

BICA2014 Three Papers ***Muneo Kitajima & Makoto Toyota***

- **Paper 15**

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

- **Paper 16**

- *Topological considerations of memory structure*

- **Paper 18**

- *The role of consciousness in memorization: Asymmetric functioning of consciousness in memory encoding and decoding*

- We have three papers for the BICA conference.
 - ▶ Paper 15: Hierarchical structure of human action selection – An update of Newell's time scale of human action
 - ▶ Paper 16: Topological Considerations of Memory Structure
 - ▶ Paper 18: The role of consciousness in memorization: Asymmetric functioning of consciousness in memory encoding and decoding
- These three papers are mutually related because each is built on a common cognitive architecture.
- So, in order to make my talk organized, I'd like to start by explaining the common cognitive architecture, and then describe each paper.



Outline of the Talk

- **Part 1: The basis of the studies**

- *NDHB-Model/RT on O-PDP*

- NDHB-Model/RT : Nonlinear Dynamic Human Behavior Model with Realtime Constraints
 - O-PDP : Organic Parallel Distributed Processing
 - <http://oberon.nagaokaut.ac.jp/ktjm/organic-self-consistent-field-theory/index.html>

- **Part 2: BICA2014 papers**

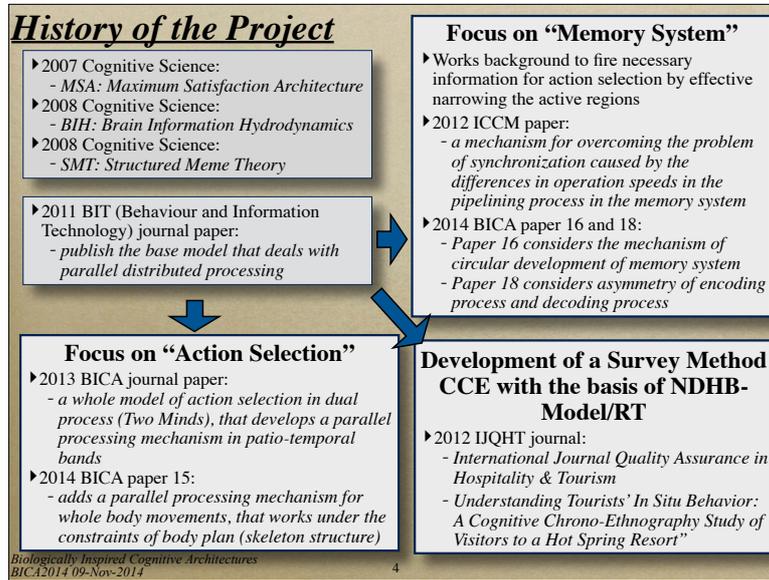
- *With the focus of their relationships with NDHB-Model/RT*

- Here is the outline of my talk.
- At first, I'd like to explain the basis of the studies, which is Nonlinear Dynamic Human Behavior Model with Realtime Constraints implemented on Organic Parallel Distributed Processing.
- This is the outcome of twelve years of collaboration of Makoto Toyota and myself.
- The purpose of collaboration is to extend Alan Newell's unified theories of cognition and this model is its result.
- The BICA2014 papers are the final pieces to make it complete.



Part 1: NDHB-Model/RT under O-PDP





- Here is the history of the development of the project.
- We published three core theories, MSA, Maximus Satisfaction Architecture, BIH, Brain Information Hydrodynamics, and SMT, Structured Meme Theory, at the annual meetings of Cognitive Science Society in 2007 and 2008.
- In 2011, we published an article from BIT concerning the base model that deals with parallel distributed processing which is the basis of our theory.
- The BIT study was extended in three directions.
- One is with the focus on action selection in which a BICA journal paper was published and one paper for this conference is related with this direction.
- The other is on memory system and two papers for this conference are related with this direction.
- And the other is development of a survey method, CCE or Cognitive Chrono-Ethnography with the basis of the model, a journal article is published from International Journal of Quality Assurance in Hospitality & Tourism.



O-SCFT: Organic Self-Consistent Field Theory

- **SCFT: Self-Consistent Field Theory in Physics**

- *In physics, self-consistent field theory studies the behavior of large and complex stochastic models by studying a simpler model.*

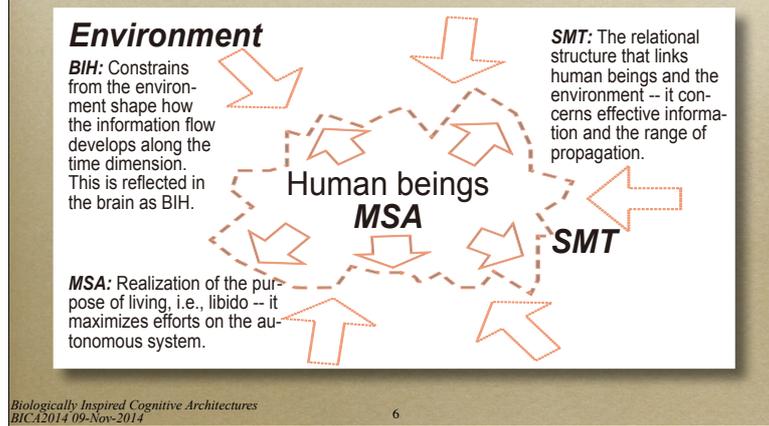
- **O-SCFT: “Organic” Self-Consistent Field Theory**

- *Organic systems are comprised of human beings as their components. Any organic system can be represented as a model that considers a large number of interacting individual human beings which interact with each other.*

- *The behavior of human-beings in the universe is quasi-stable, not stable but develop or evolve triggered by some fluctuations, a feature of dissipative system – a fluctuation of the system caused by an environmental change would trigger creation of a new order or catastrophe.*

- We have constructed the theories, that should extend Newell’s unified theories of cognition in a principled way. The base principle is self-consistent field theory. This theory is about physical phenomena but we applied it to organic phenomena due to a significant resemblance.
- In physics, self-consistent field theory studies the behavior of large and complex stochastic models by studying a simpler model. Such models consider a large number of small interacting individual components which interact with each other. The effect of all the other individuals on any given individual is approximated by a single averaged effect, thus reducing a many-body problem to a one-body problem.
- We applied it to organic systems. Organic systems are comprised of human beings as their components. Any organic system can be represented as a model that considers a large number of interacting individuals which interact with each other.
- We consider that the behavior of human-beings in the universe is quasi-stable, which means that it is not stable but develop or evolve triggered by some fluctuations, a feature of dissipative system – a fluctuation of the system caused by an environmental change would trigger creation of a new order or catastrophe.
- ■
- In addition, individual “organic” human beings interact with “inorganic” physical environment as well, which is modeled by self consistent field theory. We prefixed the word “organic” to SCFT in order to explicitly indicate that the application domain of SCFT is extended to organic systems.

Human beings considered in O-SCFT: MSA, BIH, and SMT



- At the zeroth-order approximation of O-SCFT, each human being interacts with the integrated environment consisting of inorganic components and organic components.
- Each human being is considered as autonomous system, and interaction is best represented by information flow from the view point of human being.
- This figure shows three nonlinear constructs.
- MSA, which corresponds to human beings.
 - It is about realization of the purpose of living, i.e., libido – it maximizes efforts on the autonomous system.
 - It deals with how autonomous systems achieve goals under constraints defined by BIH and SMT.
- BIH, which corresponds to inorganic SCFT components.
 - Constrains from the environment shape how the information flow develops along the time dimension.
 - This is reflected in the brain as Brain Information Hydrodynamics, BIH.
 - It deals with information flow in the brain and its characteristics in the time dimension.
- And SMT, which corresponds to organic Organic-SCFT components.
 - It is the relational structure that links human beings and the environment.
 - Structured Meme Theory, SMT, concerns effective information and the range of propagation.



