the multi-dimensional memory frames and the resonance mechanism for incorporating memory, i.e., interneurons, in the mapping process. Perception with the M-dimensional perceptual information resonates with the contents in the PMD-frame. The activation in the PMD-frame spreads to the other memory frames. The activated portions of memory frames resonate with the System 1 and System 2 processes and are included in these processes. In the left portion of Figure 2, the resonance processes are shown graphically by •——•. It is suggested that the mirror-neuron system is the physical/neurological support for the resonance in human behavior [1] that can be regarded as the process of $M \otimes N$ mapping. The mirror system is thought to directly match visual input from an observed action with a stored motor program for the same behavior (e.g. [12][13][14]). If that motor program is then executed, the result is imitation.

MHP/RT assumes that actions are carried out by feedforward processes (System 1) or feedback processes (System 2) with the help of the resonance mechanism for utilizing existing memory. The processing principle of MHP/RT is that it should work in one of four different modes when one looks at it from *a particular event* that occurred at the absolute time T [15]. These modes are called Four-Process in the MHP/RT architecture. In Figure 2, these four modes are indicated where appropriate to show how they are supported by the resonance mechanism to utilize the contents stored in memory (System 1 and System 2 Before modes), and how they affect in forming memory (System 1 and System 2 After modes) as described below.

1) Rise of Resonance: Two modes work before the event. In the time range of $T-\beta \leq t < T-\beta'$, MHP/RT uses memory for *consciously* preparing for what would happen in the future (*System 2 Before Mode*), and in the time range of $T - \beta' \leq t < T$, it *unconsciously* coordinates motor activities to the interacting environment (*System 1 Before Mode*), where $\beta' \sim$ 500msec and β ranges from a few seconds to hours, and even to months. In these two modes, the part of memory activated through resonance in response to perceptual processing could resonate with System 1 processing and System 2 processing (see Figure 2, left).

2) Convergence of Resonance: The other two modes work after the event. In the time range of $T < t \leq T+\alpha'$, MHP/RT *unconsciously* tunes the connections between sensory inputs and motor outputs for better performance for the same event in the future (*System 1 After Mode*), and in the time range of $T+\alpha' < t \leq T+\alpha$, it *consciously* recognizes what has happened and then modifies memory concerning the event (*System 2 After Mode*), where $\alpha' \sim$ 500msec and α ranges from a few seconds to minutes, and even to hours. In these two modes, the results of action selection for the event at T would be reflected in the network connections of the respective multi-dimensional memory frames (see Figure 2, middle).

III. Meme Propagation by Means of Resonance

Memory is represented as a network of neurons. It is initially activated through an M-dimensional multimodal sensory input through a resonance mechanism, a large part of which originates from the other human beings or artifacts they have created; then the activation spreads in the connected memory regions. The information generated by human beings propagates among them by means of imitative behavior in which resonance connects memory and the PCM processes to carry out imitation. This raises the question of what causes resonance to be maintained in humans. This section introduces the Structured Meme Theory [16] which provides an answer to this question.

A. What Can Resonate

The O-PDP system that defines a human being interacts with the environment, which consists of not only inanimate objects but also other O-PDP systems (people who interact with him/her). Resonance is the mechanism by which action is taken at appropriate times. Resonance increases when the organism is in System 1 and 2 Before Modes of the MHP/RT, but converges when in the System 1 and 2 After Modes which effectively update the internal neural networks for future resonance. This section describes what resonates in an O-PDP system. The resonance mechanism, which is implemented by means of mirror neurons [1] in the human brain, is incorporated in the MHP/RT as the mechanism for making available the part of memory activated by perception in System 1 and 2 (see Figure 2, left).

The cyclic loop of perception and movement shown in Figure 1 carries out continuous updates of network connections of constituent neurons during the convergence of resonance period in the MHP/RT. Human behavior is structured in four bands (biological, cognitive, rational, and social bands) [10], and memory is constructed as five distinctive multi-dimensional memory frames (see Figure 2, middle). This suggests that the information is coming from an environment where the informant could either be other humans or inanimate objects. This information will generate resonance in the recipient of the information in a specific way that reflects the states of the development of the multi-dimensional memory frames. For a set of given external stimuli, a human being generates resonance by using the current memory for carrying out the next action and updates it. On the one hand, the PCM processes utilize the resonance mechanism to create the subsequent actions. On the other hand, the external entities, that make resonance generate internally, are created ultimately by humans. Human action associated with a band of the Newell's time scale could be associated with the part of memory that participates via the resonance mechanism.

