Two Minds and Emotion

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***Abstract*—Human behavior can be viewed as the integration of the outputs of Systems 1, i.e., unconscious automatic processes, and System 2, i.e., conscious deliberate processes. System 1 activates a sequence of automatic actions. System 2 monitors System 1's performance according to the plan it has created, and it activates future possible courses of actions as well. At the same time when these forward processes are working, System 1 and System 2 deal with the outcome of the forward processes by estimating the results of System 1's and System 2's performance, i.e., good or bad, and generating emotions depending on the degree of goodness or badness of the estimation. Emotions are generated through the dynamics of the parallel processing of System 1 and System 2, which is called O-PDP, Organic Parallel Distributed Processing. This paper discusses how emotion generation process is integrated with the Kahneman's System 1 and System 2 model of human decision-making.**

***Keywords*–Two Minds; Organic-PDP; Two Minds; Consciousness; Unconsciousness; Emotion.**

I. INTRODUCTION

Two Minds is the basis of behavioral economics founded by Kahneman [1][2]. It considers that Two Minds govern human decision-making: a human being's behavior is the outcome of two different systems including an experiential processing system, System 1, and a rational processing system, System 2. Figure 1 illustrates the workings of the two systems. In short, 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, e.g., one is seized by one's emotion. In contrast, System 2 is a slow feedback control process driven by the cerebrum and oriented toward future action. It is experienced actively and consciously, e.g., one intentionally follows the rules of inductive and deductive reasoning. However, traditional cognitive modeling has not treated human behavior as the result of intense interaction between System 1 and System 2. Indeed, traditional cognitive modeling has been primarily aiming at implementing and testing theories explaining behavior driven by rational, multi-step cognition. ACT-R [3][4] and Soar [5] are the most successful cognitive architectures in this direction. However, there are many human behaviors that seem to be driven by aspects of behavior that are not the same as rational cognition: emotional, intuitive, and other non-rational behavior. These aspects have not been addressed in these cognitive architectures adequately.

Recently, studies aiming at incorporating Two Minds into traditional cognitive modeling have emerged. For example, Kennedy and Bugajuska [6] presented computational cognitive models that take into account the interactions between conscious processes and unconscious processes. Their models implemented different strategies in the ACT-R cognitive architecture [7][4] to allow a human to consciously inhibit an undesirable fast response. ACT-R is a symbolic and subsymbolic, production-based cognitive architecture [3]. The internal modules of ACT-R represent relatively specific cognitive functions (and regions of the brain) including declarative and procedural memory (long-term memory), auditory and visual perception, and vocalization and motor functions.

This paper suggests another approach to incorporating Two Minds in cognitive modeling by stemming on the cognitive architecture, Model Human Processor with Realtime Constraints (MHP/RT), the authors have developed [8][9]. MHP/RT considers that human behavior in the real world occurs in such a way that the agent's next behavior is determined by a combination of the situation of the environment and that of the agent itself. Therefore, in order to simulate the processes of human behavior, it is necessary to explicitly include the real-time constraints that affect the synchronization of behavior selection. Neither Soar nor ACT-R was designed as an architecture model for simulating an agent's behavioral processes that evolve in synchrony with the environment where real-time constraints are the critical factors to organize the agent's behavior. The predictions made by these architecture models are derived essentially by linear algorithms that calculate the best paths for a sequence of behavioral selections [8].

As described in [9], this feature of MHP/RT should be contrasted with the goal-oriented cognitive architectures such as ACT-R [3][4] in which the conscious processes are considered as the processes to control people's behavior and the unconscious processes are considered subordinate to the conscious or intentional processes. What ACT-R tries to do is to show how System 2 can be implemented on top of System 1. The procedural memory system is very similar to System 1 (fast, learning based on rewards/experience, intuitive), and then ACT-R models tend to consist of a set of production rules that (when run on this System 1 module and in combination with symbolic working memory buffers and a long-term memory system) give rise to the slower, deliberative planning behaviors seen in System 2. This is a very different approach to MHP/RT. However, ACT-R models are totally adequate for simulating stable human activities with weak time constraint in which deliberate decision making would work effectively, but might be hard for the situations with strong time constraint where the environmental condition changes chaotically and deliberate decision making implemented on System 2 might not work as effective.