O-PDP: “Organic” Parallel Distributed Processing

- MSA, BIH, and SMT with the focus on information flow in the brain
- O-PDP develops cross-networks of neurons in the brain as it accumulates experience of interactions in the environment
- The neural network development process is circular
 - Meaning that any experience at a particular moment should reflect somehow the experience of the past interactions that have been recorded in the shape of current neural networks
- O-PDP system is organized evolutionally
 - Realized as a neural network system, including the brain, the spinal nerves, and the peripheral nerves

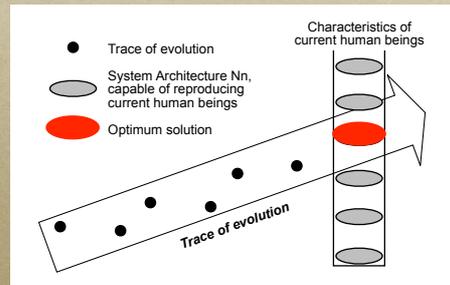
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- We are interested in not only how individual human being's brain processes information but also how it develops from his/her birth. We have been challenging this problem under MSA, BIH, and SMT.
- We focus on information flow in the brain. We considered that PDP is the fundamental mechanism for developing brain architecture. As we consider PDP under Organic-SCFT, we prefixed “O (organic)” to PDP.
- Organic-PDP develops cross-networks of neurons in the brain as it accumulates experience of interactions in the environment. The neural network development process is circular, which means that any experience at a particular moment should reflect somehow the experience of the past interactions that have been recorded in the shape of current neural networks.
- In this way, an O-PDP system is organized evolutionally, and realized as a neural network system, including the brain, the spinal nerves, and the peripheral nerves.

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Architecture Selection: The Guideline



It is quite reasonable to consider the one as the optimum solution that resides at the intersection of the trace of evolution of human beings and the system architectures that are capable of reproducing the characteristics of current human beings.

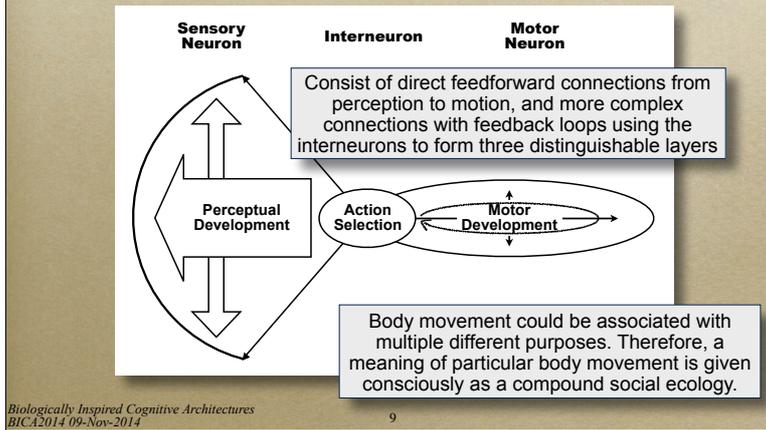
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- This slide shows the guideline we adopted for constructing an architecture model.
- Organic-PDP represents the working of the entire organic system, in which a number of autonomous systems function in the ever-changing environment.
- The strong constraint is that an Organic-PDP evolves over time for millions of years in the largest scope, and develops from one's birth in the one-generation scope in the environment of Gaia.
- It is likely that a number of architectures could explain the behavior of human beings in the current status of Gaia. However, we aimed at constructing one that should be consistent with the evolution history of human beings as well.
- It is quite reasonable to consider the one as the optimum solution that resides at the intersection of the trace of evolution of human beings and the system architectures that are capable of reproducing the characteristics of current human beings.

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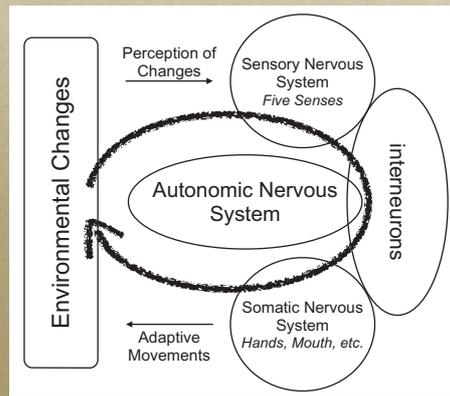
Evolutional Consideration: *Sensory-, Inter-, and Motor-Neurons*



- As Swanson explains, cross-networks of neurons in the brain develop in a systematic way to show three-layered structure of interneuron 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. 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 environment. A motion is executable when it is exerted with stable postures, 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.



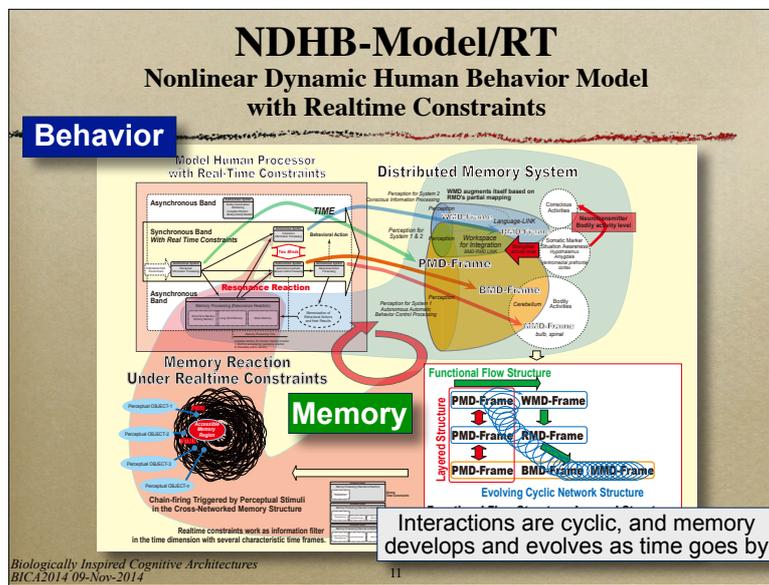
Continuous cyclic loop of perception and movement



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- According to Damasio, 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.
- 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.
- ■
- 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.



- Pushing this further, we have developed NDHB-Model/RT as an architecture model that consists of a behavioral processing system and a memory processing system that interact with each other as autonomous systems.
- The interactions are cyclic, and memory develops and evolves as time goes by.
- I focus on the behavioral processing system first.
- ■
- We have published a series of studies that focus on the details of the structure of respective systems, their functioning, and their characteristics. A number of theories have been constructed as the project develops.

MHP/RT: Model Human Processor with Realtime Constraints

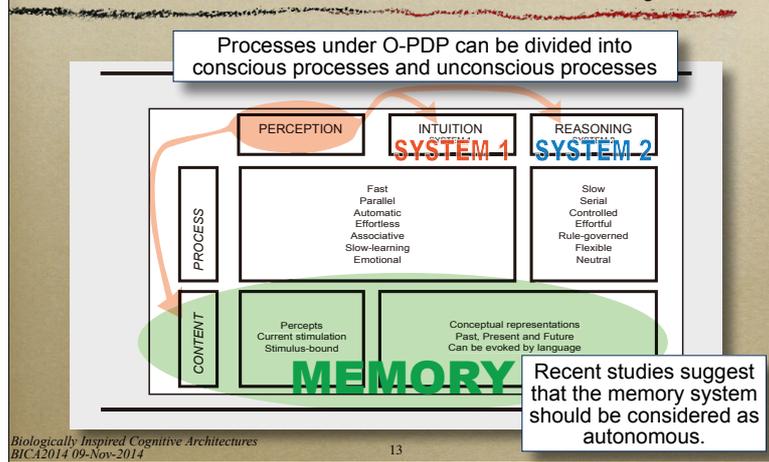
*An Implementation of NDHB-Model/RT
with Two Minds and Autonomous Memory System with the
focus of decision making and action selection*

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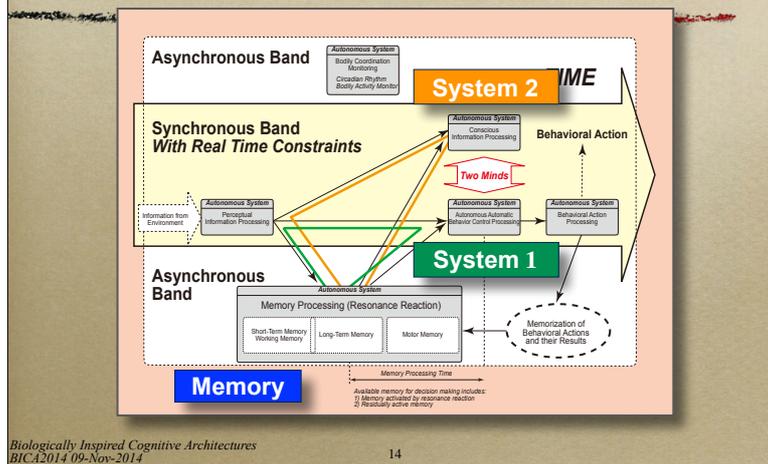
- We have developed an architecture model MHP / RT as an implementation of NDHB-Model / RT.
- It is capable of simulating decision making and action selection in daily life, consisting of Two Minds, i.e., conscious processes, System 2, and unconscious processes, System 1, and an autonomous memory system.
- MHP / RT focuses on synchronization between System 1 and System 2 in the information flow under Organic-PDP.
- ■
- In other words, MHP / RT deals with one aspect of working of NDHB-Model / RT, which is synchronization between conscious system and unconscious system in the ever-changing environment where human-beings make decisions and action selections to behave properly.