From the above argument, it is plausible to assume that a human could create an entity that makes the others generate resonance for performing the subsequent actions and vice versa. This assumption represents what was meant by the term "meme" that Richard Dawkins [17] coined in the 1970s, which was conceptual and was not defined clearly. The Structured Meme Theory (SMT) proposed by Toyota et al. [16] defines memes as entities that represent the information associated with the objects that the brain can recognize.

Figure 4 depicts how memes propagate in the reality field. The process of propagation is facilitated by symbolization. A symbolized meme enables human beings to think at abstract levels. Suppose that Object-O_1, Object-O_2, or Object-O_3 appear in the environment. Each of these resonates with memory by using patterns stored in the PMD-frame and causes activation of RMD-, BMD-, and MMD-frames. The part of memory that is activated, Pattern-P_a (see Figure 4, bottom), will be used in action selection through resonance. Any entities in the environment that match Pattern-P_a are treated in the

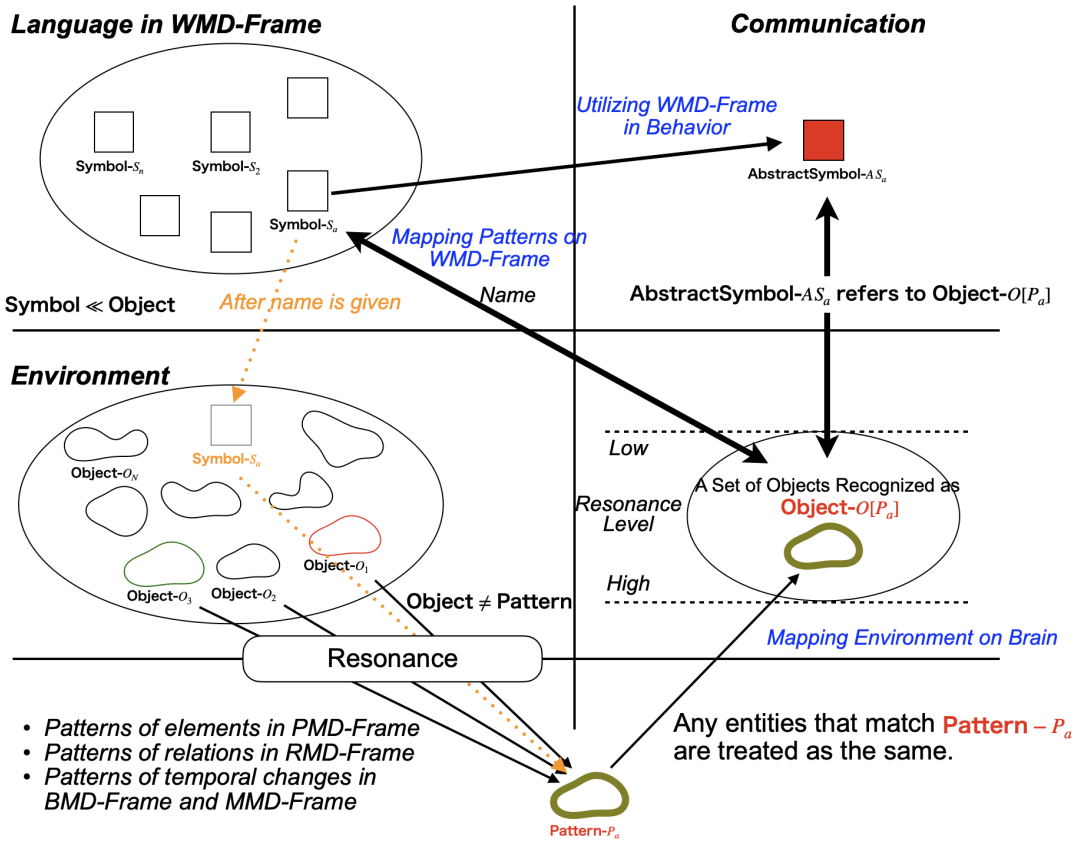

Figure 4. Propagation of Meme

same way in the action selection process as Object-$O[P_a]$. Pattern-P_a will be given a unique name Symbol-S_a and it will be stored in WMD-frame. In the future, when Symbol-S_a appears in the environment in someone's utterances, it might resonate with Pattern-P_a. Symbol-S_a could be associated with Object-O_1, Object-O_2, or Object-O_3. Therefore Symbol-S_a effectively functions as its abstraction, AbstractSymbol-AS_a, when it is used in communication. It is reasonable to assume that the higher the resonance level of Symbol-S_a becomes, the longer AbstractSymbol-AS_a is maintained and inherited as an effective communication medium.

B. Structured Meme

The recent consensus is that the range of information inherited by the genes is limited to physical functions and infantile behavior. Human beings need to acquire basic behavioral skills and communication skills through the experience of acting in the environment. As described in Section III-A, memes that can cause resonance constitute an important part of experience. This section explains that memes are structured in such a way that the memory is structured in multi-dimensional memory frames.