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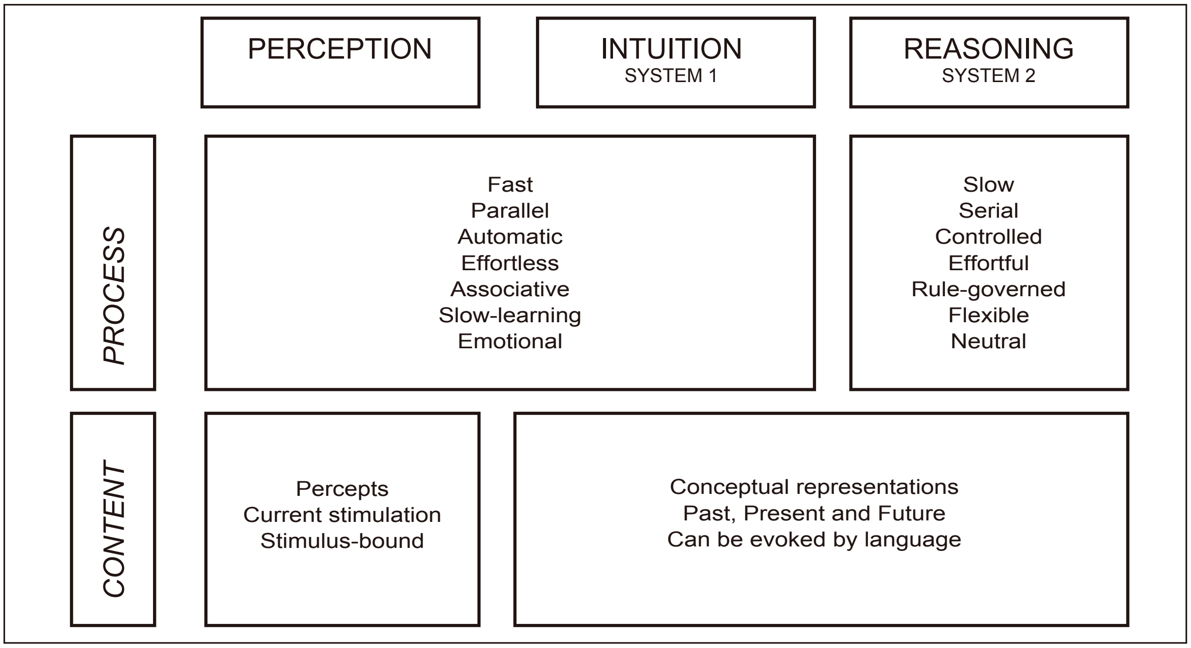

Figure 1. Process and Content in Two Cognitive Systems (adapted from [1]).

In summary, traditional cognitive modeling, including ACT-R or Soar based models, has not considered how System 1 and System 2 develop along the time dimension in synchronous with the ever-changing environment. Especially, the intense interaction between emotion in System 1 and consciousness in System 2 has not been considered appropriately due to the lack of proper treatment of the time dimension. This paper discusses how *emotion generation processes* are integrated with Two Minds on the basis of MHP/RT [8][9] and its superordinate model, the Nonlinear Dynamic Human Behavior Model with Real-Time Constraints (NDHB-Model/RT), that the authors proposed at the past Cognitive Science conferences [10][11][12].

This paper is organized as follows. In Section II, this paper starts by describing NDHB-Model/RT, followed by an explanation of dynamics of consciousness–emotion interaction based on NDHB-Model/RT in Section III. Section IV describes relationship between Two Minds and emotions, and Section V concludes the paper.

II. NDHB-MODEL/RT

The relationship between Two Minds and emotion is best understood by considering how behavior is generated in the time dimension. This section introduces some ideas to make it possible. First, it introduces two basic ideas, Organic Self-Consistent Field Theory (O-SCFT), and Organic Parallel Distributed Processing (O-PDP). Then it derives Nonlinear Dynamic Human Behavior Model with Realtime Constraints (NDHB-Model/RT), which is a framework for considering the behavior of human beings in the universe as defined by O-SCFT and O-PDP. Then, it introduces a cognitive architecture, Model Human Processor with Realtime Constraints (MHP/RT), that is capable of simulating human being's daily decision making and action selection under NDHB-Model/RT.

A. O-SCFT: Organic Self Consistent Field Theory

1) Self-Consistent Field Theory in Physics: In physics, self-consistent field theory (SCFT) 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. In field theory, the Hamiltonian may be expanded in terms of the magnitude of fluctuations around the mean of the field. In this context, SCFT can be viewed as the "zeroth-order" expansion of the Hamiltonian in fluctuations. Physically, this means an SCFT system has no fluctuations, but this coincides with the idea that one is replacing all interactions with a "self-consistent field." Quite often, in the formalism of fluctuations, SCFT provides a convenient starting-point to studying first or second order fluctuations.

2) "Organic" Self-Consistent Field Theory: We applied SCFT in physics to organic systems. Organic systems are those 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. In addition, individual *organic* human beings interact with *inorganic* physical environment as well, which is modeled by SCFT. We prefixed the word "Organic" to SCFT in order to explicitly indicate that the application domain of SCFT is extended to organic systems. 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 [13].