Two Minds (Kahneman, 2003) and Autonomous Memory



- Processes under Organic-PDP can be divided into conscious processes and unconscious processes.
- The first type of process, System 1, is a fast feed-forward control process driven by the cerebellum and oriented toward immediate action. Experiential processing is experienced passively, outside of conscious awareness.
- In contrast, the second type of process, System 2, is a slow feedback control process driven by the cerebrum and oriented toward future action. It is experienced actively and consciously.
- Recent studies suggest that the memory system should be considered as autonomous.
- ■
- As Squire and Kandel (2008) write, unconscious memory establishes links to amygdala and is able to generate emotional response towards particular perceptual stimuli.
- This results in a great deal of strong active regions of memory, and therefore it is adequate to consider memory as a distinctive system.

MHP/RT: Model Human Processor with Realtime Constraints



- This slide shows the outline of MHP / RT.
- Green lines indicate the path associated with System 1.
- And orange lines indicate the one associated with System 2.
- At a given time, MHP / RT's state is considered from the viewpoint "which part of MHP / RT is working" or "how MHP / RT is working."
- ■
- It is a real brain model comprising of System 1's unconscious processes and System 2's conscious processes at the same level. 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.

Four Operation Modes

“Which part of MHP/RT is working”

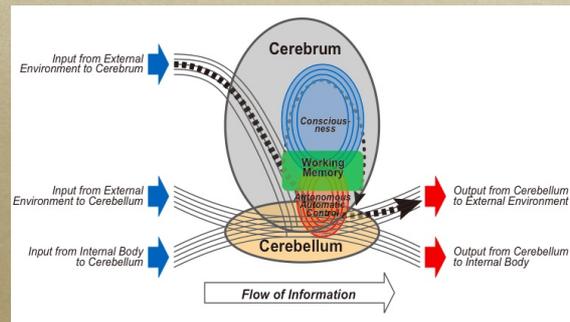
- Depending on the situation, behavior is driven mainly by either System 1 or System 2
- When both systems work synchronously by sharing working memory:
 - Mode 1: System 1 driven
 - Mode 2: System 2 driven
- In some situations, however, both work asynchronously:
 - Mode 3, System 1 and System 2 work asynchronously, working memory may be shared weakly
 - Mode 4; System 1 and System 2 work independently, working memory may be used separately

- In MHP/RT, behavior is the outcome of activities in System 1 and System 2 both of which use working memory to prepare for the next action.
- Depending on the situation, behavior is driven mainly by either System 1 or System 2.
- When both systems work synchronously by sharing working memory, there are two operation modes.
- System 1 driven mode and System 2 driven mode.
- However, in some situations, both work asynchronously, which is Mode 3, and working memory may be shared weakly
- Or both work independently, which is Mode 4, and working memory may be used separately.



Four Operation Modes

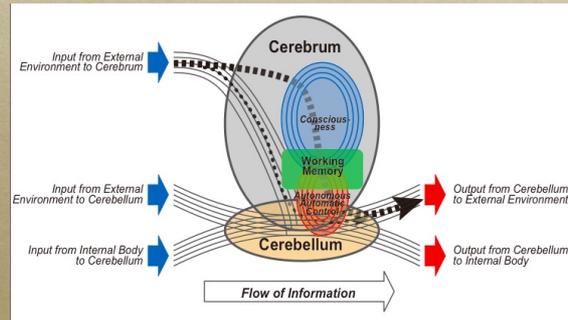
Mode 1



- When System 1 governs behavior, the updating rate of the cognitive frame is the fastest, and the system behaves unconsciously. The system refers to the memory that is activated via the resonance reaction, and the outcome of behavior is consciously monitored, which is System 2's mission in this mode.
- As long as the output of behavior is consistent with the representation of the contents of activated memory, or prediction, no feedback control is applied.
- No serious decision-making is required but a series of unconscious action selections would result in smooth behavior.
- ■
- An example of this behavior mode is riding a bicycle on a familiar road.

Four Operation Modes

Mode 2



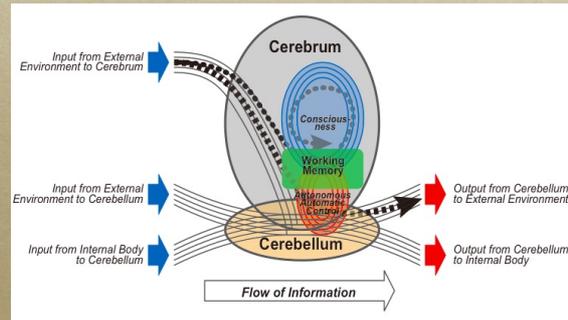
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- When System 2 governs behavior, the systems try to behave according to the image System 2 created **or meditated** with no bodily movement.
- The least resources are allocated for initiating behavior according to input from the environment.
- This corresponds to a situation in which the amount of flow of information in System 1 is small.
- Working memory is occupied by activities related to System 2.
- However, the sensory-information filter functions so that the system can react to a sudden interruption from the environment.
- ■
- (e.g., a phone call)

Four Operation Modes

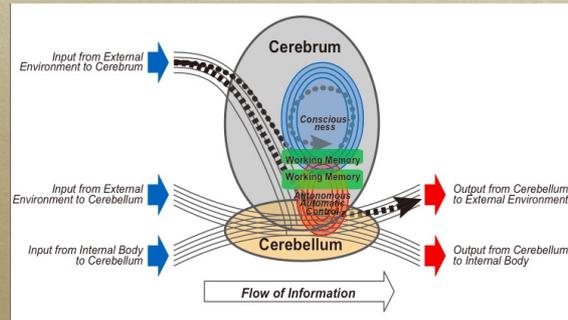
Mode 3



- In some cases, it is not necessary to monitor the behavior with high frequency.
- As a result, System 2 may initiate tasks that are not directly relevant to unconscious behavior.
- In such a situation, consciousness is free from behavior that is tightly embedded in the environment.
- This mode is characterized by weak coupling of System 1 and System 2, which means that pieces of information that reside in working memory are shared by System 1 and System 2, and therefore they could trigger the processes carried out by System 1 and System 2.
- For example, while waiting for his/her name called in a lobby of a hospital, he/she may read a book.
- ■
- In this case, at the time when his/her name is called, he/she would be able to stand up immediately to start walking to the consultation room.
- In his/her working memory, the pointer to the action would be kept active while reading a book and waiting for the announcement.
- And then, Mode 1 or Mode 2 takes over the operation.
- The shared information originates from perceptual encodings of the environment.

