Decision-Making and Action Selection in Two Minds

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Abstract. This paper discusses the differences between decision-making and action selection. Human behavior can be viewed as the integration of output of System 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, at the same time, it activates future possible courses of actions. Decision-making narrowly refers to System 2's slow functions for planning for the future and related deliberate activities, *e.g.*, monitoring, for future planning. On the other hand, action selection refers to integrated activities including not only System 1's fast activities but also System 2's slow activities, not separately but integrally. This paper discusses the relationships between decision-making and action selection based on the architecture model the authors have developed for simulating human beings' *in situ* action selection, Model Human Processor with Real time Constraints (MHP/RT) [3] by extending the argument we have done in the argument we have made in previous work [5].

Keywords: decision-making, action planning, Two Minds

1 Decision-Making and Action Selection

Decision-making is the act or process of choosing a preferred option or course of action from a set of alternatives. It precedes and underpins almost all deliberate or voluntary behavior. *Action selection* is the process for selecting "what to do next" in dynamic and unpredictable environments in real time. The outcome of decision-making is regarded as part of resources that are available when selecting actions [9]. As dual-processing theories suggest (*e.g.*, [2]), two qualitatively different mechanisms of information processing operate in forming decisions. The first is a quick and easy processing mode based on effort-conserving heuristics. The second is a slow and more difficult rule-based processing mode based on effort-consuming systematic reasoning. The first type of process is often unconscious and tends to automatic processing, whereas the second is invariably conscious and usually involves controlled processing.

Kahneman, winner of the Nobel Prize in economics in 2002, introduced behavioral economics, which stems from the claim that decision-making is governed by the so-called "Two Minds" [2], a version of dual processing theory, consisting of System 1 and System 2. System 1, the first type of process, 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 (one is seized by one's emotions). In contrast, System 2, the second type of process, is a slow feedback control process driven by the cerebrum and oriented toward future action. It is experienced actively and consciously (one intentionally follows the rules of inductive and deductive reasoning).

This paper discusses the relationships between decision-making and action selection based on the architecture model the authors have developed for simulating human beings' *in situ* action selection, Model Human Processor with Real time Constraints (MHP/RT) [3] by extending the argument we have done in the argument we have made in previous work [5]. MHP/RT defines how System 1 and System 2 work together to generate coherent behavior being synchronized with ever-changing environment.

2 MHP/RT: Model Human Processor with Realtime Constraints

We proposed Model Human Processor with Realtime Constraints (MHP/RT) as a simulation model of human behavior selection. It stems from the successful simulation model of human information processing, Model Human Processor (MHP) [1], and extends it by incorporating three theories we have published in the cognitive sciences community. The Maximum Satisfaction Architecture (MSA) deals with coordination of behavioral goals [7], the Structured Meme Theory (SMT) involves utilization of long-term memory, which works as an autonomous system [10], and Brain Information Hydrodynamics (BIH) involves a mechanism for synchronizing the individual with the environment [6].

MHP/RT includes a mechanism for synchronizing autonomous systems (square-like shapes with rounded corners in Figure 1), working in the "Synchronous Band." MHP/RT was created by combining MHP and Two Minds by applying our conceptual framework of Organic Self-Consistent Field Theory [4].

MHP/RT works as follows:

1. Inputting information from the environment and the individual,
2. Building a cognitive frame in working memory (not depicted in the figure but it resides between the conscious process and the unconscious process to interface them),
3. Resonating the cognitive frame with autonomous long-term memory to make available the relevant information stored in long-term memory; cognitive frames are updated at a certain rate and the contents in the cognitive frames are frames are a continuous input to long-term memory to make pieces of information in long-term memory accessible to System 1 and System 2,