3) Human beings considered in O-SCFT: At the zeroth-order approximation implied by O-SCFT, each human being interacts with the integrated environment consisting of inorganic components and organic components. Each human being

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is considered as *autonomous system*, and interaction is best represented by *information flow* from the view point of human being. O-SCFT is decomposed into three nonlinear constructs, Maximum Satisfaction Architecture (MSA), Brain Information Hydrodynamics (BIH), and Structured Meme Theory (SMT) that correspond to human being, inorganic SCFT components, and O-SCFT components, respectively.

a) Maximum Satisfaction Architecture (MSA): MSA 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 [10].

b) Brain Information Hydrodynamics (BIH): Constrains from the environment shape how the information flow develops along the time dimension. This is reflected in the brain as BIH. It deals with information flow in the brain and its characteristics in the time dimension [11].

c) Structured Meme Theory (SMT): SMT concerns the relational structure that links human beings and the environment, and thereby deals with effective information and the range of propagation [12].

B. O-PDP: Organic Parallel Distributed Processing

We are interested in not only how individual human being's brain processes information, originated either from external or internal environment, but also how it develops chronologically from his/her birth. We challenge this problem under the concepts of MSA, BIH, and SMT. As we focus on information flow in the brain, we considered that Parallel Distributed Processing (PDP) is the fundamental mechanism for developing brain architecture [14]. Since PDP is considered under O-SCFT, we prefixed "O (organic)" to PDP, and call this approach O-PDP.

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*, 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, a PDP system is organized evolutionally, and realized as a neural network system, including the brain, the spinal nerves, and the peripheral nerves to construct an O-PDP system. This mechanistic statement might be expressed simply and casually with a less rigorous but easier to understand way as follows: the brain processes information thanks to a dynamically reconfigurable network of neurons to which one must add the spinal chord and peripheral nerves.

C. NDHB-Model/RT

On the basis of O-SCFT and O-PDP, 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. NDHB-Model/RT represents *consciousness* as one-dimensional linear operations, i.e., language, corresponding to System 2 of Two Minds, and *unconsciousness* including emotion as a hydrodynamic flow of information in multi-dimensional parallel operations in the neural networks, corresponding to System 1 of Two Minds. NDHB-Model/RT has autonomous memory systems that mediate between consciousness and unconsciousness to display the dynamic interactions between them.

NDHB-Model/RT suggests that the brain consists of the following three non-linearly connected layers. Behavioral decisions and action selections are made by integrating the results of operations of these three layers:

- C-layer: Conscious state layer, i.e., System 2 of Two Minds
- A^2BC-layer: Autonomous-Automatic Behavior Control layer, i.e., System 1 of Two Minds
- B-layer: Bodily state layer

B-layer prioritizes the 17 behavioral goals, i.e., happiness types defined by [15], such as "target happiness for an achiever", "cooperative happiness for a helper", "rhythmic happiness for a dancer", and so on. The other two layers interact with each other in order to derive the next behavior that should satisfy the highest prioritized goal. In normal situations in our daily life, temporal changes in the environment impose the strongest constraint on the decision of the next behavior, and thus A^2BC-layer plays a more dominant role than C-layer in organizing behavior. To put it simply, in our daily life we act more by reflex than by reasoning.

The next behavior is determined by extracting objects from the ever-changing environment and attaching values to them according to the degree of the strength of the resonance with what is stored in the autonomic memory system. This is followed by deliberate judgement by using the knowledge associated with the highly valued objects. The former is controlled by the processes in A^2BC-layer, System 1; the latter, by the processes in C-layer, System 2.

D. MHP/RT

NDHB-Model/RT can be simulated by the architecture model, Model Human Processor with Real time Constraints (MHP/RT) [8][9][16]. MHP/RT simulates in situ human behavior by switching among four processing modes, conscious/unconscious activities for the future events, and conscious/unconscious activities for the past events. MHP/RT focuses on synchronization between System 1 and System 2 in the information flow under O-PDP. More specifically, 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.

Figure 2 depicts the outline of MHP/RT. 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. In Figure 2, solid lines and dotted lines indicate the path associated with System 1 and the one associated with System 2, respectively. These two flows are synchronized before carrying out some behavior.