Four Operation Modes

Mode 4



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- In other cases, System 2 would initiate an independent process than System 1 is currently engaging.
- For example, he/she may use a mobile phone to talk with a friend while riding a bicycle, in which he/she might think deliberately to provide topics to enjoy conversation.
- In this case, his/her working memory would be used for two independent processes; talking with the friend over phone and riding bicycle safely.
- When encountering a dangerous situation, the system needs to take care of it primarily, which means that he/she needs to quit the phone conversation and uses his/her working memory for controlling bicycle.
- Switching the part of memory used for the phone call to the bicycle ride would cause a certain amount of delay in action.
- This mode is characterized by isolation of System 1 from System 2, which means that each uses different portion of working-memory for the respective processes.
- ■
- System 2 could be either totally detached from System 1, e.g., daydreaming, or in the deliberate thinking mode like Mode 2, in which System 2 mainly controls behavior and System 1 works under the control of System 2 by using the area of working memory for this process.
- Mode 3 and Mode 4 are similar because the process System 1 takes control and the one initiated by System 2 are carried out quasi-independently, but they are different in terms of the usage of working memory, i.e., Mode 3 has the area in working memory that holds information available to the two processes but Mode 4 does not.

Four Processing Modes “How MHP/RT is working”

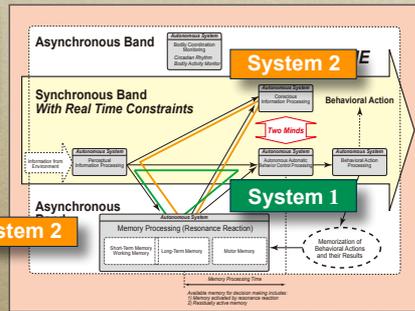
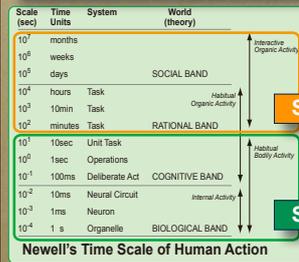
- **Decision making and action selection along the time dimension**
- **Event as the object for decision making and action selection**
 - *For MHP/RT, an event corresponds to a point on the time dimension where it can make decisions on selecting an action from the alternatives under a specific environmental condition.*
 - *The environment makes chaotic changes, and human beings, modeled by MHP/RT, are required to develop an adaptive system that is capable of dealing with a set of events that happen in such an environment.*

- We are interested in decision making and action selection along the time dimension.
- It is important to introduce the concept of event for considering basic processing modes of MHP/RT.
- Event is the object for decision making and action selection.
- For MHP/RT, an event corresponds to a point on the time dimension where it can make decisions on selecting an action from the alternatives under a specific environmental condition.
- The environment makes chaotic changes, and human beings, modeled by MHP/RT, are required to develop an adaptive system that is capable of dealing with a set of events that happen in such an environment.



Four-Processes and Time Constraints

At a particular time before/ after the event, one engages in conscious processes and unconscious processes concerning the event.

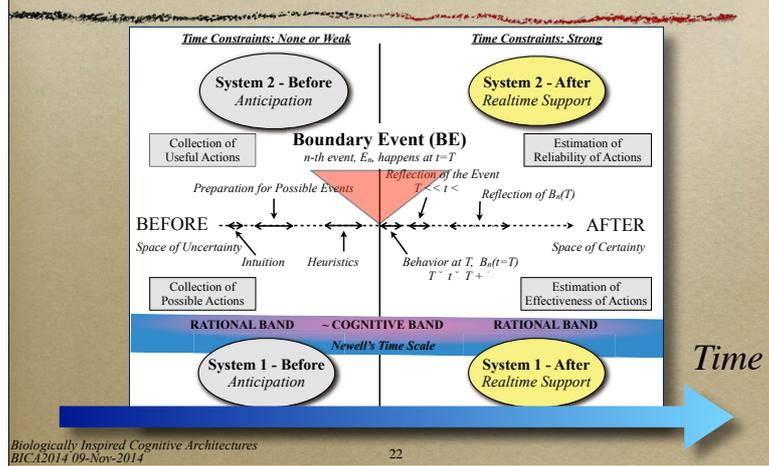


What one can do before and after the event is strongly constrained by the Newell's time scale of human action.

- At a particular time *before* the event, one engages in conscious processes and unconscious processes concerning the event to happen in the future.
- At a particular time *after* the event, one engages in conscious processes and unconscious processes concerning the event that has already happened in the past.
- What one can do before and after the event is strongly constrained by the Newell's time scale of human action.
- System 2 carries out the processes surrounded by an orange **round-cornered** rectangle, whereas System 1 does those surrounded by a green one.

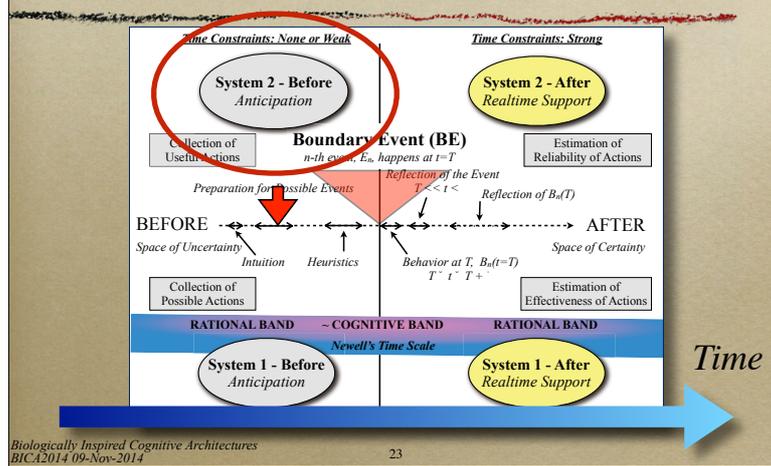


How the Four Processing Modes Work



- This slide illustrates the Four Processing Modes along the time dimension expanding before and after the event.
- At each moment along the time dimension human behaves in one of the four processing modes and he/she switches among them depending on the internal and external states.
- There are four processing modes:
- ■

How the Four Processing Modes Work



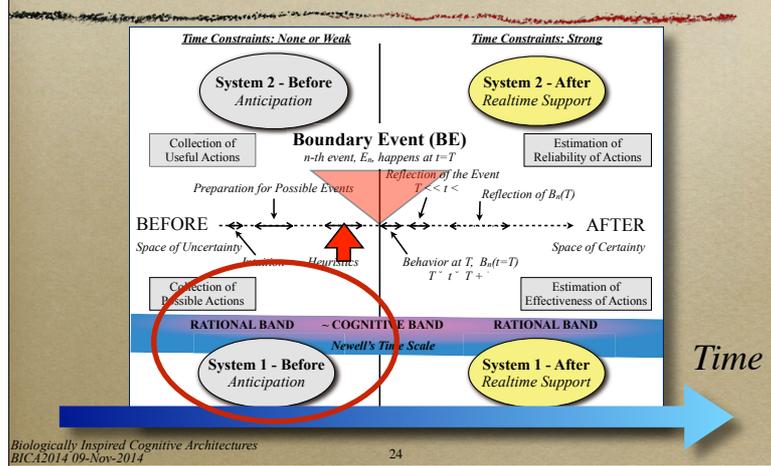
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- System 2 Before Mode:
- In this mode, long-term memory or knowledge is used consciously before the event.
- System 2 operates for anticipating the future event, or it engages in decision-making.

