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The Role of Resonance in the Development and Propagation of Memes

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A Short Resume of the Presenter

Muneo Kitajima currently works at the Department of Management and Information Systems Engineering, Nagaoka University of Technology. His recently published book "Memory and Action Selection in Human-Machine Interaction" (2016) proposes a unified theory of action selection and development by integrating PDP, Two Minds, and Layered structure of human action. The theory provides a comprehensive view of how our brain functionally works in our daily life. His current interest is to understand the implications of the theory to development of skill of adaptive problem solving, the important skill for survival.

Background and Motivation

❖ ***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.

❖ ***Questions:***
  - *How do memes propagate among group members?*
  - *How do memes develop in individual members?*

❖ This paper claims that <u>the concept of resonance</u> should play an important role in propagation and development of memes.

❖ Dinet et al. (2020) [1] pointed out that the concept of resonance originally issued from physics has been successfully applied to cognitive processes for behavior selection.
  - *The Model Human Processor with Real-Time Constraints (MHP/RT) model (Kitajima and Toyota, 2012) [2] 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.*

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Outline of the Presentation

❖ Introduction of the basic concepts:
  - *Human behavior viewed as continuous cyclic loop of perception and movement.*
  - *Model-Human Processor with Real-time Constraints (MHP/RT) as a comprehensive model of action selection and memory with the following features:*
    · Organic Parallel Distributed Processing (O-PDP) system,
    · The dual processes of System 1, at the unconscious level, and System 2, at the conscious level (Two Minds), and
    · Organized under happiness goals at the top level.
    · *MHP/RT suggests that connections between levels is provided by the resonance mechanism.*

❖ Memorizing the results of resonance:
  - *Interneurons to memorize effective $M \otimes N$ mappings (M-dimensional perception and N-dimensional motion), and*
  - *The roles of Conscious/Unconscious Processes Before/After an event.*

❖ Meme propagation by means of resonance
 - *What Can Resonate;*
  - *How memes are structured over time.*

❖ Development of PIM and multi-dimensional memory frames
  - *Co-development of perceptual and motor processes intervened by Interneurons, and memory.*

❖ Conclusion

Continuous cyclic loop of perception and movement

❖ A person interacts with the environment by running an endless stream of:

- *Perceptions involving the external and internal environments through the five senses 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.*

❖ The next cycle of perceptual-motor processes occur as s/he perceives the results of movement of his/her body parts as well as the changes in the external environment.

❖ **Interneurons** convert the input patterns to the output patterns.
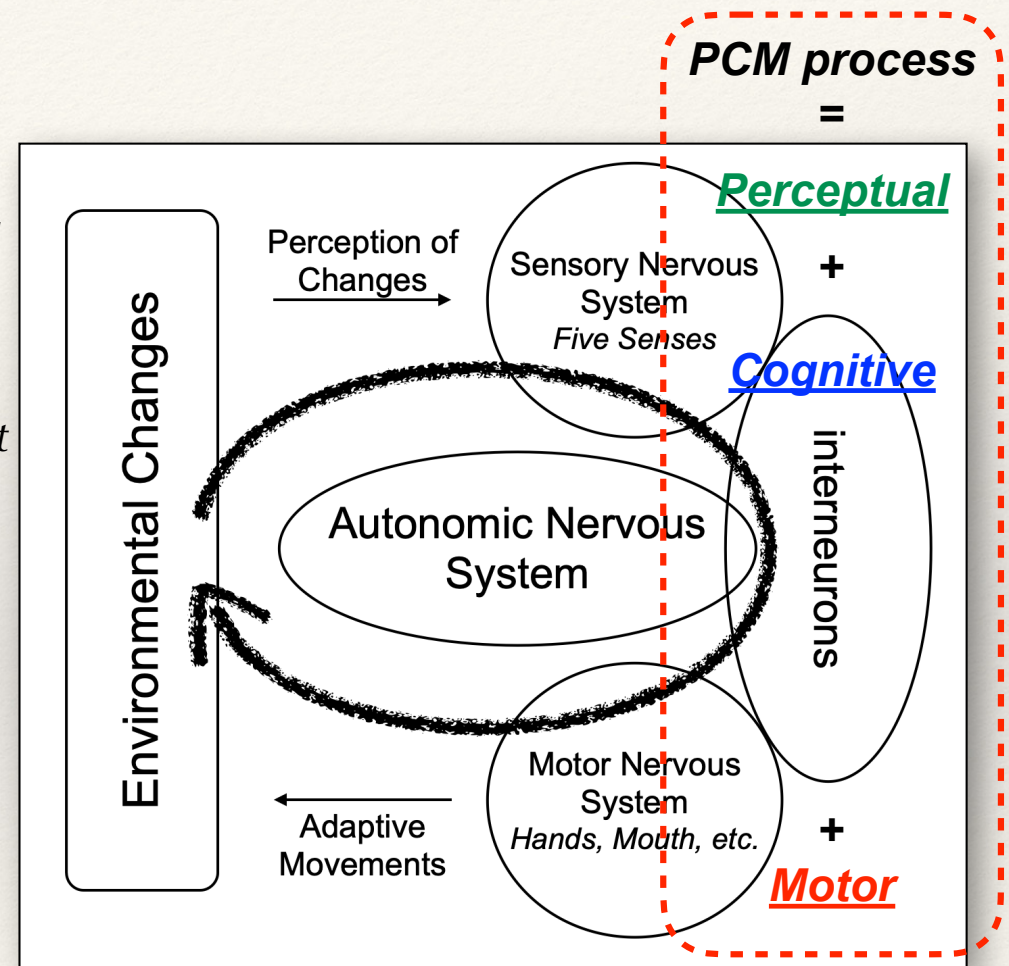
Model-Human Processor with Real-time Constraints (MHP/RT)

❖ An implementation of the continuous cyclic loop:

- *A comprehensive theory of action selection and memory, Model-Human Processor with Real-time Constraints (MHP/RT), providing a basis for constructing any models for an acting person (Kitajima and Toyota [3][4]).*

❖ MHP/RT is an extension of Model Human Processor proposed by Card, Moran, and Newell [5] that can simulate routine goal-directed behaviors.