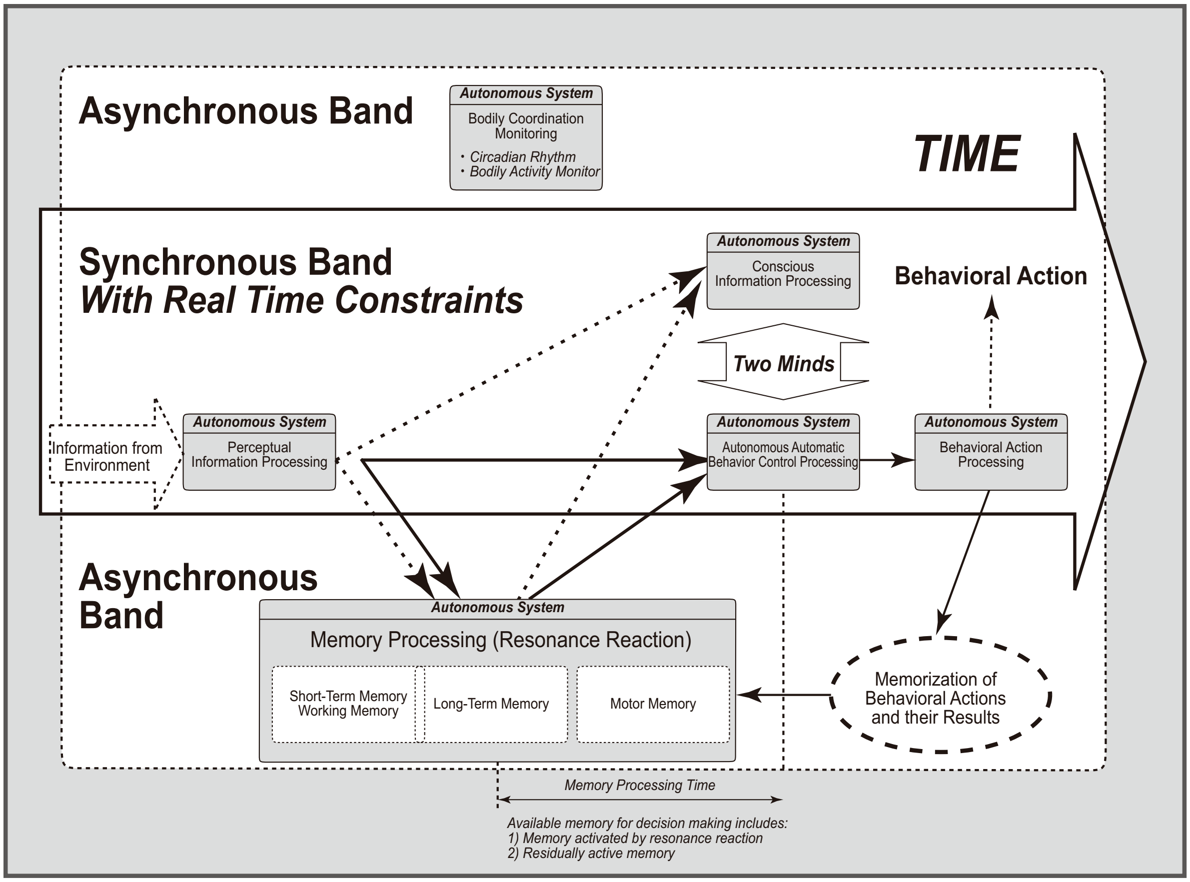

Figure 2. Outline of MHP/RT.

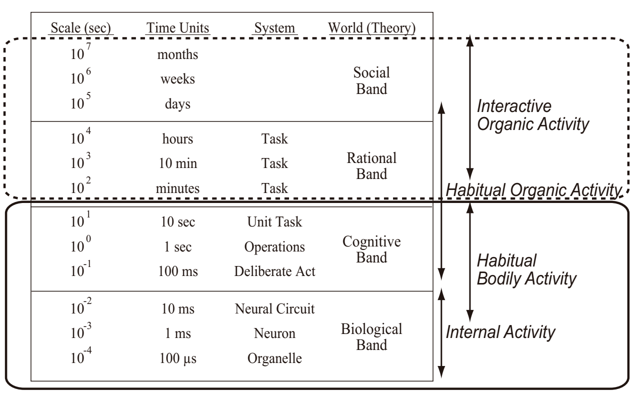

Figure 3. Newell's time scale of human action (adapted from [17]).

E. Four Processing Modes of MHP/RT

MHP/RT suggests that at a particular time *before the event*, say T_{before}, one engages in System 2's conscious processes and System 1's unconscious processes concerning the event. At a particular time *after the event*, one engages in conscious processes and unconscious processes. What one can do before and after the event is strongly constrained by the Newell's time scale of human action as shown by Figure 3. It indicates that System 2 carries out the processes surrounded by a round-cornered rectangle with dotted lines, whereas System 1 does those surrounded by a round-cornered rectangle with solid lines.

MHP/RT works under the following four processing modes, ordered from the past to the future:

- **System 2 Before Mode:** Conscious use of long-term memory before the event, i.e., System 2's operation for anticipating the future event, or decision-making.
- **System 1 Before Mode:** Unconscious use of long-term memory before the event, i.e., System 1's operation for automatic preparation for the future event, or action selection.
- **System 1 After Mode:** Unconscious use of long-term memory after the event, i.e., System 1's operation for automatic tuning of long-term memory related with the past event.
- **System 2 After Mode:** Conscious use of long-term memory after the event, i.e., System 2's operation for reflecting on the past event.