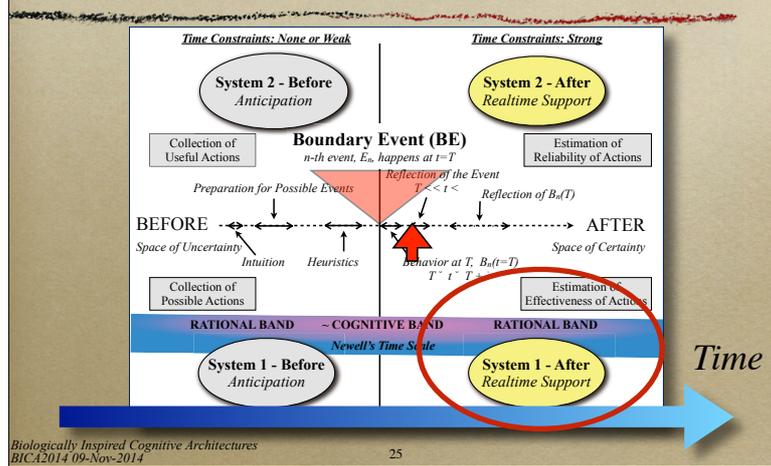


How the Four Processing Modes Work



- System 1 Before Mode:
- In this mode long-term memory is used unconsciously before the event.
- System 1 operates for automatic preparation for the future event, or it carries out action selection.
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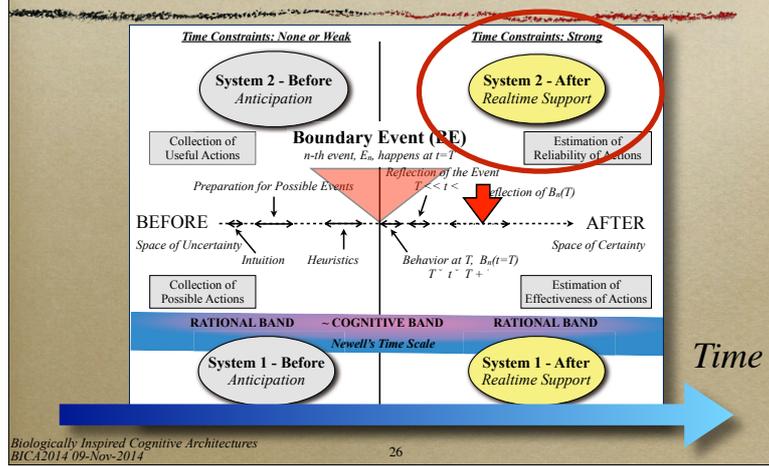
How the Four Processing Modes Work



- System 1 After Mode:
- In this mode long-term memory is used unconsciously after the event.
- System 1 operates for automatic tuning of long-term memory related with the past event.

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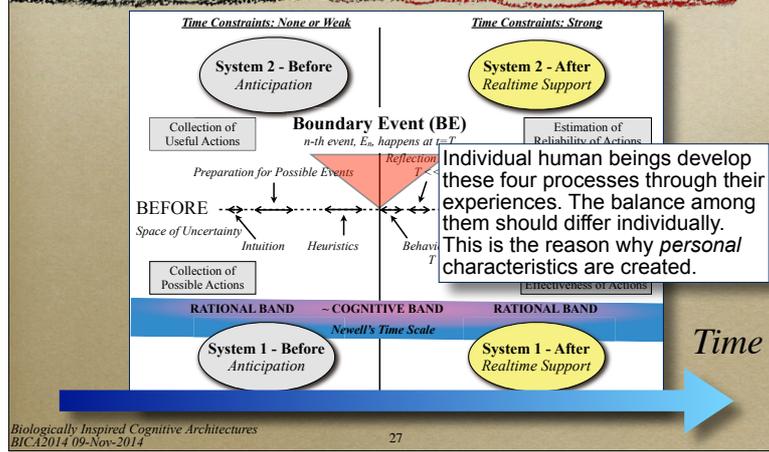
How the Four Processing Modes Work



- System 2 After Mode:
- In this mode long-term memory is used consciously after the event.
- System 2 consciously reflects on the past event.

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How the Four Processing Modes Work



- Individual human beings develop these four processes through their experiences.
- The balance among them should differ individually.
- This is the reason why *personal* characteristics are created.



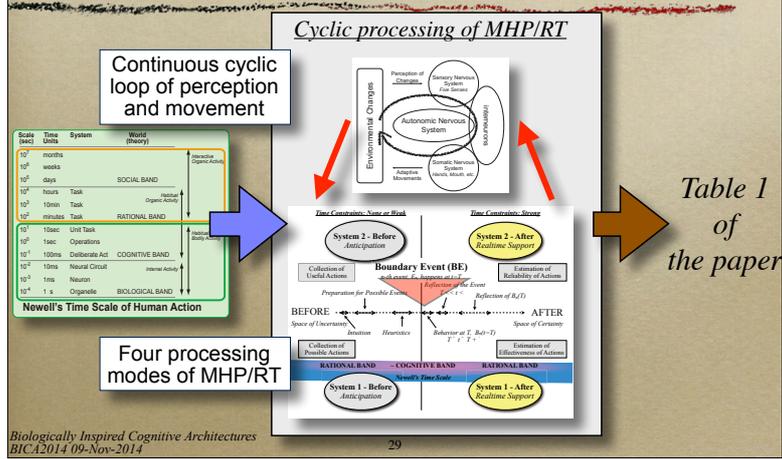
Part 2-1: Hierarchical structure of human action selection – An update of Newell’s time scale of human action

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.

- I’ve explained how human behavior is considered in an Organic-PDP framework and introduced a [cognitive architecture model](#) MHP/RT as a behavioral processing system in it.
- MHP/RT *operates* in one of the four operation modes and *processes* a particular event in the four processing modes.
- This particular BICA2014 paper views how Organic-PDP works at a specific fixed point of time by updating Newell’s time scale of human action.



Updating Newell's time scale of human action



- This slide shows the policy of the updating.
- We reconsider Newell's time scale of human action by integrating "continuous cyclic loop of perception and movement" and "four processing modes of MHP/RT"
- In the course of development, interneurons system 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 in memory.
- MHP/RT creates this memory in its after event processing modes, and uses in its before event processing modes.
- A series of events one has experienced from his/her birth to the present has accumulated circularly.
- By considering this way, Newell's time scale of human action is translated into another classification scheme as shown by Table 1 in the paper.
- ■
- Suppose you have just made a right turn at a certain intersection. This right-turn event is carried out at the time frame around T_{event} . In addition, in relation with the event at T_{event} , we can define the time frame Before-the- event locating somewhere on the time line extending from T_{event} to the past, and After-the-event locating somewhere on the time line extending from T_{event} to the future. The extent of the past could become very far beyond one's life from the birth considering the nature of inheritance of memory as the form of artifact (Stiegler, 2008).
- MHP/RT works continuously along the time dimension for the series of events.
- Newell's time scale of human action, in which human activity is classified by different levels

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	Vison-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

- It shows three layers that correspond to Newell's time scale of human action, and the nature of neural networks associated with the respective layers.



Three Layers of Interneurons System

- **Two layers in the autonomous automatic behavior control processing, both of which controlled by feedforward loops**
 - *Level-1: Associated with reactive activities carried out by the spinal nerves characterized by automatic and simple reflexive movements*
 - *Level-2: 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**
 - *Level-3: Associated with activities carried out by the frontal lobe and the cerebrum characterized by deliberate movements*

- Interneurons system is organized in three layers.
- Direct feedforward connections from perception to motion, and more complex connections with feedback loops using the interneurons to form three distinguishable layers.
- There are two layers in the autonomous automatic behavior control processing, both of which are controlled by feedforward loops.
- The first layer is associated with reactive activities carried out by the spinal nerves characterized by automatic and simple reflexive movements.
- 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.
- The third layer is associated with activities carried out by the frontal lobe and the cerebrum characterized by deliberate movements.



Developmental Paths

- **Early stage: 0 ~ 6 years of age**
 - *Feedforward loops are the dominant control mechanism*
 - *0 ~ 3 years of age:*
 - Establishes inter-connections between Layer-1 and Layer-2
 - *4 ~ 6 years of age:*
 - Acquires the skill of behaving in relation with the other persons
- **Middle stage: 7 ~ 12 years of age**
 - *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*
 - *Key is the existence of symbols that intervene various connections between input and output*

- The paper explains the developmental paths of the neural networks as human beings grow as the function of their ages.
- In 0~6 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, 0~3 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, **4~6 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.
- Later, in 7~12 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.



Developmental paths

◦ Later stage: 13 ~ 18 years of age

- *Feedback loops come into play, which are used to form language processing circuits in a single layer, Layer 3*
- *Interconnections of the neural networks evolve among the three layers*
 - Ability of logical writing by using an ordinary language affects significantly the evolving process
 - Without language, structural recognition is formed dominantly via visual information
 - 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~ years of age

- *Feedback loops become dominant, which make possible to form a compound language processing circuits*

- In 13~18 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 13~18 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.
- 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](#).