❖ 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:

1) Cyclic PCM processes, 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;

2) The autonomous memory system consisting of multi-dimensional memory frames of perception, motion, behavior, relation, and word, and working asynchronously with the external environment.

❖ ***MHP/RT assumes that the synchronous PCM processes and the asynchronous memory system communicate with each other through a resonance mechanism.***

MHP/RT and the distributed memory system implemented as multi-dimensional memory frames
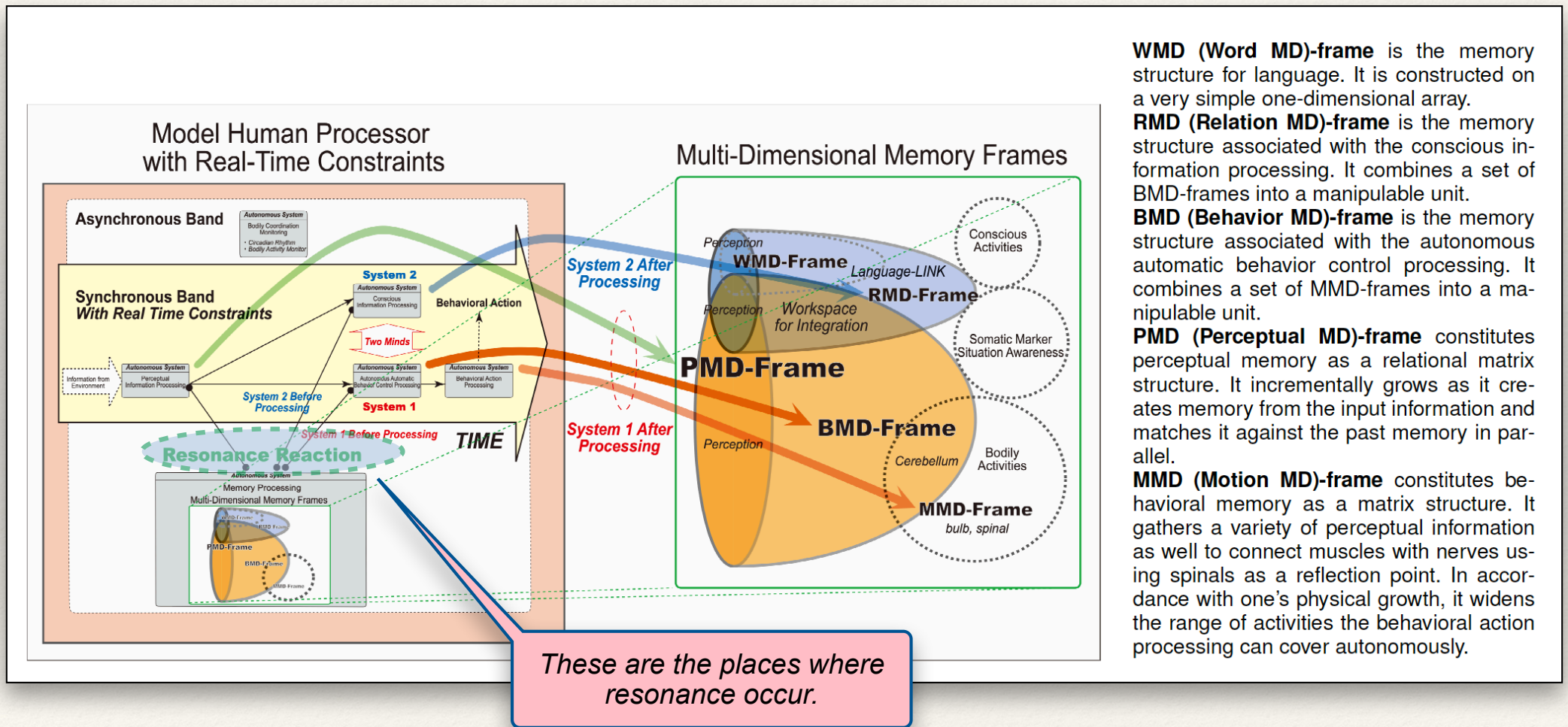
WMD (Word MD)-frame is the memory structure for language. It is constructed on a very simple one-dimensional array.

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.

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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.

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).

Sensory Neuron   **Interneuron**   **Motor Neuron**

I
M ⊗ N mapping

P
M-dimension

Perceptual Development   **Action Selection**   **Motor Development**

M
N-dimension

Perception (P) captures various kinds of environmental changes via the sensors (*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*).

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
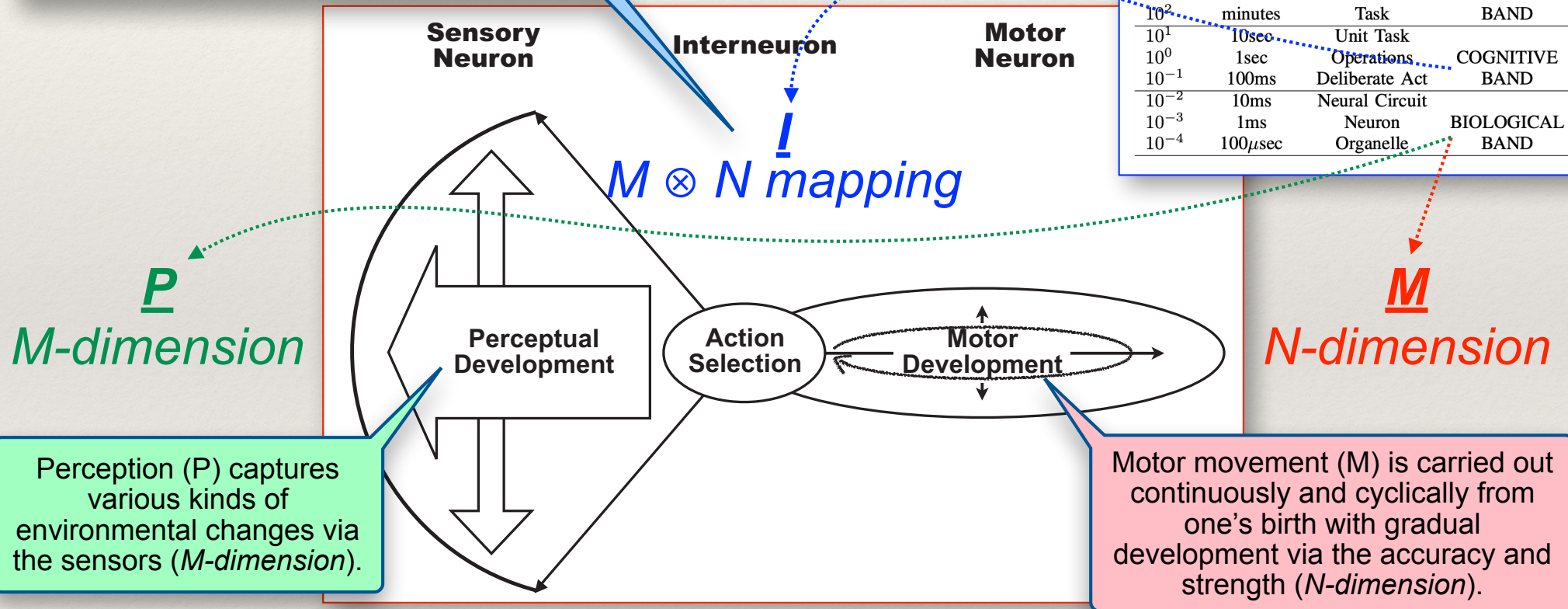
PIM develops by expanding behavioral-ecological bandwidth.