Figure 4 illustrates the four processing modes along the time dimension expanding before and after the event, which is shown as *boundary event*. At each moment, one behaves in one of the four processing modes and he/she switches among them depending on the internal and external states.

III. Dynamics of Consciousness–Emotion Interaction: An Explanation by NDHB-Model/RT

A. Interaction between Consciousness and Emotion

The processes in A^2BC-layer and those in C-layer are not independent. Rather, they interact with each other very intensely in some cases but very weakly in other cases. We investigate this issue in more detail below.

1) Onset of consciousness: With the onset of arousal, the sensory organs begin to collect environmental information, or paying attention to the information. This information flows into the brain, and the volume of information flow grows rapidly. As the information flow circulates in the neural networks, the center of the flow gradually emerges. It corresponds to the location where the successive firings of the neural networks concentrate. At this time, the center of information flow induces activities in C-layer via the cross-links in the neural networks.

2) Conscious activities: Figure 5 depicts the state of the brain when consciousness starts working. The location of consciousness is indicated as a dot in C-layer. In many cases, the working of consciousness includes such cognitive activities as comprehension of self-orientation and an individual's circumstances. The judgement on what decision-making is needed for the current situation is equivalent to initiating some action to move the location of consciousness to an appropriate direction. The direction of movement is determined by the information needs at that time. It could move either in the direction in which the initial information will be deepened (left in the figure, moving upstream in the information flow) or to the direction in which the initial information will be widened (right in the figure, moving downstream in the information flow). The density of information would change depending on how far the center of consciousness would have moved. However, the location of the consciousness would not move when carrying out a routine task.

Koch and Tsuchiya [18] suggested that attention and consciousness are two distinct brain processes. They showed functional roles of attention and consciousness and the four ways of processing visual events and behaviors. The upstream move of consciousness to the information flow corresponds to "attention with consciousness" in [18] and the downstream move corresponds to "consciousness in the near absence of attention."

3) Emergence of emotion: After the onset of consciousness, a new thread of information coming into the brain via the sensory organs triggers successive firing within the neural networks. This causes a new information flow in the brain that reflects the past experience that resonates with the input information. If there is a discrepancy between the new information flow (the dotted line in the figure) and the existing information flow (the solid line in the figure), emotion emerges. Emotion works to reduce the amount of discrepancy. This view is consistent with the one suggested by Tsuchiya and Adolphs [19], discussing the interaction between emotion and consciousness by reviewing experimental studies.

4) Determination of next behavior: When A^2BC-layer works continuously within its capacity, consciousness does not interfere with the working of A^2BC-layer but monitors the individual's behavior, prepares for the next behavior, and/or

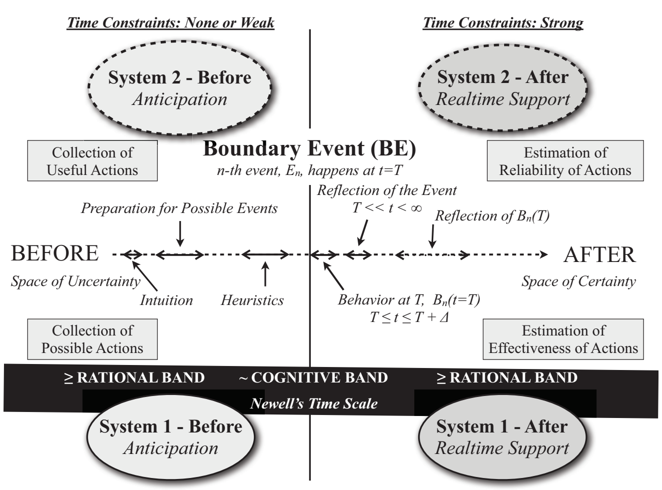

Figure 4. How the Four Processing Modes work (adapted from [9]).

