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Four Processing Modes of *in situ* Human Behavior

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Abstract. Human behavior is considered as a series of moment by moment decision-makings in the ever-changing environment. Each decision-making process is carried out by System 1 and System 2 of Two Minds [3] under real time constraints, which basically requires synchronization between the workings of System 1 and System 2 in the real world by taking into account each system's characteristic times defined by Newell's time scale of action [4]. The result of decision-making is an event, that includes the direct output of decision-making, or behavior, and the resultant state of the external world. This paper proposes Four Processing Modes of *in situ* human behavior, consisting of before-event and after-event System 1 activities, and before-event and after-event System 2 activities for each event. Moment-by-moment decision-making process is regarded as a series of mental and physical actions performed in one of Four Processing Modes. This paper also provides evidence of Four Processing Modes from our field study concerning guide-sign supported navigation behavior at railway stations [9].

Keywords. Time scale of action, Two Minds, decision-making

1. *in situ* Human Behavior

Human behavior is represented as a series of discrete events, and each event is considered as the result of decision-making processes at the time the event has occurred. Let's take an example of human behavior represented as a series of events, that is associated with conducting a tour. The tourist's behavioral events are oftentimes associated with the origination of a single tour. For example, before arriving at a destination, one has to decide when to initiate planning a tour, how to collect information about the candidate destinations, which destination to visit, whom to accompany, which hotel to stay in, which restaurant to have dinner at, and so on. These decisions define the plan for the tour. On arrival at the destination, a tourist has to decide what to do in each specific situation according to the pre-specified plan.

However, the plan should be regarded as just one of several resources for organizing human behavior. Human behavior is the result of a series of decisions, but it might not necessarily be carried out according to a pre-specified plan. Rather, it should be regarded as situated in the environment where the current activities are carried out, *i.e.*, as situated

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action [1,2]. A tourist makes a variety of *in situ* decisions on how to enjoy the visit to the destination. However, there might be unforeseeable circumstances that would force him or her to change the pre-specified plan. Therefore, tourist's decision-making at the site of tour should be conceived as dependent on the circumstances he or she is in.

Each event is differently treated by decision-making processes *before* the event and *after* the event. In this example, the event, "arrival at the destination," is special because it divides the entire tour events into two categories; "before arrival events" and "after arrival events." Let us call an event "boundary event" when we consider two classes of decision-making processes in relation with the boundary event; the ones that happen before the boundary event and the others that happen after the boundary event. The arrival event is a characteristic boundary event of touring behavior. Before the boundary event, decision-making is for anticipating events that will develop after the boundary event. After the boundary event, especially immediately after it, decision-making is for conducting *in situ* activities by utilizing the anticipation, where behavior selection at each moment is strongly affected by the internal conditions, *i.e.*, his/her physical and/or mental conditions, and the external conditions, *i.e.*, the states of the environment, and most importantly, human behavior is synchronous with the state of environment which could have resulted in the his/her past behaviors, and the present internal and external states should affect the future decision-makings. Later on, after the boundary event, the results of the boundary event and the behavior carried out for the boundary event will be estimated in terms of reliability and effectiveness of the actions taken.

2. Four Processing Modes in Human Behavior

This paper introduces *Four Processing Modes* of *in situ* human behavior that are derived by augmenting the theory of decision-making, *Two Minds* [3], 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 [4]. We will review briefly Kahneman's Two Minds [3] and Newell's time scale of human action [4] and show how they are combined, and describe 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. We provide supporting evidence from our observational study at railway stations for understanding how people use guide signs in conducting navigation tasks [9].

2.1. Two Minds: The Theory of Decision-Making

Human decision-making has been a central topic in economics. Herbert A. Simon, winner of the Nobel Prize in economics in 1978, proposed principles of human beings' decision-making processes. He described the decision-making process as a "bounded rationality principle" as well as a "satisficing principle" [5,6]. Simon claimed that agents, or human beings, face uncertainty about the future and costs when acquiring information in the present. These factors limit the extent to which human beings can make a fully rational decision. Thus, they possess only "bounded rationality" and must make decisions by "satisficing," or choosing the path that might not be optimal, but which will make them happy enough.