Resonance in MHP/RT

❖ MHP/RT assumes the multi-dimensional memory frames and the resonance mechanism for incorporating memory in the mapping process.

  - *Action selection includes mapping M-dimensional perception to N-dimensional motion via interneurons;*
  - *The resonance mechanism works for making available the portion of interneurons implemented as the multi-dimensional memory frames in MHP/RT.*

❖ Incorporation of the resonance mechanism in the action selection process of MHP/RT

  - *Perception with the M-dimensional perceptual information <u>resonates</u> 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 that include N-dimensional motion <u>resonate</u> with System 1 and System 2 processes and are included in these processes — this process is detailed in the next slide.*

❖ Remarks on neuronal evidence of resonance phenomena:

  - *It is suggested that the mirror-neuron system is the physical/neurological support for the resonance in human behavior that can be regarded as the process of M ⊗ 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.*
  - *If that motor program is then executed, the result is imitation.*

Detailed look at the resonance in MHP/RT

❖ 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.

- *System 2 Before Mode: MHP/RT uses memory for consciously preparing for what would happen in the future.*
- *System 1 Before Mode: MHP/RT unconsciously coordinates motor activities to the interacting environment.*
- *System 1 After Mode: MHP/RT unconsciously tunes the connections between sensory inputs and motor outputs for better performance for the same event in the future.*
- *System 2 After Mode: MHP/RT consciously recognizes what has happened and then modifies memory concerning the event.*

❖ The role of resonance in the four processing modes of MHP/RT

- *Rise of Resonance: In System 1 and System 2 Before modes, the resonance mechanism provides support to utilize the contents stored in memory. 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.*
- *Convergence of Resonance: In System 1 and System 2 After modes, the resonance mechanism affects while forming memory. 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.*

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Question: What causes resonance to be maintained?

❖ Framing the question:

- *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.*

❖ *What causes resonance to be maintained in humans?*

❖ The answer: The Structured Meme Theory proposed by Toyota et al. (2008) [16]

What Can Resonate (1)

❖ The O-PDP system interacts with the environment:

- *The O-PDP system is a human being.*

- *The environment consists of not only inanimate objects but also other O-PDP systems (people who interact with him/her).*

❖ Resonance is the mechanism for:

- *Making available the part of memory activated by perception in System 1 and System 2, and*

- *Enabling action to be taken at appropriate times.*

❖ Rise and convergence of resonance in the four processing modes of MHP/RT

- *Resonance increases in the System 1 and System 2 Before Modes for selecting next action and carrying it out;*

- *Resonance converges in the System 1 and System 2 After Modes for updating the internal neural networks for future resonance.*

What Can Resonate (2)

❖ An individual's action selection and memorization via the resonance mechanism:

- *For a set of given external stimuli (information), a human being does the following:*
  - Generates resonance by using the current memory for carrying out the next action;
  - Updates the current memory reflecting the results of resonance.
- *These processes are carried out under the following structural constraints:*
  - Behavior is structured in Newell's four bands (biological, cognitive, rational, and social bands), and
  - Memory is constructed as five distinctive multi-dimensional memory frames.
- *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.*
- *The resonance generated in the recipient of the information reflects the states of the development of the multi-dimensional memory frames.*
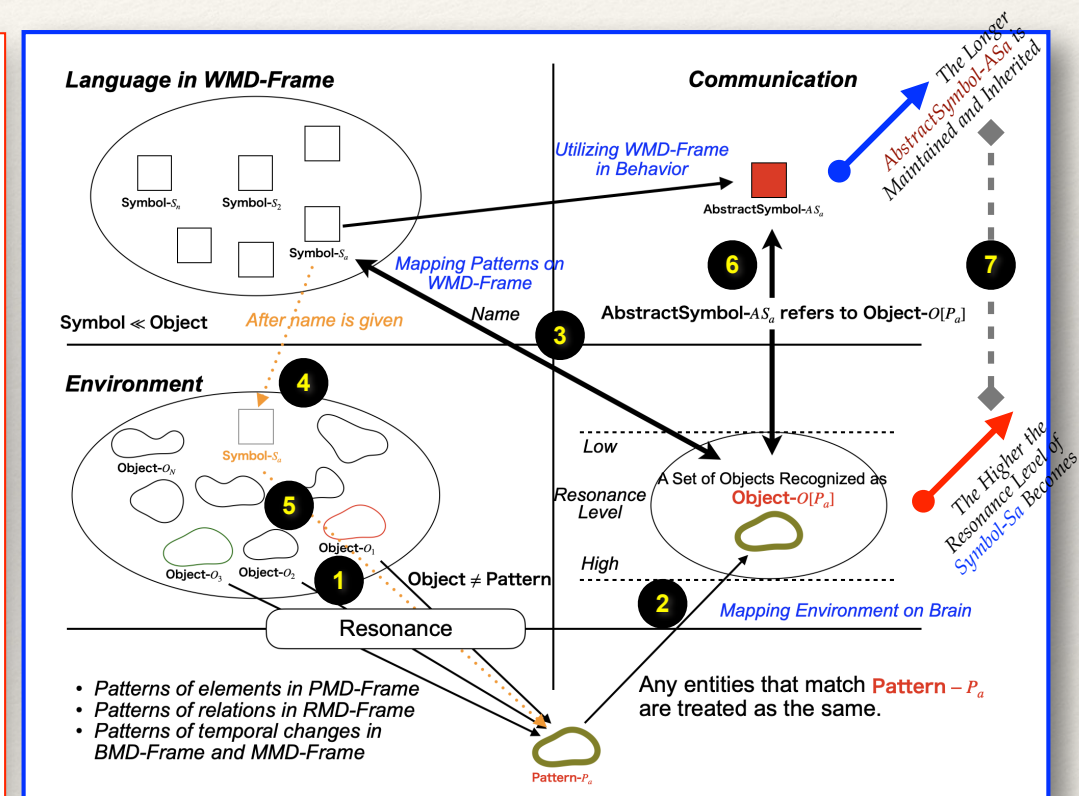
What Can Resonate (3)