Figure 5 expands Pattern-P_a, that appears at the bottom of Figure 4, and the processes shown in Figure 5 as "Mapping Patterns on Brain" and "Mapping Patterns on WMD-frame" in order to show which portions of the neural networks would participate while a human being utilizes the WMD-frame in communication. As shown by Figure 4, symbols in the WMD-frame are gradually incorporated into the environment in the form of a thesaurus, i.e., lists of words in groups of synonyms and related concepts, languages used for person-to-person communication (individual language), which might include not only direct but also metaphorical uses, and languages used in cultural contexts (cultural language), in which appropriate understanding of common sense that has been established in the specific community, is essential for successful communication. Thesauruses, individual languages, and cultural languages increase their complexity in this order in terms of the patterns they are linked with the objects in the environment. Thesauruses are associated with the objects in the environment that are encoded in the neural networks in the initial development stage from the birth to 3 years. Individual languages are associated with not only the objects in the environment but also the symbols that have already been incorporated in the environment. The same is true for cultural languages.

The process of "Mapping patterns on symbols in WMD-frame" shown in Figure 4 can be subdivided into three processes based on the degree of complexity of mapping. The patterns that were mapped on the thesauruses, individual languages, and cultural languages are shown as Action-Level Meme, Behavior-Level Meme, and Culture-Level Meme (see Figure 5), respectively, that were introduced in the Structured Meme Theory proposed by Toyota et al. [16] . The mechanism

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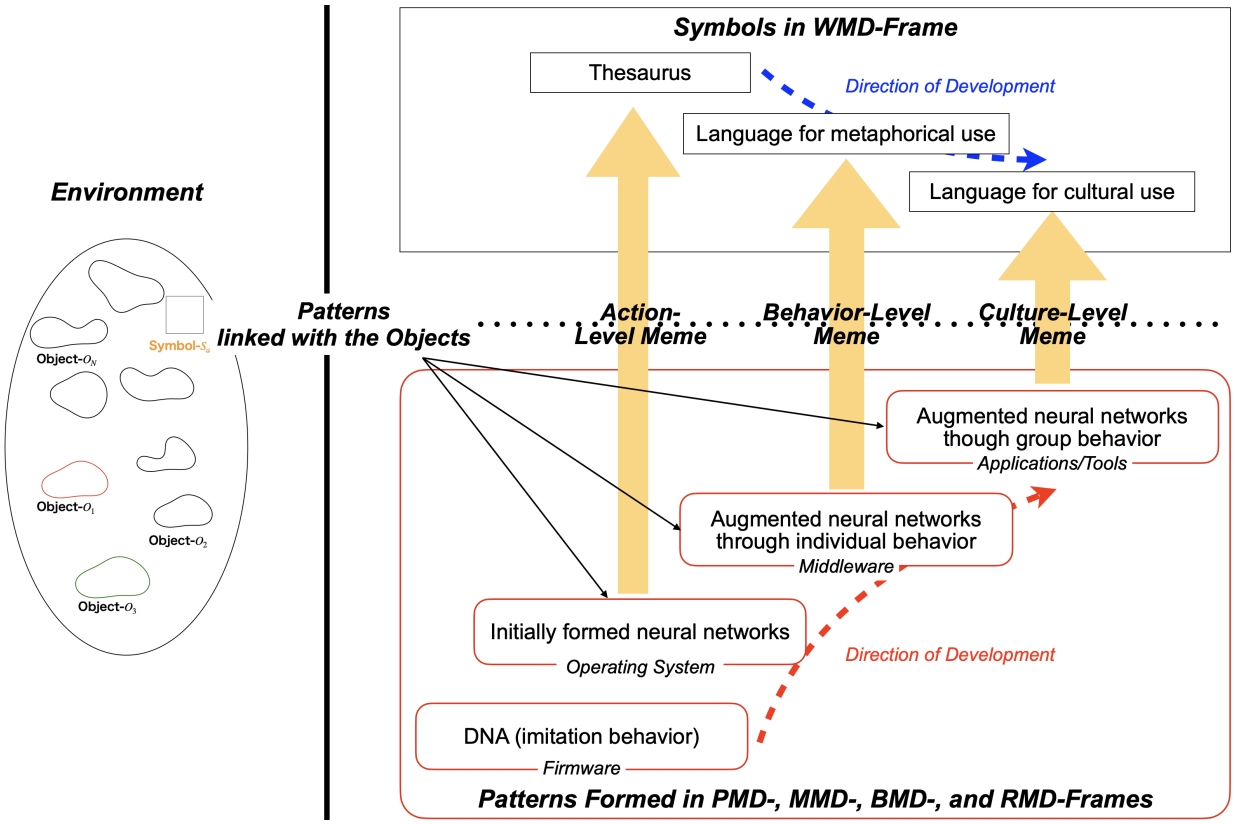