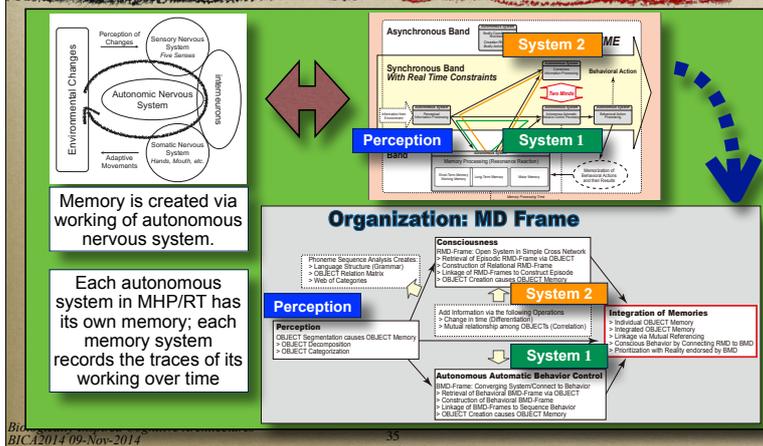
Part 2-2: Topological Considerations of Memory Structure

Abstract: The human memory system is an integration of three distributed memory systems associated with respective autonomous organic systems; the perceptual system that takes care of sensory input from the environment, the conscious system that performs deliberate decision making, and the unconscious system that carries out action selections in the environment. The memory system works as a memory component in the comprehensive brain model, MHP/RT (Kitajima & Toyota, 2013), which is capable of simulating human daily behavior considering the real time constraints that should define strong mutual dependencies among the three systems. This paper reconsiders MHP/RT's memory system by mapping it on the real interconnections between the cranial nerves and the spinal nerves to obtain a topological representation of the distributed memory system.

- This [BICA2014](#) paper views how memory is created under Organic-PDP with the cognitive architecture, MHP / RT.

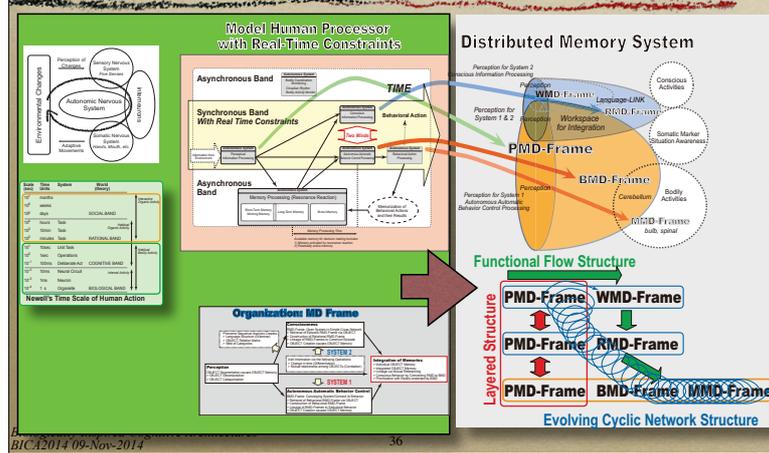


Memory Structure: MD Frame



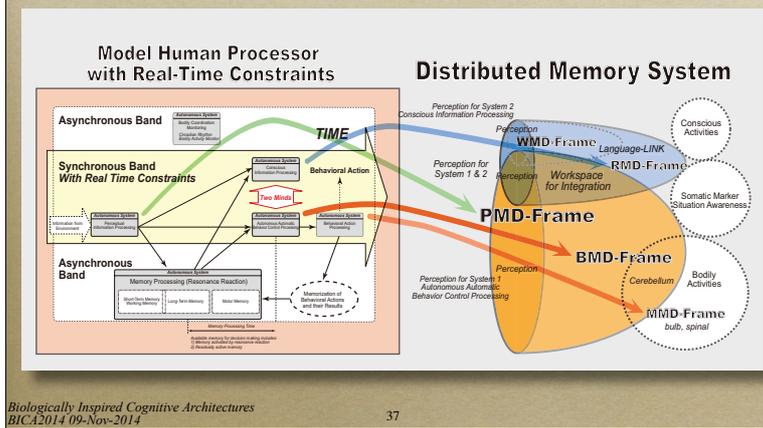
- At the baseline, memory is created via working of autonomous nervous system that operates along the information flow from the sensory nervous system to somatic nervous system via interneurons under the time constraints that would reflect the environmental conditions at the time of operation.
- To begin with, we can derive structural features by considering the fact that each autonomous system in MHP/RT has its own memory; **each memory system records the traces of its working over time.**
- Therefore, the human memory structure is modeled conceptually as shown here.
- MHP/RT assumes that memory is organized by Multi-Dimensional Frame for storing information.
- As the main modules, MHP/RT consists of perceptual system, conscious processing system, and unconscious processing system.
- This illustrates memory systems associated with these main modules.
- In addition, memories are added that are created by integrating individual memories associated with System 1 and System 2, respectively.
- Pushing this argument further by considering Newell's time scale of human action, we can layout topologically the memory systems associated with respective autonomous systems of MHP/RT as shown in the next slide.
- ■
- , and that is created by analyzing phoneme structures associated with language activities

Memory Structure



- They reflect the following facts:
- 1) unconscious processing is several order of magnitude faster than conscious processing, 2) both are often times initiated by the common perceptual input, and 3) they must interact with each other to exhibit coherent activities at the moment.
- Somatic markers that associate respective memories with rewards have strong effect on the behavior of memory system.
- The figure on the top-right shows respective memory systems that interact with each other and the figure on the bottom-right shows their relationships along the time dimension.
- The somatic nervous system that leads to BMD is created autonomously under the constraints defined by the mutual relationships among nerves, muscles and skeletons.
- This determines what is written in the memory.
- ■
- The entire memory system is topologically represented by these figures.
- This is used when reading information from memory, which determines actually read memory under the influence of reward and status of short-term memory.

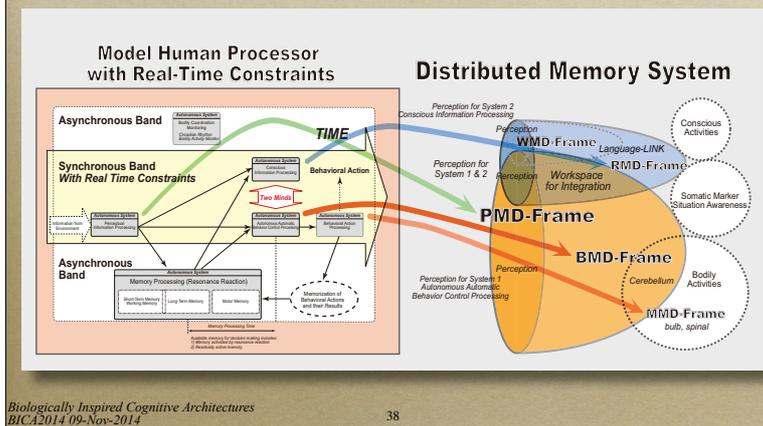
Multidimensional frame as a distributed memory system



- Here is how memory is constructed in detail.
- 1) Collecting information from the environment via perceptual sensors; 2) integrating and segmenting the collected information, centering on visually collected objects; 3) 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.
- Thus, when objects that are the result of the just-finished integration and segmentation 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) -frame.



Multidimensional frame as a distributed memory system



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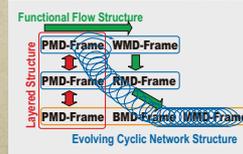
- PMD (Perceptual Multi-Dimensional)-frame constitutes perceptual memory as a relational matrix structure. It collects information from external objects followed by separating it into a variety of perceptual information, and re-collects the same information in the other situations, accumulating the information 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 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.

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Three Structures in MD-Frames

◦ Functional flow structure:

- Describes memory activation paths starting from PMD-frames to WMD-frame, RMD-frame, or BMD-frame to MMD-frame.
- Describes how perception triggers motions.
- MMD-frame is the terminal MD-frame and therefore the paths from WMD-frame to RMD-frame, and RMD-frame to BMD-frame exist.



◦ Layered Structure

- PMD-frame — WMD-frame layer:
 - The top layer controlled by words. It consists of simple one-dimensional array of symbols, logically constructed language, grammars that specify language use, etc.
- PMD-frame — RMD-frame layer:
 - The middle layer that resides on the behavioral eco-network for the individual. In this layer, one acquires the meaning of behavior in the social ecology.
- PMD-frame — BMD/MMD-frame layer:
 - The bottom layer that creates a behavioral eco-network for the individual. This is a cyclic network starting from PMD-frame towards MMD-frame, and returning to PMD-frame.