- ❖ The chain maintained via the resonance mechanism:
  - *Perception of external stimuli (P) -> Resonance (C) -> Generating action (M) = Creating external stimuli to be resonated -> …*
  - *An individual's PCM processes utilize the resonance mechanism to create the subsequent actions.*
  - *The external entities, that make resonance generate internally, are created ultimately by humans.*

- ❖ 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 coined in the 1970s, which was conceptual and was not defined clearly. Memes are "discrete and faithfully transmitted."*
  - *Daniel C. Dennett suggests 'words are memes' in his book entitled "From Bacteria to Bach and Back: The Evolution of Minds", which is consistent with the claim of this paper.*
  - *The Structured Meme Theory (SMT) proposed by Toyota et al. (2008) [16] defines memes as entities that represent the information associated with the objects that the brain can recognize.*

How Memes Propagate in the Reality Field

❖ The process of propagation is facilitated by symbolization.

❖ **Illustration of the meme propagation process:**

1) Object-O_1, Object-O_2, or Object-O_3 appear in the environment.
   - Resonates with memory by using patterns stored in the PMD-frame.
   - Causes activation of RMD-, BMD-, and MMD-frames.
   - Pattern-Pa — the activated part of memory — will be used in action selection through resonance.

2) Object-O[Pa] — any entities that match Pattern-Pa — are treated in the same way in the action selection process (**Mapping Patterns on Brain**).

3) Symbol-Sa — a unique name given to Pattern-Pa — will be stored in WMD-frame (**Mapping Patterns on WMD-Frame**).

4) In the future, Symbol-Sa in someone's utterances might resonate with Pattern-Pa.

5) Symbol-Sa could be associated with Object-O_1, Object-O_2, or Object-O_3.

6) Symbol-Sa effectively functions as its abstraction, AbstractSymbol-ASa , when it is used in communication.

7) The higher the resonance level of Symbol-Sa becomes, the longer AbstractSymbol-ASa is maintained and inherited as an effective communication medium.

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How memes are structured (1)

❖ Nature of Memes:
- *Can cause resonance and constitute an important part of experience.*
- *Structured in such a way that the memory is structured in multi-dimensional memory frames.*

❖ Memes' structure is derived by examining which portions of the neural networks would participate while a human being utilizes the WMD-frame in communication focusing on the processes concerning Pattern-Pa:
- *Mapping Patterns on Brain (2)*
- *Mapping Patterns on WMD-frame (3)*

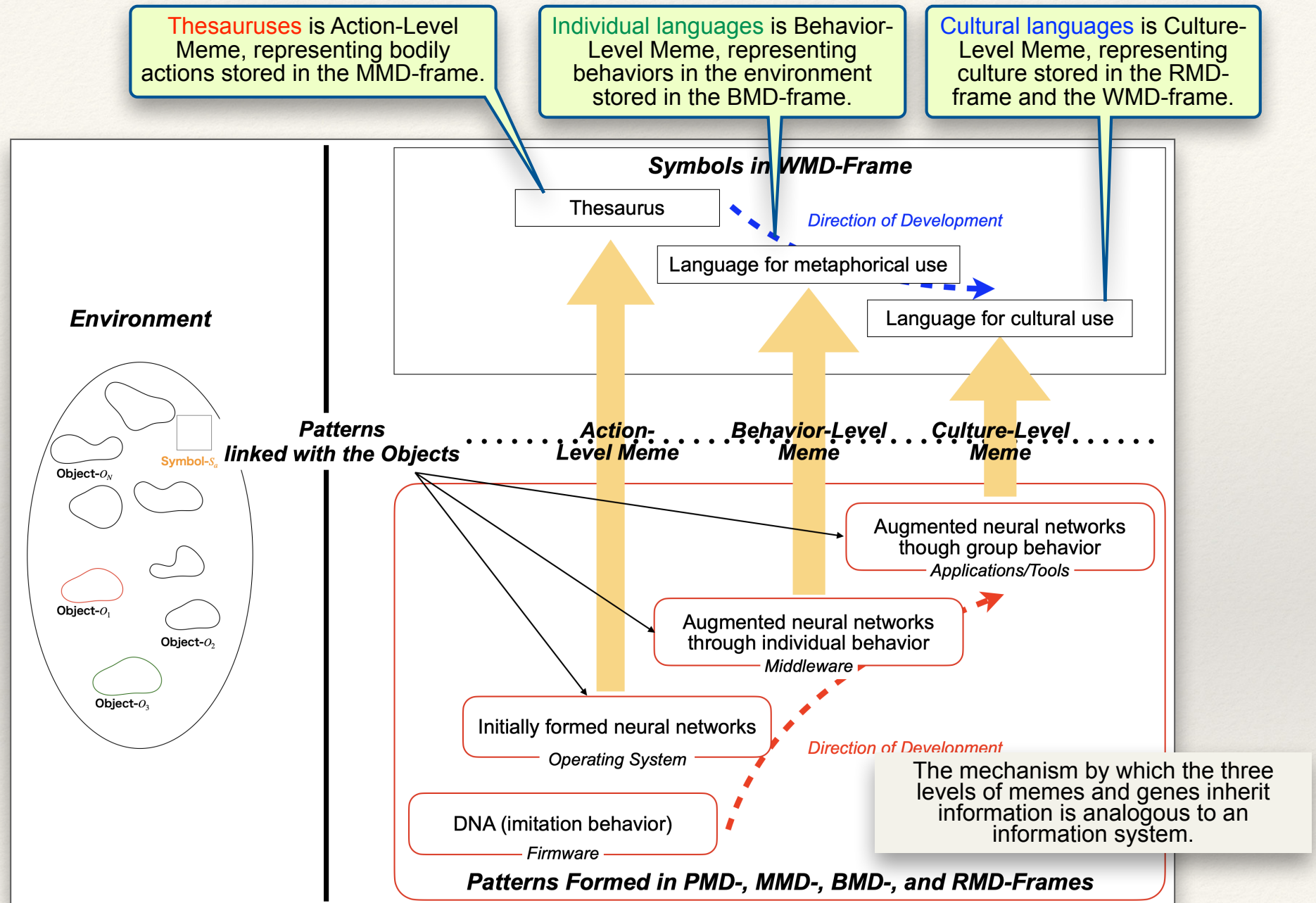❖ Symbols in the WMD-frame are gradually incorporated into the environment in the form of:
- *Thesauruses, i.e., lists of words in groups of synonyms and related concepts;*
  - Associated with the objects in the environment that are encoded in the neural networks in the initial development stage from the birth to 3 years.