Figure 5. Structure of meme

by which the three levels of memes and genes inherit information is analogous to an information system. Genes serve as firmware that mimics behavior-level activities. Action-level memes serve as the operating system that defines general patterns of spatial-temporal behavioral functions. Behavior-level memes represent middleware that extends the general patterns to concrete patterns. Culture-level memes act as application tools that extend the concrete patterns to the ones that work in a number of groups of people.

The relationships between the three levels of memes and multi-dimensional memory frames are as follows:

- Action-level memes represent bodily actions stored in the MMD-frame;
- Behavior-level memes represent behaviors in the environment stored in the BMD-frame; and
- Culture-level memes represent culture stored in the RMD-frame and the WMD-frame.

IV. Development of PIM and Multi-dimensional Memory Frames

In Section II, we described the mechanism by which PIM develops with the Four-Process by utilizing the resonance mechanism. Section III described how the contents of multi-dimensional memory frames, which could resonate with the PCM processes running synchronously with the environment, are maintained among human beings through communication. This section describes the changes in the contents of PIM and multi-dimensional memory frames over time as human beings grow up from birth to the end of adolescent. This explains human development in terms of PIM and multi-dimensional memory frames (Figure 5, bottom).

This section elaborates the four stages in PIM development as described in [9]. Table II shows the age range, rate of autonomous development of perception and motion, and the method of connecting sensory and motor neurons via interneurons and the resultant control method. Figure 6 depicts schematically the development of PIM (the sensory nervous system and the motor nervous system characterized by the functioning of interneurons connecting them (Figure 3)) and the development of multi-dimensional memory frames that shows the structured inter-connections of interneurons along with each stage (Figure 2, center). The multi-dimensional memory frames that develop at a particular stage are shown by adding shades.

A. Stage 1

At $0 \sim 6$ years of age, feedforward loops are the dominant control mechanism and these establish fundamental relationships between MMD- and BMD-frames by means of "uplinking." In the first half of this period, at $0 \sim 3$ years of age, sensory and motor neurons experience rapid autonomous development. Interneurons connect them by subordinate-intervention, resulting in feedforward control (Figure 6-1A). During this period, human beings establish inter-connections between PMD- and MMD-frames, and PMD-, MMD-, and BMD-frames. The former is related to action-level memes and the latter, to behavior-level memes. These make integrated movements of bodily actions possible on the basis of the relationships be-

TABLE II. PIM DEVELOPMENT PROCESS

		Speed of Autonomous Development		Method for Establishing Connection	Resulting Control Mechanism
Stage	Age	Perception	Motion	Interneurons	
1	$0\sim 3$	Rapid	Rapid	subordinate	Feedforward control
2	$4\sim 7$	Fast	Fast	memory-mediated	Limited feedback control
3	$7\sim 12$	Stable	Stable	memory-mediated-proactive	Wide feedback control
4	$13\sim 18$	Settled	Settled	memory-mediated-autonomous	Extended feedback control

tween the input from the perceptual system in the PMD-frame and the output expressed as reflexive movements in the MMD- and BMD-frames, for example, simple utterances (Figure 6-1B).