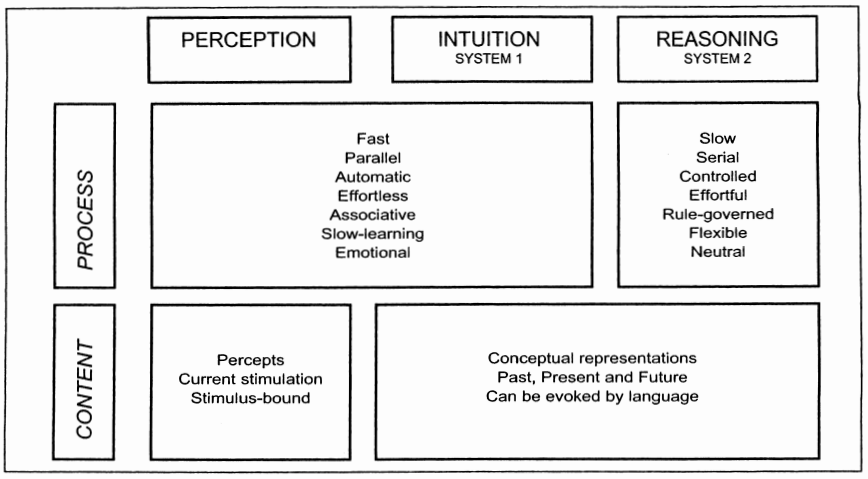

Figure 1. Two minds (adapted from [3]).

Recently, 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" [7]. In other words, 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, adapted from [3], 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 (one is seized by one's emotions). 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 (one intentionally follows the rules of inductive and deductive reasoning).

2.2. *Newell's Time Scale of Human Action*

The two systems work jointly and in synchronous with the ever-changing external world to exhibit moment by moment coherent human behavior. However, there is a large difference in processing speed between the two systems. Rational processing typically takes minutes to hours whereas experiential processing typically extends from hundreds of milliseconds to tens of seconds. Figure 2 illustrates the time scale of human action consisting of the following four bands, 1) Biological Band, 2) Cognitive Band, 3) Rational Band, and 4) Social Band, each has its characteristic processing time [4]. A large part of human beings' daily activities are immediate actions and are therefore under control of the experiential processing system (System 1). The rational processing system (System 2) intervenes with the experiential processing system to better organize the overall outcome of the processing through consciously envisioning possible futures.

2.3. *Four Processing Modes of Human Behavior*

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 bound-

Time Sale of Human Action

Scale (sec)	Time Units	System	World (Theory)
10^7	months		Social Band
10^6	weeks		
10^5	days		
10^4	hours	Task	Rational Band
10^3	10 min	Task	
10^2	minutes	Task	
10^1	10 sec	Unit Task	Cognitive Band
10^0	1 sec	Operations	
10^{-1}	100 ms	Deliberate Act	
10^{-2}	10 ms	Neural Circuit	Biological Band
10^{-3}	1 ms	Neuron	
10^{-4}	100 μs	Organelle	

Figure 2. Newell's time scale of human action.

ary event, 3) unconscious (System 1) behavior before the boundary event, and 4) unconscious (System 1) behavior after the boundary event. Table 1 summarizes the features of the Four Processing Modes.

Table 1. Four Processing Modes

	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

Figure 3 illustrates the Four Processing Modes along the time dimension expanding before and after the boundary event.

3. Evidence of Four Processing Modes

By following the underlying development philosophy of Model Human Processor [8], we developed an architecture model for simulating *in situ* human behavior, called Model Human Processor with Realtime Constraints, MHP/RT [9]. The verification of the model was done by matching the results of simulations of the model with people's behavior recorded in a series of field observations [9,10].