◦ Evolving cyclic network structure

- Respective autonomous systems generate distributed memories for their use, and the memories are cyclically related and in effect topological.

- This figure illustrates how the MD-frames are interrelated by introducing three structures.
- The functional flow structure describes memory activation paths starting from PMD-frames to WMD-frame, RMD-frame, or BMD-frame to MMD-frame, which describes how perception triggers motions. Notice that MMD-frame is the terminal and therefore the paths from WMD-frame to RMD-frame, and RMD-frame to BMD-frame exist.
- There are three layers.
- The top layer, PMD-WMD-frame layer, is controlled by words. It consists of simple one-dimensional array of symbols, logically constructed language, grammars that specify language use, etc.
- The middle layer, PMD-RMD-frame layer, resides on the behavioral eco-network for the individual. In this layer, one acquires the meaning of behavior in the social ecology.
- The bottom layer, PMD-BMD-MMD-frame layer, creates a behavioral eco-network for the individual.
- This is a cyclic network starting from PMD-frame towards MMD-frame, and returning to PMD-frame. The evolving cyclic network structure, **depicted by** a blue spiral, refers to the fact that respective autonomous systems generate distributed memories for their use, and the memories are cyclically related and in effect topological.
- These three features enable pipelining the processes. This cyclic connection is critical to understand the relationship between behavior and memory.

Part 2-3: The role of consciousness in memorization: Asymmetric functioning of consciousness in memory encoding and decoding

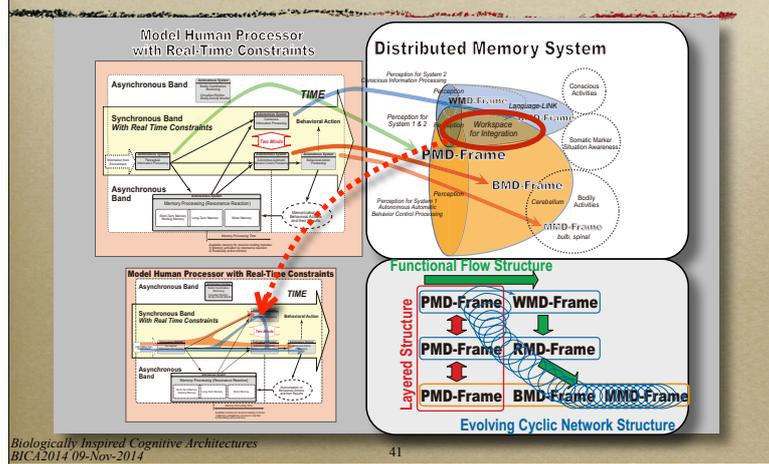
Abstract: ... this paper provides a deeper understanding of the role of consciousness in memorization, or memory encoding, based on MHP/RT, with the supporting empirical evidence consistent with the following prediction. MHP/RT assumes that decision-making and action selection should be controlled by Two Minds in general, and Four-Processes in detail. Four-Processes distinguishes the functioning of System 1 and 2 before and after an event. Four-Processes predicts that deliberate reflection of the past event using System 2 would create a memory encoding of the event that would be recallable in the future; on the other hand when the event is processed solely by System 1, it would create a memory encoding that is not consciously recallable via System 2 in the future. This paper provides evidence of the asymmetric functioning of consciousness in memory encoding and decoding that is consistent with this prediction from an experiment at a movie theater where the participants encoded the movies into their memories as they usually would do, and asked to decode them afterwards.

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- This [BICA2014](#) paper views what is actually written while encoding.
- [need to change]
- ■

Distributed Memory System



- This figure shows that activity traces of autonomous systems of MHP /RT create respective memories as MD-Frames.
- If the area indicated as “Work space for integration” is used for creating memory, it integrates multiple MD-Frames.
- Later, this integration enables a set of MD-Frames to make chain-firing when provided with similar perceptual stimuli. As shown by the green arrows, chain-firing goes from PMD to MMD via WMD, RMD, and BMD.
- This paper demonstrated that the integration happens in some cases but not in the others, by showing the results from observational field study at a movie theater.
- As would be easily understood, unless the integration, there is no activation paths to reach conscious level, **WMD-Frame**, from unconscious level, **MMD-Frame** or **BMD-Frame** and vice versa.

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Observational field study at SSF

Paper 18



- This observational study consisted of observation at the festival and follow-up retrospective interviews.
- The field observation was conducted at SSF2009, and the interviews were conducted a few weeks after the festival.
- The study was conducted to observe monitors' behavior at SSF.
- Study monitors participated in SSF in a manner that was typical of film viewers.
- Cognitive-Chrono Ethnography was adopted for this study to understand participants' behavior at the study site.
- Their activities were recorded during two 90-minute programs.
- Each monitor was required to attend two 90-minute retrospective interview sessions in the following month.
- The purpose of the interviews was to clarify participants' conscious memories that were active while carrying out the observed behavior.
- ■
- The SSF started in 2006 and is organized by the City of Sapporo, Hokkaido, Japan, and the SSF executive committee.
- This study involved the observation of study monitors while they watched short films at SSF2009.
- SSF is held annually in the autumn for one week in downtown Sapporo.
- SSF2009 was held October 14 through 18, 2009, and showed 103 short films organized into fourteen 90-minute programs.

Results

- **System 1's reaction**

- *Autonomic nervous system reaction*

- Some monitors exhibited similar autonomic nervous system reactions to the same program
 - M₅ and M₆ exhibited similar reactions while watching the programs

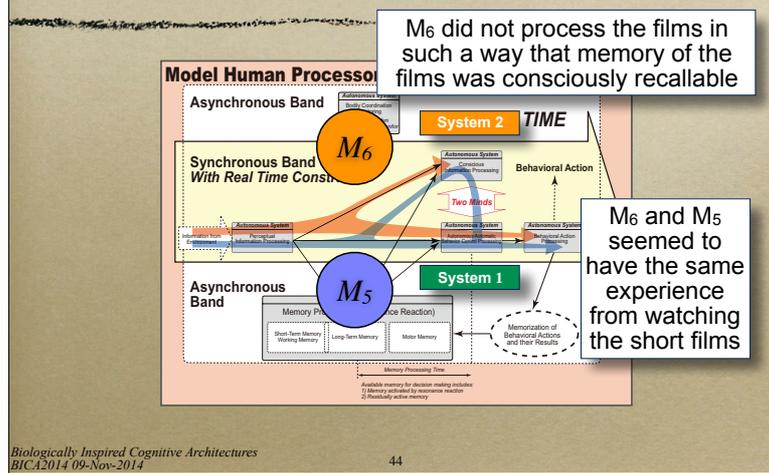
- **Memory of events**

- *M₆ barely remembered the contents*

- **They exhibited similar reactions while watching the programs, but they exhibited very different memory in their responses during the retrospective interviews.**

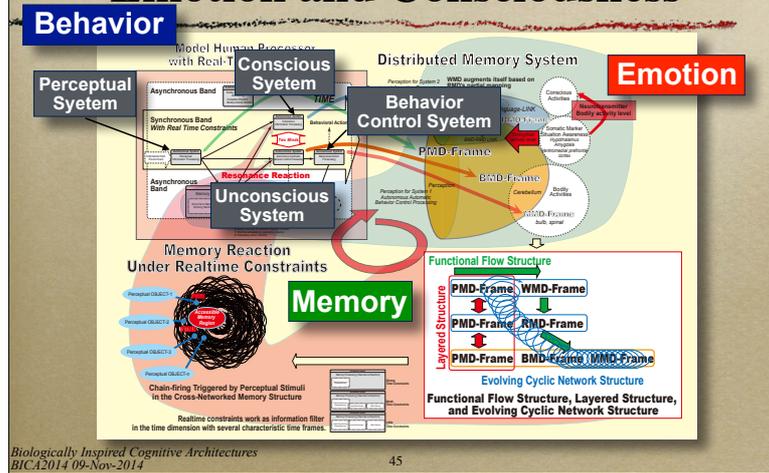
- Results of autonomic nervous system reaction
- Some monitors exhibited similar autonomic nervous system reactions to the same program.
- Results of Memory of events
- Tables in the paper briefly summarize how two study monitors, M₅ and M₆, remembered the short films they watched in program F-B.
- They exhibited similar reactions while watching the programs, but they exhibited very different memory in their responses during the retrospective interviews.
- M₆ barely remembered the contents.
- ■
- The electrocardiogram (ECG) of the study monitors while they were watching short films was measured. R-waves were detected from each ECG waveform. Time intervals between two successive R-waves (RR-intervals) were then calculated and recorded using a portable device (ActiveTracer, AC-301A, GMS, Japan). Instantaneous heart rate (HR) [bpm] was obtained by dividing 60 by the RR-interval. The human psychological condition affects autonomic nervous activity [6]. Therefore, HR increases with sympathetic nerve activation and decreases with parasympathetic nerve activation. The autonomic nervous activity is mainly affected by an individual's psychological state while watching films at a movie theater, since body movement is minimal. Moreover, since the strength of light and sound of environmental factors other than the films are stable and small in a movie theater, the main factor affecting the autonomic nervous activity would be the content of the films.