B. Stage 2

In the latter half of this period, at $4 \sim 6$ years of age, there is rapid autonomous development of sensory and motor neurons. Interneurons connect these by memory-mediated interventions, resulting in feedback controls (Figure 6-2A). During this period, human beings acquire the skill of behaving in relation with other persons and the methods for conversing with others such as the ability to explain using simple syntax. Acquisition of utterances and combined motor movements become possible by using the RMD-frame that connects simple syntax of symbols in the WMD-frame by linking PMD-, BMD-, and MMD-frames. At this stage, the conscious processes of System 2 Before and System 2 After that make feedback controls possible are initiated (Figure 6-2B).

C. Stage 3

Later, at $7 \sim 12$ years of age, parallel distributed activities are almost complete. There is stable autonomous development of the sensory and motor neurons. Interneurons connect them by memory-mediated proactive interventions, resulting in wider feedback controls (Figure 6-3A). During this period, human beings acquire the skill of first-order logical thinking by using letters or symbols and that of cooperation with other persons. These activities facilitate the development of interconnections among the multi-dimensional memory frames, resulting in very complex networks. Figure 6-3B) shows the development of interconnections in the RMD- and WMD-frames. The key is the presence of symbols that intervene between the various input and output connections; these symbols are related to culture-level memes.

Structural development precedes procedural development. The former refers to the development of connections between PMD- and MMD-frames with the support of the BMD-frame. The BMD-frame stores repetitive sequences of motor actions in the MMD-frame as single units; therefore, the action sequences in the BMD-frame can be carried out unconsciously. The latter refers to the development of connections between WMD- and RMD-frames. The connections start from spoken informal language to more abstract structural representations of formal language. The WMD-frame stores sequences of symbols as language dissociated from the real world; the RMD-frame stores a set of BMD-frames into a manipulable unit. The connections between the contents in the WMD-frame and those in the RMD-frame give reality to the contents in the WMD-frame. Structural development and procedural development interact with each other in the RMD-frame occasionally and proceed in parallel. Procedural development in the RMD-frame is critical to extend the range of behavior. Once elements in the RMD-frame are compiled in the System 2 After mode, the compiled rule can be used to initiate a behavior with longer action steps.

D. Stage 4

Finally, at age $13 \sim 18$ years, parallel distributed activities are complete. There is settled autonomous development of sensory and motor neurons. Interneurons connect these using memory-mediated autonomous intervention, resulting in even wider feedback control (Figure 6-4A). During this period, feedback loops are established; these are used to form language processing circuits in a single-layer, WMD-frame. During this period, the ability of logical writing and the generation of grammatically correct sentences by using ordinary language affects significantly the development process. The WMD-frame can evolve autonomously and extensively; part of the WMD-frame is associated with the BMD-frame and ultimately connected with the real world but the rest of the WMD-frame is dissociated from the real world because there is no connection between the WMD-frame and RMD-frame (Figure 6-4B).

V. CONCLUSION

Resonance connects remote systems enabling them to work jointly. Human beings act in the environment by using two systems: a cyclic PCM system that works in synchronization with the environment and an autonomous memory system that operates asynchronously with the environment. Based on MHP/RT, this paper describes the hypothesis that the PCM system and the memory system interact with each other via a resonance mechanism. First, this paper shows that a single action selection carried out by the PCM system was conceived as a mapping of the input from the environment represented in M-dimensional information in the PMD-frame on the output to the environment represented in N-dimensional motor actions in the MMD-frame, connected with the BMD- and RMD-frames, and discusses the role played by resonance in the PCM processes defined by the MHP/RT and updates of the memory represented by the multi-dimensional memory frames. Second, in situations where the environment comprises objects created by humans, i.e., artifacts such as symbols, manners, language, and culture, this paper discusses how artifacts are maintained over time and space with the help of resonance. A necessary condition for the survival of artifacts is that they resonate with human beings. This paper introduces action-level, behavior-level, and culture-level memes to represent resonating entities stored in memory. Third, we also described the human development process from birth to the end of adolescence in terms of the changes in PIM and memory,

taking into account the changes in memes that human beings develop in memory as they grow older.