increase complexity in terms of the patterns they are linked with the objects in the environment.

- *Individual languages (languages used for person-to-person communication), including not only direct but also metaphorical uses; and*
- *Cultural languages (languages used in cultural contexts), in which appropriate understanding of common sense that has been established in the specific community, is essential for successful communication.*
  - Associated with not only the objects in the environment but also the symbols that have already been incorporated in the environment

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How memes are structured (2)

Thesauruses is Action-Level Meme, representing bodily actions stored in the MMD-frame.

Individual languages is Behavior-Level Meme, representing behaviors in the environment stored in the BMD-frame.

Cultural languages is Culture-Level Meme, representing culture stored in the RMD-frame and the WMD-frame.

Symbols in WMD-Frame

Thesaurus

Direction of Development

Language for metaphorical use

Language for cultural use

Environment

Symbol-S_a

Object-O_N

Object-O_1

Object-O_2

Object-O_3

Patterns linked with the Objects

Action-Level Meme ... Behavior-Level Meme ... Culture-Level Meme

Augmented neural networks though group behavior
Applications/Tools

Augmented neural networks through individual behavior
Middleware

Initially formed neural networks
Operating System

DNA (imitation behavior)
Firmware

Direction of Development

The mechanism by which the three levels of memes and genes inherit information is analogous to an information system.

Patterns Formed in PMD-, MMD-, BMD-, and RMD-Frames

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Stage 1 of Co-development of PIM and Memory

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 between 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.
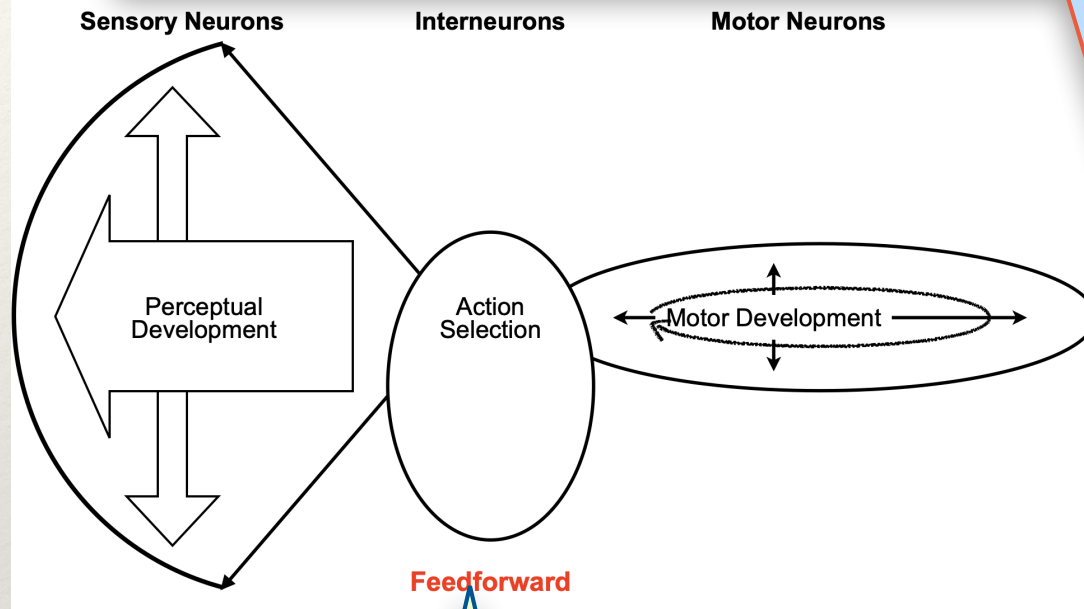