Four-Processes and Memory



- These findings can be reexamined from the viewpoint of Four-Processes and memory.
- The result of experiencing external events is directly expressed by autonomic responses, caused by the working of System 1.
- Therefore, M₆ and M₅ seemed to have the same experience from watching the short films.
- At the same time, the experience can be accompanied by another process, memorization, which forms the memory of the external events.
- At this point, they seemed to have processed the stimuli very differently: M₆ did not process the films in such a way that memory of the films was consciously recallable, whereas M₅ did.
- Based on MHP/RT simulation, it was predicted that the same experience for an event would not result in formation of the same memory trace.
- Because the experiencing an event in real time by decoding memory, and the formation of memory by encoding the event afterwards when needed are different processes performed by Two Minds.
- Possible differences in the working of Two Minds and in the contents stored in long-term memory affected the formation of memory of the event.
- ■
- The study monitors were instructed to watch short films and their behavior during the common experience were observed in order to find evidence that should support the prediction.

Conclusion: Behavior, Memory, Emotion and Consciousness



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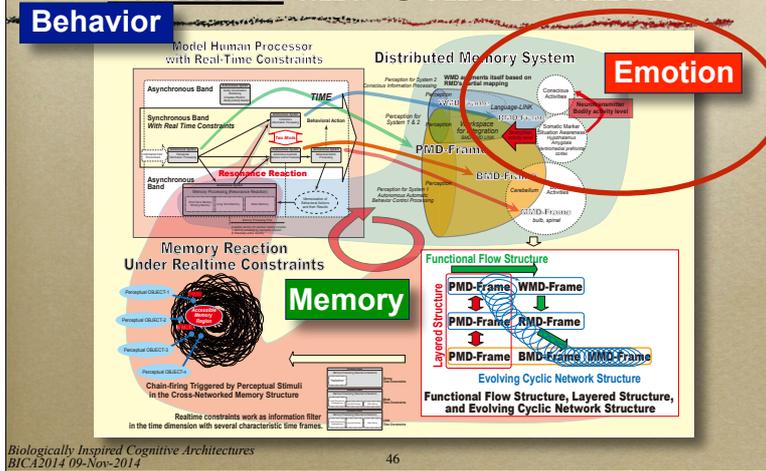
- I've talked about behavior in terms of four operation modes and four processing modes of MHP/RT, and memory that is created in the form of MD-Frames as interneurons develop and used circularly by MHP/RT.
- I'd like to conclude my talk by adding Emotion and consciousness.
- ■
- Figure 5 shows the fixed hierarchy in the behaviors accompanied with instinct of procreation through observation of behavior of *Nemipterus virgatus* (adapted from Swanson (2011)). Since the evolution of vertebrata is no more than history of increasing complexity, the results of any ecological analyses of emotions would tend to lead to thesaurus-like similar implicit structures.
- As Damasio (1999) put, consciousness is recognized for the first time.
- Feeling appears when the emotion is analyzed ecologically and recognized at the later time.
- A B

A B

RMD

A B

Conclusion: Behavior, Memory, Emotion and Consciousness

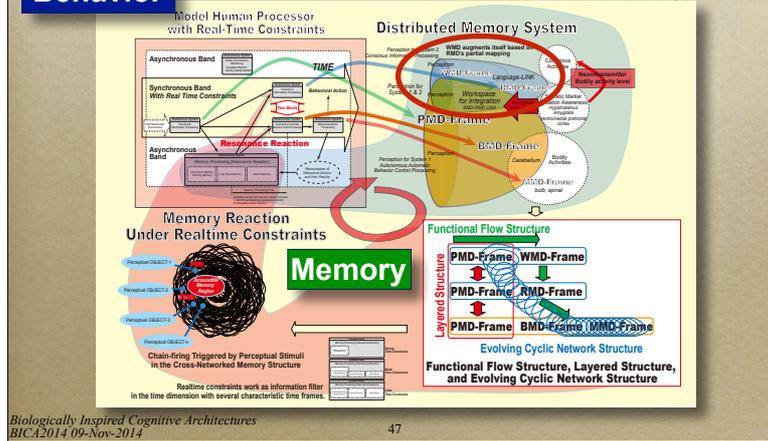


- Memory activation originates from perception and spreads in MD-frames.
- In normal operation, active memory regions are used for organizing behavior.
- For the conscious system, most active memory regions would connect to consciousness and have effect on conscious activities.
- For the unconscious bodily movement system, most active memory regions corresponding to respective body parts would directly guide action selections in parallel.
- *Somatic markers* directly guide the action selections that are carried out in a feedforward way.
- On the other hand, they have *indirect* effect on conscious activities by providing integrated information about the current status of the body via receptors of the conscious system where neurotransmitters' local density represents the integrated response to the current status of the body.
- This is emotion.
- In other words, emotion corresponds to the *inner* activities that coordinate conscious processes and unconscious processes to work coherently in the chaotic changing outer environment.



Conclusion: Behavior, Memory, Emotion and Consciousness

Behavior

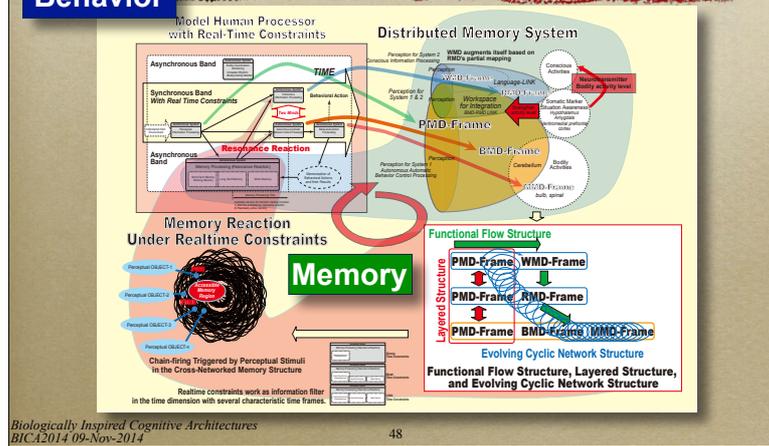


- In the MHP/RT's four processing modes, conscious processes can happen before the event and after the event.
- On the other hand, a series of events happen as time goes by, and each of which is processed by MHP/RT consciously or unconsciously.
- For the conscious processes, WMD-Frame and RMD-Frame are relevant and consciousness occurs at those levels.
- These frames are associated with perceptual MD-Frame.
- Consciousness is the phenomenon that connects WMD-Frame and RMD-Frame, and the connections are established via their relationships with BMD-Frame and MMD-Frame that are associated with the shared PMD-Frame.
- Considering this way, we can reach the conclusion that the phenomenon of consciousness is one aspect of the nature of memory system.



Conclusion: Behavior, Memory, Emotion and Consciousness

Behavior



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- Behavioral processes and memory processes interact with each other and circulate.
- Memory accumulates what one has experienced from his/her birth, but at the same time each piece of experience with objects in the environment could involve the memories associated with the objects.
- This circular system represents not only one's developmental path but also evolution of mankind.