The argument this paper has profound implications for cases where there is malfunction of resonance, and where memory that fails to resonate as reality develops.

An example of the first case is Autism Spectrum Disorder (ASD). Is ASD a resonance problem? Imitation is a potentially crucial aspect of social cognitive development [18] because imitation is an efficient tool for two main adaptive functions: learning and communication. Imitation-based communication is possible through the use of the two aspects of imitation: imitating and being imitated [19]. These two aspects give rise to two roles that partners can exchange by taking turns while they synchronize matched activities. Neuroimaging studies of interactive imitation have shown that such communicative systems involve a coordination of bottom-up and top-down processes. In accordance with some authors (e.g. [20]) and based on the MHP/RT model, we hypothesize that perceptive-motor resonance plays a more central role in imitation in infancy than does a rational evaluation of the observed action. Thus, because individuals with ASD have difficulties with imitation, the nature of which remains unclear, it is plausible to postulate that one of the main problems of ASD is related to difficulties with the mechanisms underlying resonance. Several studies have shown that very young children with ASD (M Age $<$ 48 months; for a synthesis: [21]) used imitation less often when copying the actions of others, spent less time looking at others' faces and more time looking at the actions of others; attentional, social and executive factors underlie different aspects of imitation difficulties in this population. In other words, ASD is characterized by a deficiency in the development of imitation capacity, and this deficiency implies a deficit in mapping neural codings for actions between sensory and motor modalities, rather than in motivation or executive function [22]. Thus, ASD could be characterized by abnormal development of these mappings and that of resonance mechanisms.

Another important implication of our hypothesis is related to the autonomous development of the WMD-frame at the later stage of development. This paper showed that part of the contents in the WMD-frame do not necessarily have reality, which is established by linking the WMD-frame with the chain of RMD-, BMD-, and MMD-frames. Systematic and logical knowledge as a group norm could become part of the WMD-frame through education. It could resonate with the symbols that refer to the knowledge but would not resonate with *real* objects in the environment. The larger the non-resonant part of memory, the less the person will resonate with reality in the environment.

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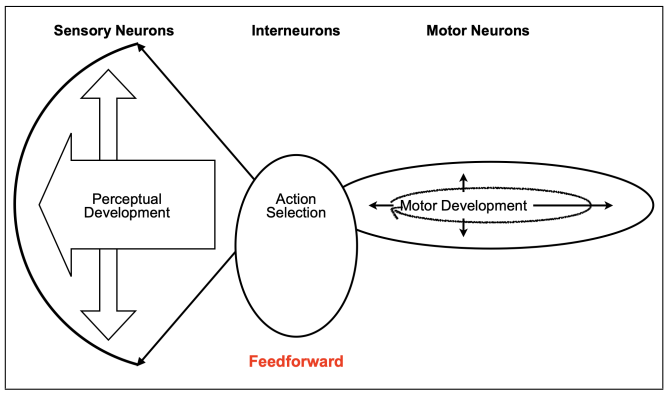