At 0 ~ 6 years of age, feedforward loops are the dominant control mechanism and these establish fundamental relationships between MMD- and BMD-frames by means of "uplinking." In the first half of this period, at 0 ~ 3 years of age, sensory and motor neurons experience rapid autonomous development. Interneurons connect them by subordinate-intervention, resulting in feedforward control.
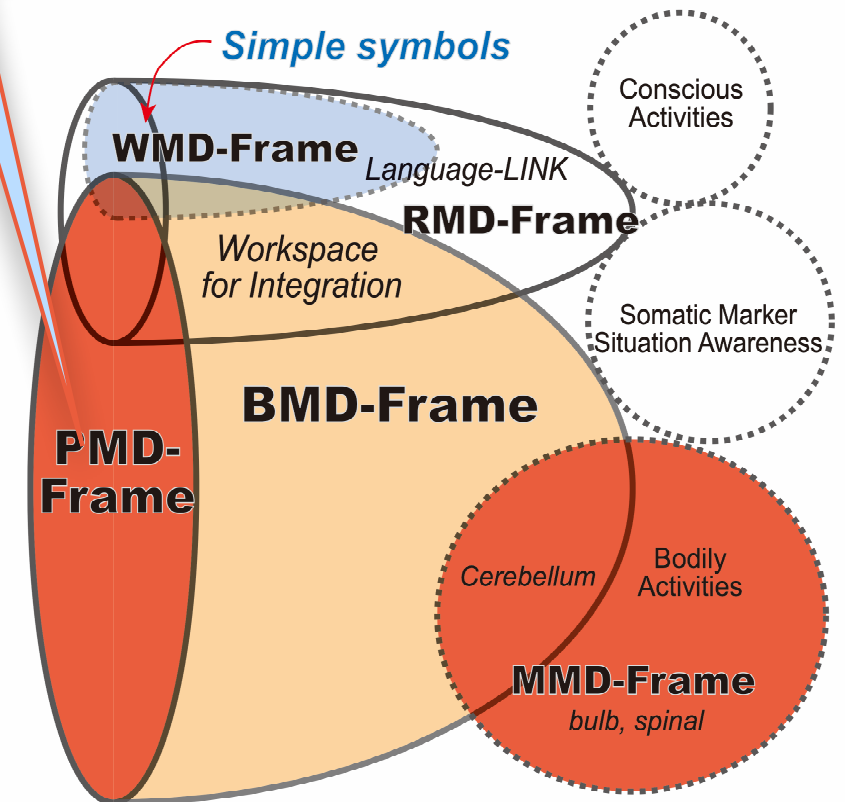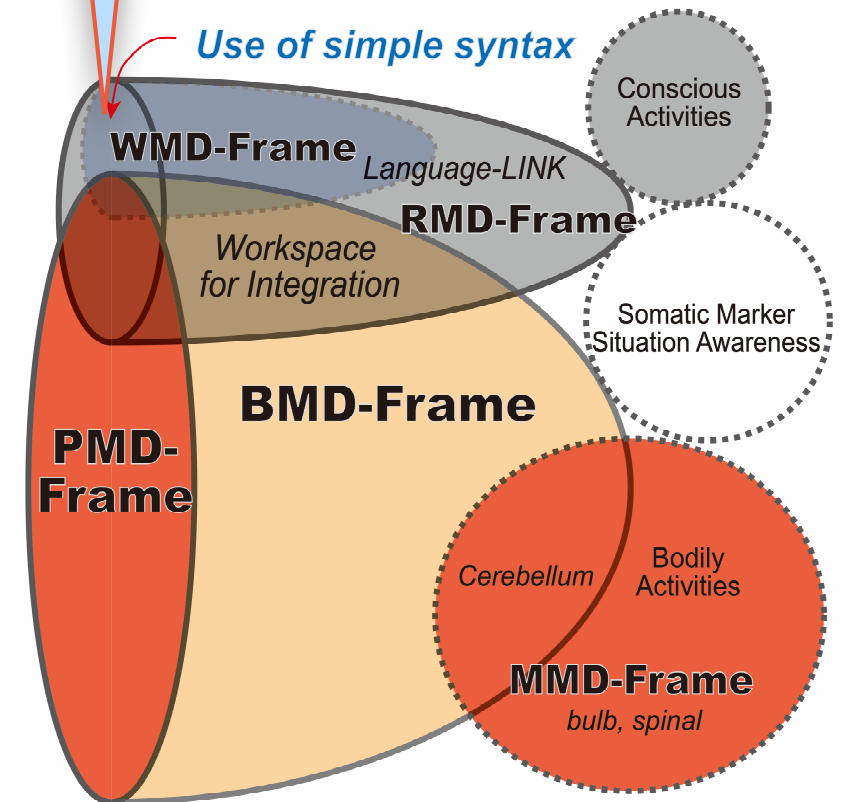
During this period, human beings acquire the skill of behaving in relation with other persons and the methods for conversing with others such as the ability to explain using simple syntax. Acquisition of utterances and combined motor movements become possible by using the RMD-frame that connects simple 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.