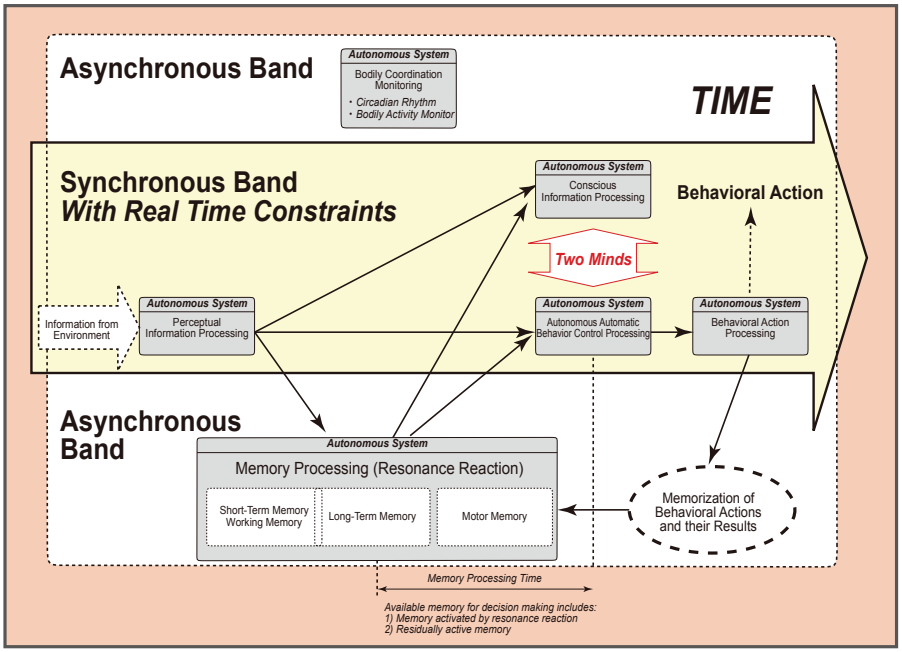

Fig. 1. MHP/RT (adapted from [3])

4. Mapping the results of resonance on consciousness to form a reduced representation of the input information, and
5. Predicting future cognitive frames to coordinate input and working memory.

3 Four Processing Modes of Human Behavior

In [5], the authors introduced Four Processing Modes of *in situ* human behavior that are derived by augmenting the theory of decision-making, Two Minds [2], by taking into account the different nature of decision-making before the boundary event and after the boundary event, that is captured by Newell's time scale of human action [8]. Table 1 shows the resultant Four Processing Modes of *in situ* human behavior; at each moment along the time dimension human behaves in one of the four modes and he/she switches among them depending on the internal and external states.

Decision-making processes before the boundary event and those after the boundary event are significantly different in terms of the impact of real time constraints on the decision-making processes. Considering that decision-making is the result of the workings of System 1 and System 2, there are four distinctive behavior modes, 1) conscious (System 2) behavior before the boundary event, 2) conscious (System 2) behavior after the boundary event, 3) unconscious

Table 1. Four Processing Modes [5]

	System 2 Conscious Processes		**System 1 Unconscious Processes**	
	Before	*After*	*Before*	*After*
Time Constraints	none or weak	exist	none or weak	exist
Network Structure	feedback	feedback	feedforward + feedback	feedforward + feedback
Processing	main serial conscious process + subsidiary parallel process	main serial conscious process + subsidiary parallel process	simple parallel process	simple parallel process
Newell's Time Scale	Rational / Social	Rational / Social	Biological / Cognitive	Biological / Cognitive

(System 1) behavior before the boundary event, and 4) unconscious (System 1) behavior after the boundary event.

4 Decision-Making and Action Selection in the Four Processing Modes

This section discusses the differences between decision-making and action selection using Figure 2, adapted from [5], that illustrates the Four Processing Modes along the time dimension expanding before and after the boundary event.

4.1 Creation and utilization of event memory

The four processing modes are defined by referring to a single event (boundary event). Therefore, it is useful to consider how each of the four processing modes works when one encounters an event for the first time, and it encounters the same event in the future.

When one encounters an event for the first time, "System 1 After" processing and/or "System 2 After" processing will work to create encodings of the event as an experiential memory frame. "System 2 After" processing will elaborate on the outcome of "System 1 After" processing. Usually, several times of repetition of encountering the same event will be necessary to establish a cohesive memory frame.