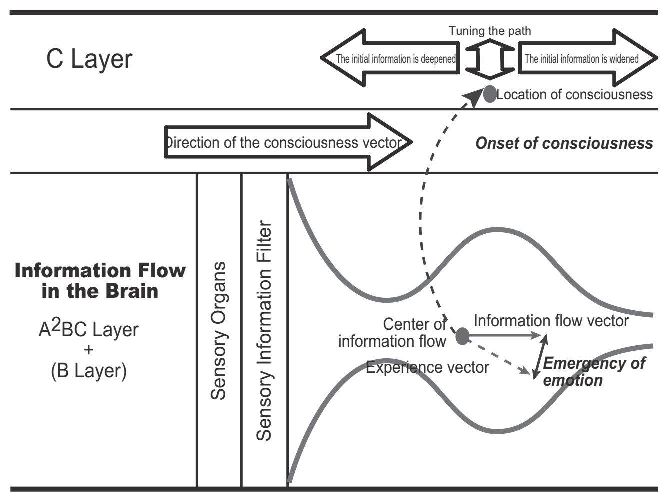

Figure 5. Onset of consciousness and emergence of emotion

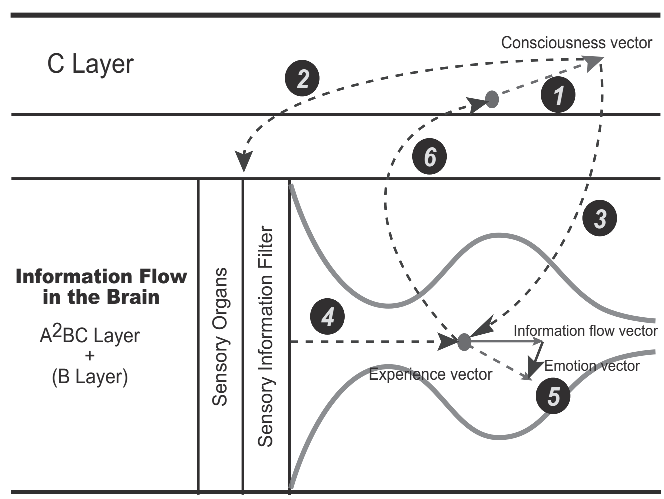

Figure 6. Determination of next behavior

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ponders issues that come to mind. However, if A^2BC-layer has difficulty in determining the next behavior, C-layer takes over and determines it. However, note that decision-making deals with planning for future behavior in the "System 2 Before Mode." Actions that will be taken actually in the ever-changing real world are determined by the system flexibly in an ad-lib fashion in the "System 1 Before Mode" [9][16].

5) Summary: The following depicts the flow of the processes that would happen (see Figure 6).

1) Consciousness determines the next behavior by considering the current emotion state, which is the functional aspects of an emotion [20], and the self-recognition.
2) Consciousness tunes the orientation of the sensory organs in preparation for initiating the next behavior just determined.
3) Consciousness commands initiating the next behavior.
4) The behavior results in changes in the information flow.
5) The direction of emotion changes.
6) The new state of emotion affects the process of determining the next behavior.

B. Synchronization between the C layer and the A^2BC layer: MHP/RT's perspective

We assume that the C layer and the A^2BC layer operate together in order to determine the next behavior. However, as described above, the interaction between them could be weak or strong, depending on the situation. There thus needs to be a synchronization mechanism for them to work together appropriately. The degree of discrepancy could be measured by the amount of efforts to re-establish good synchronization between the two systems.

We suggest that the visual-frame reconstruction process in the C layer should be used for establishing synchronization between the C layer and the A^2BC layer. In Figure 2, this synchronization process is indicated schematically as an arrow with the label "Two Minds." The C layer predicts the representation of the visual frame of reference that should appear in the future and uses it for synchronization. The information flow for this process is indicated in the dotted lines in Figure 2, which occurs in the characteristic times surrounded by a round-corner rectangle with dotted lines in Figure 3. On the other hand, when the A^2BC layer mainly controls the behavior, the visual-frame updating rate would be around 10 frames per second. The information flows as indicated by the solid lines in Figure 2, with the characteristic times in the round-corner rectangle with solid lines in Figure 3.

When the C layer mainly controls the behavior as in the former case, the rate would become lower and vary depending on the interest of consciousness. In the latter case, the C layer would monitor the self-behavior by occasionally matching the expected visual frame of reference and the real visual frame of reference in the A^2BC layer. For the former situation, the visual-frame density is high but the information density is low; for the latter situation, the visual-frame density is low but the information density is high. Discrepancy would be detected easier in the former case than the latter.

IV. Relationships between Two Minds and Emotions

A. Taxonomy of emotions: behavioral perspective

Table I summarizes the relationships between Two Minds and emotions as a combination of the states of C-layer and A^2BC-layer. The top half of the table lists the kinds of decision-makings that C-layer would do before some event happens. Depending on the intensity of the signals emitted from A^2BC-layer and the self-estimate of the state of the system, C-layer decides to do something with large effort, small effort, or just do nothing, or do nothing intentionally. Note that no emotion will take place at the time when C-layer makes decisions concerning the system's future.

On the other hand, as shown in the bottom half of the table, emotions will emerge when actions are carried out by A^2BC-layer. A specific emotion type would emerge depending on the combinations of the possible states of the following four conditions:

1) the signal intensity of A^2BC-layer,
2) C-layer's estimate of the system state,
3) the nature of C-layer's decision-making, and
4) the result of A^2BC-layer's action.