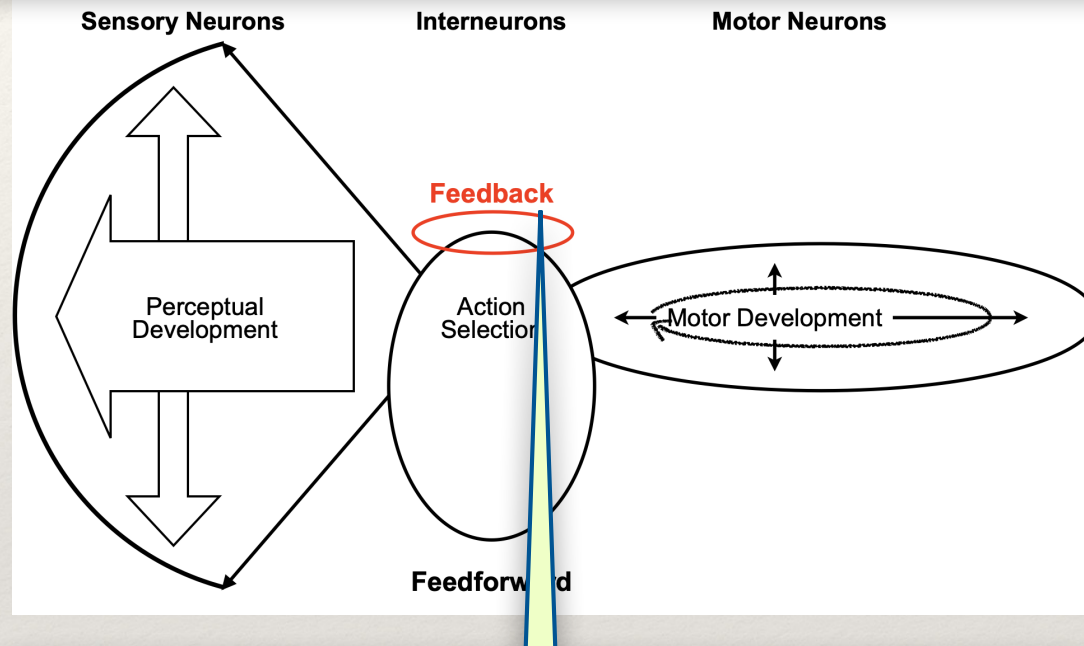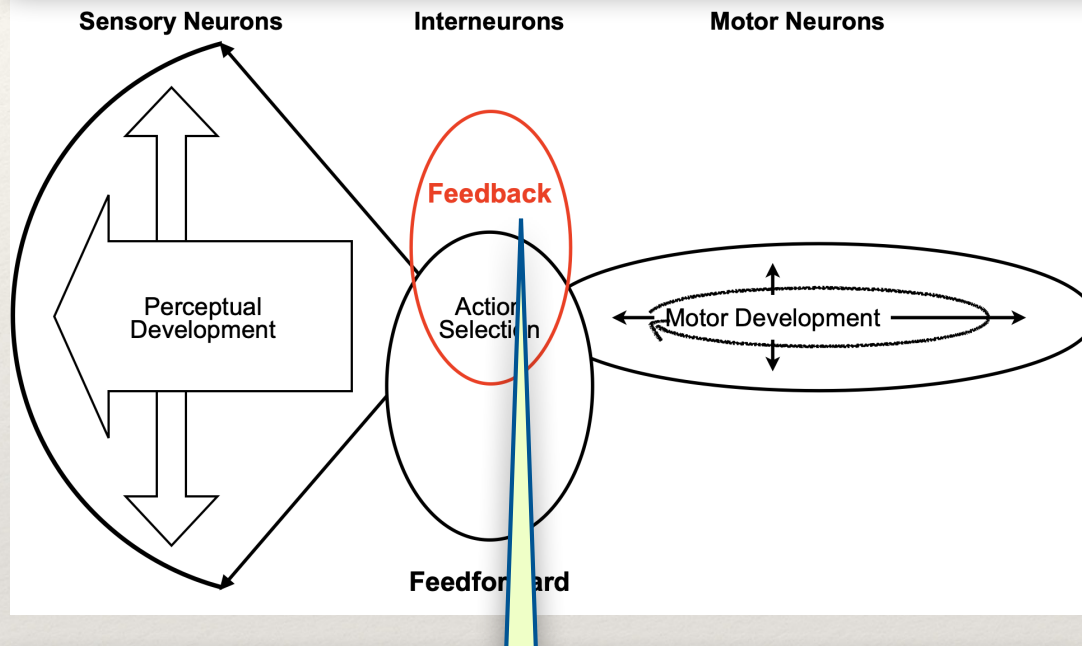
In the latter half of this period, at 4 ~ 6 years of age, there is rapid autonomous development of sensory and motor neurons. Interneurons connect these by memory-mediated interventions, resulting in feedback controls.
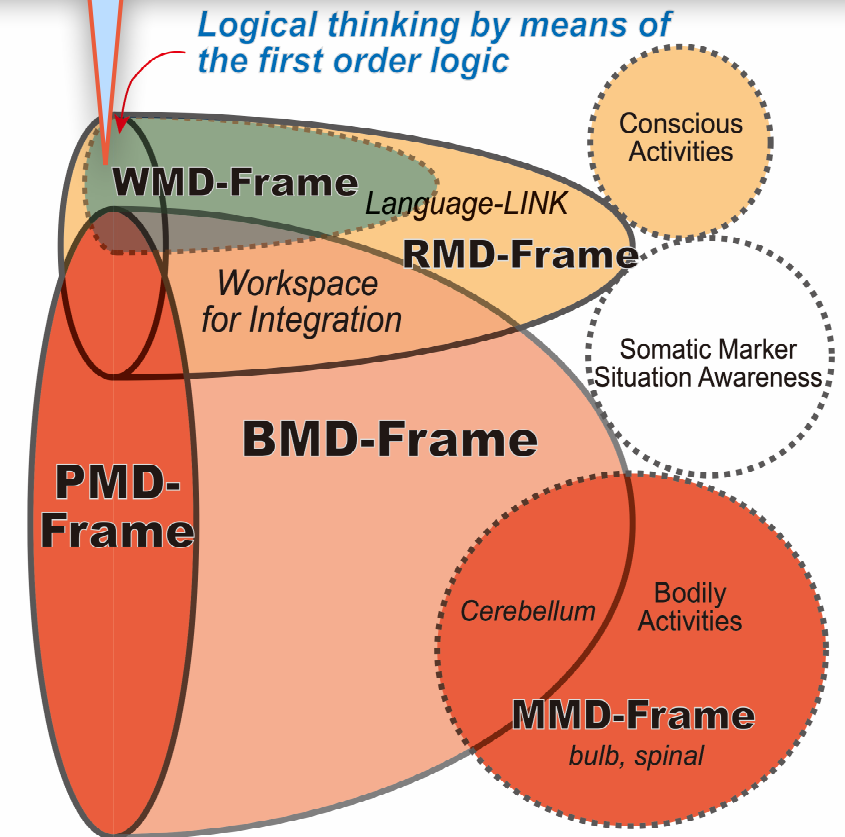
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During this period, human beings acquire the skill of first-order logical thinking by using letters or symbols and that of cooperation with other persons. These activities facilitate the development of interconnections among the multi-dimensional memory frames, resulting in very complex networks. 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.