The experiential memory frame thus created may be activated before the event happens through "System 1 Before" processing and/or "System 2 Before" processing. This paper suggests that action selection corresponds to "System 1 Before" processing and decision-making corresponds to "System 2 Before" processing. Since characteristic times of System 1 and those of System 2 are significantly different, they have different meanings for the behavior to be taken for the event. As shown in Figure 3, "System 2 Before" processing, or decision-making, for the future event will work long before the event happens when

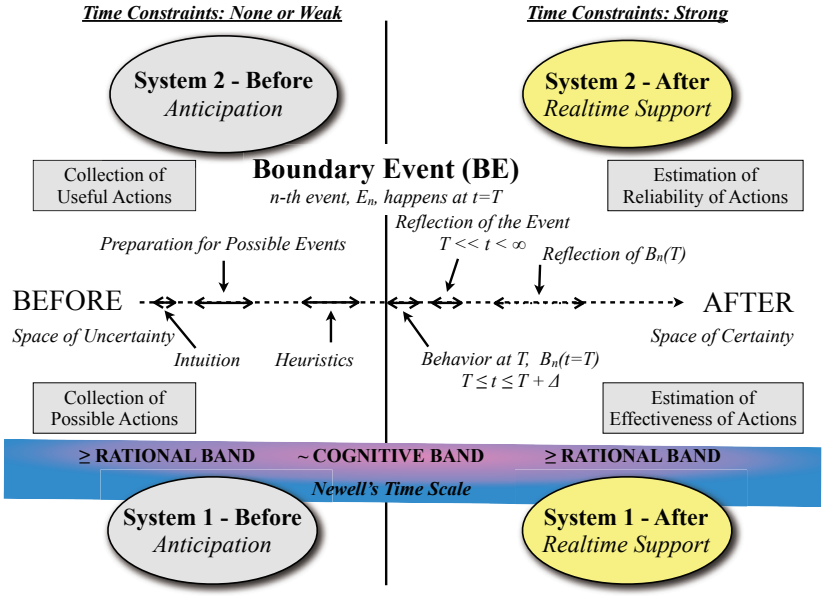

Fig. 2. How the Four Processing Modes work (adapted from [5])

there is time available for collecting possible actions through deliberate thinking, whereas "System 1 Before" processing, or action selection, for the immediate future anticipatory event will happen; one will be able to select action to behave appropriately, not only experiencing the event but also avoiding the event (not experiencing the event but an alternative event).

4.2 Transition from experiential memory to prospective memory

An experiential memory frame that "System 1 After" processing has created will be converted into an prospective memory frame, that can be used by "System 1 Before" processing for anticipating and preparing for future events. This conversion process can be automatic when "System 1 After" processing is able to identify the perceptual objects that are associated with the encoding of the event stored in the experiential memory frame.

For example, when one has encountered a harmful insect and been stung, he or she would immediately and automatically establish a link between the visual and auditory perceptual signals of the insect and the action to drive away the insect by his/her hand. Otherwise, "System 2 After" processing will be required for identifying the objects that might be useful for anticipating the event and associating them with perceptual features of the objects that can be detected by the perceptual system before the event happens in the future.

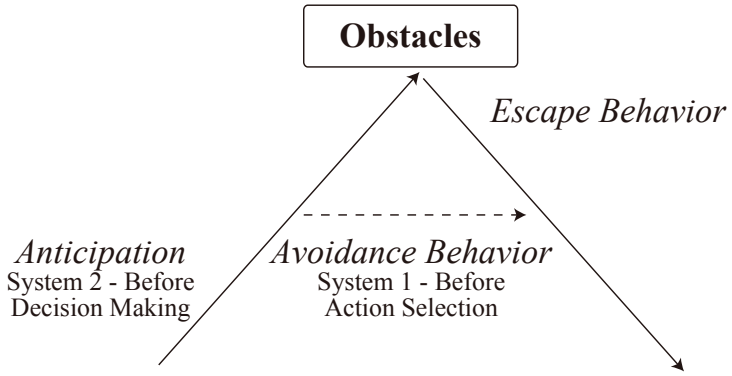

Fig. 3. Decision-making carried out by "System 2 Before" processing mode and action selection by "System 1 Before" processing mode of MHP/RT.

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