For example, in Case 9, though A^2BC-layer emits good signals, C-layer estimates the situation to be fearful. It decides not to do anything. However, A^2BC-layer reacts to the situation autonomously and the situation eventually turns good. C-layer feels relieved. Feeling is the conscious experience of the emotion [21]. In sum, this table provides a taxonomy of emotions in terms of the activities of A^2BC-layer and C-layer. The architecture-based approach towards taxonomy of emotion this paper has taken is different from traditional one, which studies in detail the relationships between the observed phenomena and the triggering conditions. The strength of this approach is that it would be free from increasing complexity of society and diversity of cultures.

B. Emotion initiation via memory processes

The processes depicted in Figure 5 include activation of memory via information flow in the brain. In order to disentangle these processes, we first show Figure 7 that illustrates how each MD-frame, to be explained below, is created as the result of working of autonomous processes in MHP/RT and how MD-frames are mutually interrelated [22]. This essentially details the process "Memorization of Behavioral Actions and their Results" shown by the dotted oval in the diagram of MHP/RT, Figure 2, by considering neuronal activities that actually happen. The basic idea is that each autonomous system has its own memory.

1) MD-frame: MHP/RT assumes that memory is organized by Multi-Dimensional Frame for storing information. It is a primitive cognitive unit that conveys information that can be manipulated by brain under various constraints.

Object cognition occurs as follows [23]:

1) Collecting information from the environment via perceptual sensors;
2) Integrating and segmenting the collected information, centering on visually collected objects;
3) Continuing these processes until the necessary objects to live in the environment are obtained.

TABLE I. RELATIONSHIPS BETWEEN TWO MINDS AND EMOTIONS.

System 2's before-event expectation					
Case	*C-layer's before-event decision-making*	*Signasl emitted from A^2BC-layer*	*C-layer's estimate when expectation was formed*		
1	do something with small effort	stable (no signal)	relaxed		
2	do nothing intentionally	bad	prepared for bad		
3	do something with large effort	bad	positive		
4	do something with large effort	good	strongly positive		
5	do nothing	good	calm		
System 2's after-event decision-making					
Case	*C-layer after-event decision-making*	*Signals emitted from A^2BC-layer*	*C-layer's estimate when decision-making was done*	*Result of A^2BC-layer's action*	*Emotion after A^2BC-layer's action was taken*
6	do something with small effort	good	good	$+$	satisfaction
				$-$	shock, lostness
7	do nothing intentionally	bad	bad	$+$	amazement, pleasure
				$-$	regret, despair
8	do something with large effort	bad	uneasy	$+$	self-praise
				$-$	apology
9	do nothing	good	fearful	$+$	relief
				$-$	regret