Later, at 7 ~ 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.

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Stage 3 is very important for development

❖ Development of structure and procedure:
  - *Structural development precedes procedural development.*
  - ***Structural development***: *Referring 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.
  - ***Procedural development***: *Referring 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.
  - *Structural development and procedural development interact with each other in the RMD-frame occasionally and proceed in parallel.*
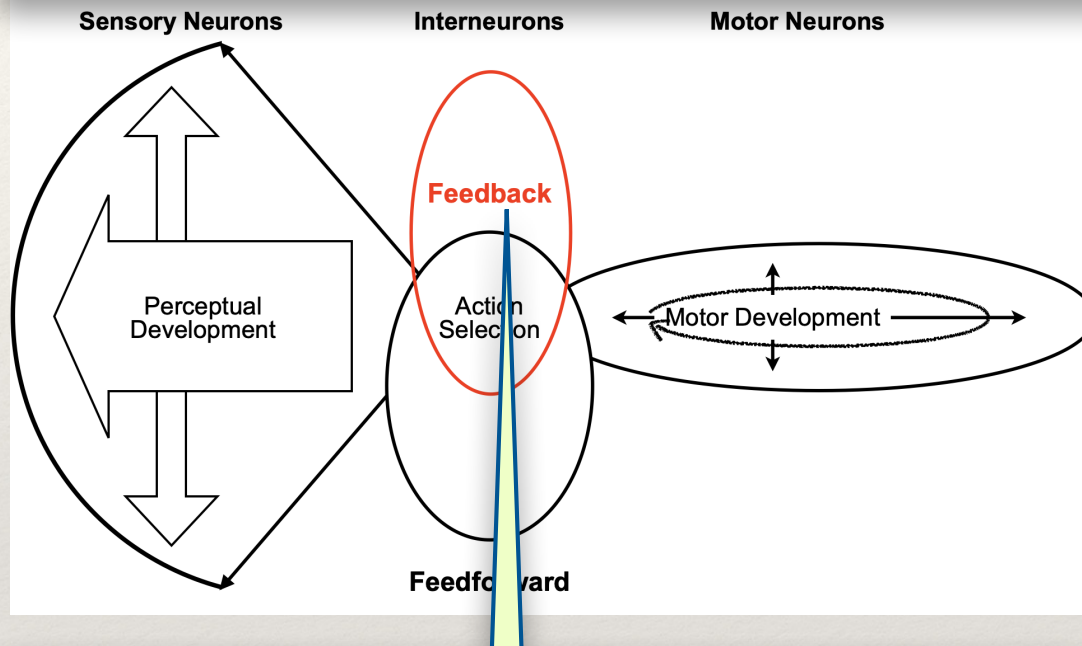
❖ Issue of reality:
  - *The connections between the contents in the WMD-frame and those in the RMD-frame give reality to the contents in the WMD-frame.*
  - *Structural development and procedural development interact with each other in the RMD-frame occasionally and in the RMD-frame give reality to the contents in the WMD-frame.*

❖ Procedural development in the RMD-frame is critical to extend the range of behavior.
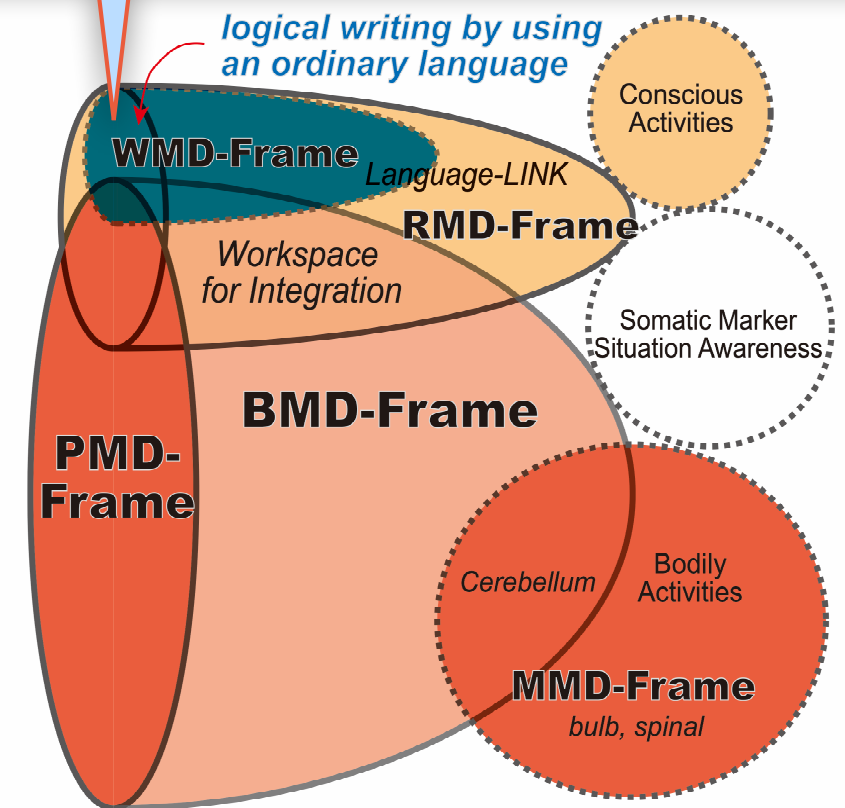 - *Once elements in the RMD-frame are compiled in the System 2 After mode, the compiled rule can be used to initiate a behavior with longer action steps.*

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Stage 4 of Co-development of PIM and Memory

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.

Sensory Neurons **Interneurons** **Motor Neurons**

Feedback

Perceptual Development

Action Selection

Motor Development

Feedforward

logical writing by using an ordinary language

WMD-Frame *Language-LINK*

Conscious Activities

RMD-Frame

Workspace for Integration

Somatic Marker Situation Awareness

BMD-Frame

PMD-Frame

Cerebellum Bodily Activities

MMD-Frame *bulb, spinal*

Finally, at age 13 ~ 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.

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Summary: PIM Development Process

Stage	Age	Speed of Autonomous Development		Method for Establishing Connection	Resulting Control Mechanism
		Perception	Motion	Interneurons	
1	0~3	Rapid	Rapid	subordinate	Feedforward control
2	4~6	Fast	Fast	memory-mediated	Limited feedback control
3	7~12	Stable	Stable	memory-mediated-proactive	Wide feedback control
4	13~18	Settled	Settled	memory-mediated-autonomous	Extended feedback control

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Two Important Implications

❖ **Is Autism Spectrum Disorder (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].
    - 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.
- *Individuals with ASD have difficulties with imitation:*
    - 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.
- *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].*
- *ASD could be characterized by abnormal development of these mappings and that of resonance mechanisms.*

❖ **Autonomous development of the WMD-frame at the later stage of development can cause reality problems.**

- *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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Conclusions

❖ The resonance mechanism in generating actions:

- *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, the PCM system and the memory system interact with each other via a resonance mechanism.*

❖ This paper showed:

- *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.*
- *The role played by resonance in the PCM processes defined by the MHP/RT.*
- *How artifacts are maintained over time and space with the help of resonance.*
  - The artifacts include objects created by humans, i.e., artifacts such as symbols, manners, language, and culture.
- *A necessary condition for the survival of artifacts is that they resonate with human beings.*
- *Resonating entities in memory are structured as memes at the action-level, behavior-level, and culture-level.*
- *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.*

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