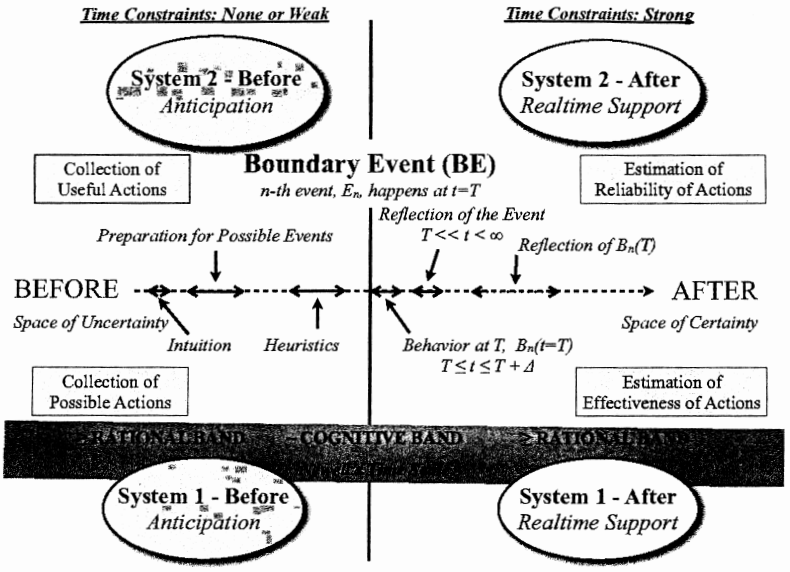

Figure 3. How the Four Processing Modes work.

3.1. Way-Finding Behavior at Railway Stations [9]

Suppose a person is placed in an environment that he/she has never visited and given a navigation mission that is familiar to him/her. He/she can anticipate the goal state and imagine the problem space that should extend as he/she proceeds. The representation could be very detailed or coarse, depending on his/her knowledge of this situation. Based on MHP/RT, it is suggested that in this situation, two qualitatively different modes of navigation processes exist. The first is *anticipation-based navigation* in which feedback from consciousness works effectively. The second is *event-based navigation* in which feedback does not work, and moment-by-moment decision-making is required. These two navigation modes specify the patterns of the Four Processing Modes that could appear in navigation behavior.

3.2. Anticipation-based navigation and event-based navigation

3.2.1. Anticipation-based navigation

This navigation mode is characterized by "<System 1 & 2 – Before> followed by <System 1 – After> with occasional intervention by <System 2 – After>." Even if the environment is new to the participant, the mission is familiar to him/her. Therefore when starting the mission, he/she is able to activate mental models associated with the mission. If the level of the representation of the mental model is appropriate for the sensory-information filter to function effectively in the environment, it is possible for him/her to input information from the environment as specified by the mental model. The mental model may be one for procedures or one for objects in the environment. The input information resonates with the knowledge in LTM and updates the representation of the active mental models to be used to create feedback from consciousness. The feedback forms anticipation concerning the future development of the person and the environment. While this cycle continues as the person navigates, it is said that the person is navigating in the mode of anticipation-based navigation. In this mode, System 2 monitors the opera-

tion of System 1 and intervenes when a large discrepancy exists between the anticipation concerning the situation to come next and the actual situation.

3.2.2. *Event-based navigation*

This navigation mode is characterized by "<System 2 – Before> followed by <System 2 – After>." When anticipation-based navigation seriously breaks down, the participant is forced to switch to the event-based navigation mode in order to continue the mission. Breakdown can occur when the initial mental model is found to be inappropriate: (1) the level of representation is appropriate, but the sensory-information filter that reflects feedback from consciousness does not work because of a serious discrepancy between the representation of the filter and the actual environment, or (2) the level of representation is not detailed enough for consciously defining the sensory-information filter. A person who is in the event-based navigation mode must monitor the progress more frequently than one who is in the anticipation-based navigation mode, and must select the next action within the time allowed by deliberate processing. Therefore, the action selection process in this situation looks like obeying the satisficing principle by [5]. In this mode, System 2 takes control of navigation behavior.

3.3. *Evidence of Four Processing Modes*

The observational study at train stations reported in [9] indicated that participants showed behavior that reflected the Four Processing Modes. For example, it was observed that two participants got lost in the same situation in under control of two different modes. One person had a deficit in the planning function, and therefore, his/her behavior was in large part governed by <System 1 – Before> and <System 1 – After> modes. This is a version of anticipation-based navigation with little contribution from System 2. And the other had a deficit in the attention function, and therefore his/her behavior was in large part governed by <System 2 – Before> and <System 2 – After>, consistent with the event-based navigation pattern.

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