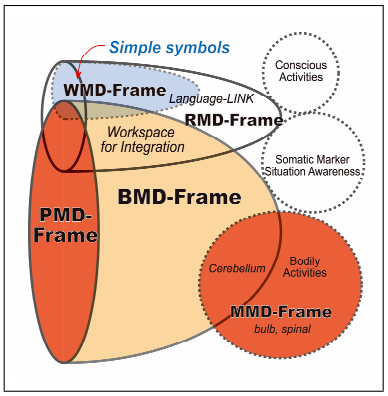

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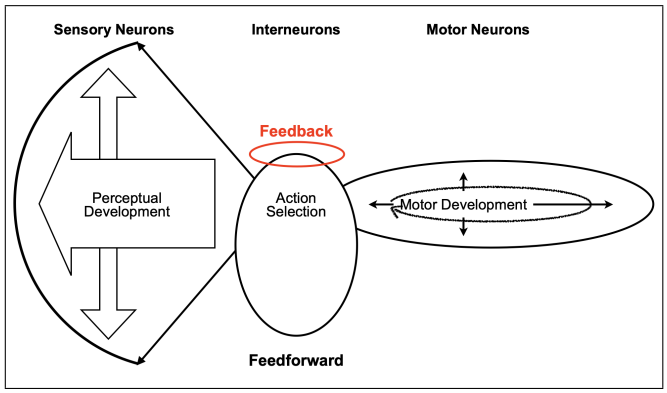

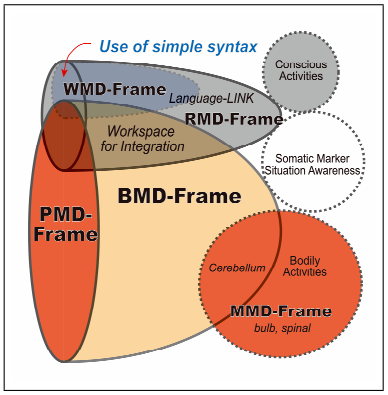

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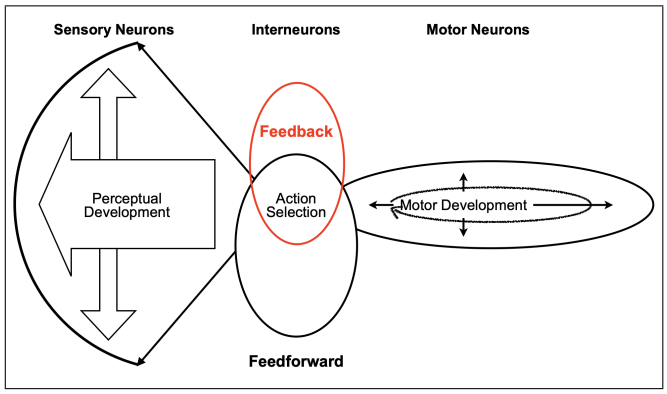

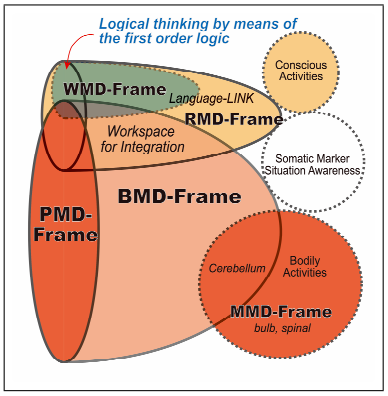

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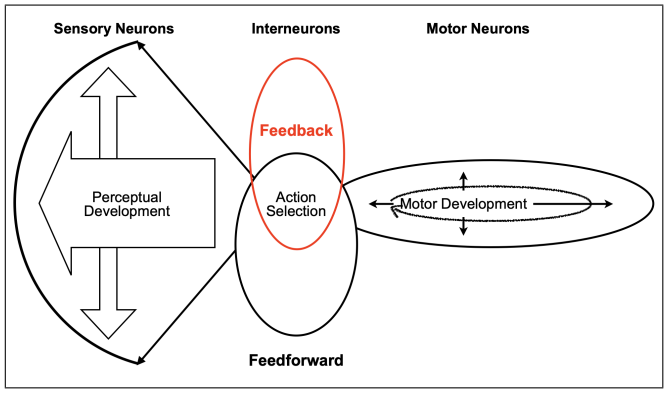

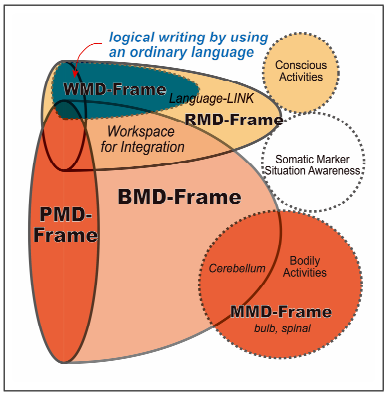

Stage 4 4A 4B

Figure 6. Development of PIM and multi-dimensional memory frames

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