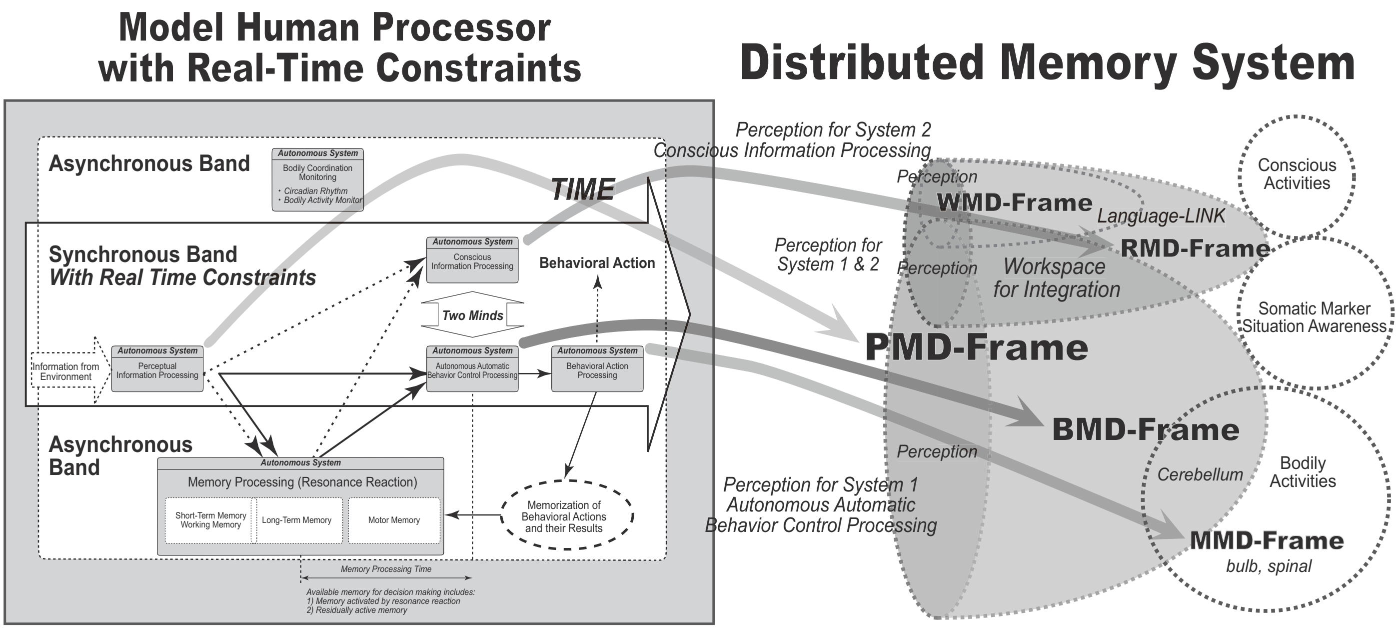

Figure 7. MHP/RT and the distributed memory system [22].

These objects are then used independently in Systems 1 and System 2, 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 process, are processed in the next cycle, representation of the objects may serve as the common elements to combine System 1 memory and System 2 memory to form an inter-system memory. We call this memory the Multi-Dimensional (MD) -frame.

There are five kinds of MD-frame in MHP/RT.

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

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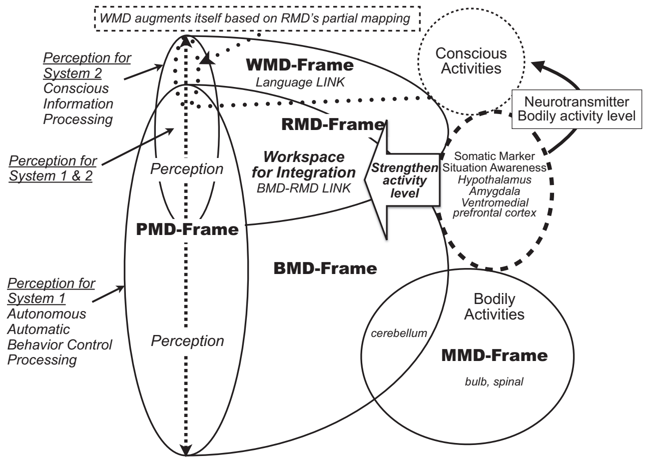

Figure 8. MD-frames and emotion.

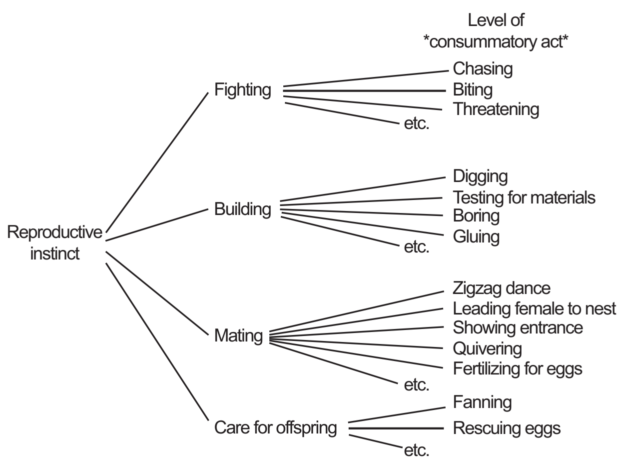

Figure 9. Fixed hierarchy in the behaviors accompanied with instinct of procreation (redrawn Figure 8.10 in [24])

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.

2) Consciousness/unconsciousness in MD-frames: 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 them 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, or MD-frames.

Metaphorically speaking, consciousness is one of tips of icebergs that appear above the sea level, and the tips are interrelated with each other via the unseen relationships established below the sea level. A system of icebergs develops in the natural condition of seawater and atmosphere, which may or may not be trivial for any people.

3) Emotion initiation in MD-frames: Figure 8 illustrates processes in MD-frames with the focus of emotion. 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 effects 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 feed-forward way. On the other hand, they have indirect effects 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. In other words, emotion corresponds to the internal activities that coordinate conscious processes and unconscious processes to work coherently in the ever-changing environment. As [21] put it, emotion emerges when consciousness is recognized for the first time. Feeling appears when the emotion is analyzed ecologically and recognized at the later time.

V. CONCLUSION

This paper suggested that emotion is a means for establishing synchronization between consciousness and unconsciousness internally via memory processes, with its taxonomy on the basis of the Four Processing Modes of MHP/RT, which is a cognitive architecture under NDHB-Model/RT with the guiding concepts of O-SCFT and O-PDP.

Figure 9 shows the fixed hierarchy in the behaviors accompanied with instinct of procreation through observation of behavior of Nemipterus virgatus [24]. 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, which is free from complication of society and diversity in culture, as suggested in this paper.

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