Organic Self-Consistent Field Theory and NDHB-Model/RT on O-PDP

An Introduction

November 8, 2014

Muneo Kitajima
and
Makoto Toyota

1 Introduction

The purpose of this document is to provide a bird's-eye view of our project, development of a framework for considering the behavior of human-beings in the universe, *NDHB-Model/RT*, and a cognitive architecture, *MHP/RT*, that is capable of simulating human being's daily decision making and action selection under NDHB-Model/RT. The underlying idea can be expressed by the term, *Organic Self-Consistent Field Theory*.

1.1 Organic Self-Consistent Field Theory

Self-Consistent Field Theory in Physics

In physics and probability theory, self-consistent field theory (SCFT also known as mean 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.

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 launch-point to studying first or second order fluctuations.

▶ MHP/RT:
Model Human Processor with Real-Time Constraints
▶ O-SCFT:
Organic Self-Consistent Field Theory
▶ O-PDP:
Organic Parallel Distributed Processing
Glossary:
▶ NDHB-Model/RT:
Nonlinear Dynamic Human Behavior Model with Real-Time Constraints

"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.

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 is considered as *autonomous system*, and interaction is best represented by *information flow* from the view point of human being. Figure 1.1 shows three nonlinear constructs, MSA, BIH, and SMT that correspond to human being, inorganic SCFT components, and organic O-SCFT components, respectively.

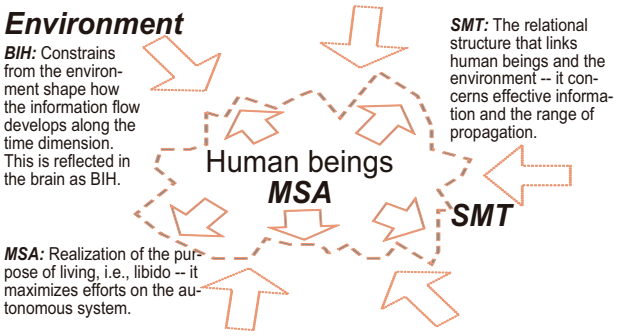


Figure 1.1: Three fundamental constructs of O-SCFT.

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 (Kitajima, Shimada, & Toyota, 2007).

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 (Kitajima, Toyota, & Shimada, 2008).

Structured Meme Theory (SMT): The relational structure that links human beings and the environment. SMT concerns effective information and the range of propagation (Toyota, Kitajima, & Shimada, 2008).

1.1.1 Scale Mix

OSCF provides a rather macroscopic viewpoint and considers the system in question stable and it obeys the law of increase in entropy (second law of thermodynamics), whereas BIH provides a rather microscopic viewpoint where

the universe is essentially a dissipative structure of a complex system that self-organizes (Prigogine & Stengers, 1984) as a hierarchical structure.

Gaia, the environment of the earth as a whole, is an extremely developed world of a complex hierarchical structure. Any phenomena in Gaia appear as the results of scale-mixed compound of individual phenomena, that coexist, at different hierarchies characterized by their own scales in time and space that coexist and , therefore. Any entities in the complex hierarchical structure that live across the multiple hierarchies should exist under a certain balance in the scale-mix.

1.2 Development of Brain Architecture Model under NDHB-Model/RT

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 from his/her birth. We challenge this problem under the concept of MSA, BIH, and SMT.

1.2.1 O-PDP

We focus on information flow in the brain. We considered that *PDP (Parallel Distributed Processing)* is the fundamental mechanism for developing brain architecture (McClelland, Rumelhart, & Group, 1987). Since PDP is considered under O-SCFT, we prefixed "O (organic)" to PDP, O-PDP, as before to indicate it explicitly.

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.

1.2.2 Architecture Selection: The Guideline

O-PDP represents the working of the entire organic system as a whole, in which a number of autonomous systems function in the real ever-changing environment. The strong constraint is that O-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. This is the guideline we adopted for constructing an architecture. Figure 1.2 depicts it schematically.

1.2.3 Evolutional consideration

As Swanson (2011) explains, cross-networks of neurons in the brain develop in a systematic way to show three-layered structure of interneurons system (Figure 1.3). Interneurons intervene the sensory nervous system that is responsible

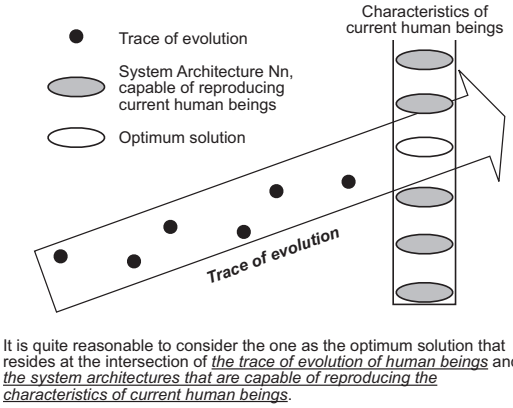


Figure 1.2: The guideline we adopted for selecting architecture.

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.

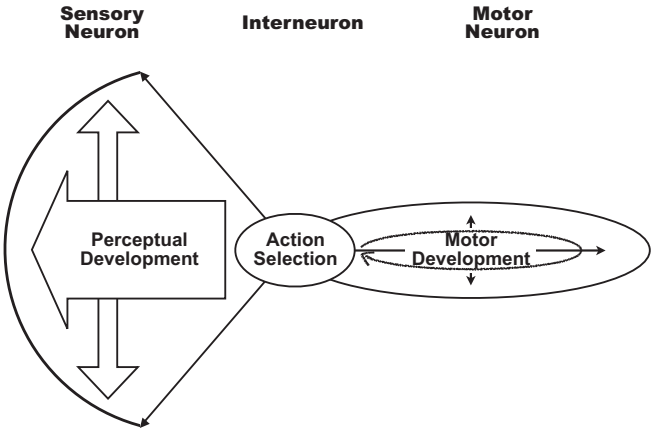


Figure 1.3: Development of the sensory nervous system and the somatic nervous system, and interneurons connecting them with action selection process.

Body movement is constructed by selecting executable motions and sequencing them in such a way that it adapts to the current environmental under environmental constraints. A motion is executable when it is exerted with stable postures, which are 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. In this way, PDP by McClelland et al. (1987) is naturally integrated with evolutional view described by Swanson (2011).

According to Damasio (1999), 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

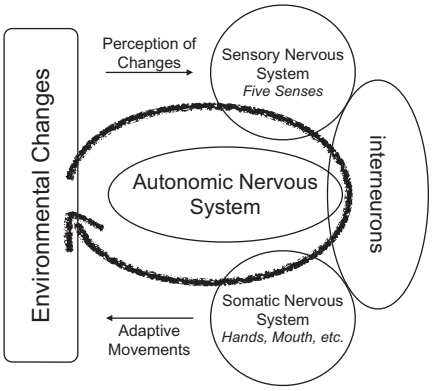


Figure 1.4: Continuous cyclic loop of perception and movement.

selective sensing, which is a paired structure with feedback between perception and movement. 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.

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. Figure 1.4 depicts this loop schematically.

Pushing this further, we have developed NDHB-Model/RT as an architecture model that consists of a number of autonomous systems; including perceptual system, conscious system (System 2), unconscious system (System 1), memory system, behavior control system, and so on. 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. Respective theories take different view points for observing a variety of phenomena generated by the single mechanism of O-PDP. The entire list of our publications is given at the end of this document.

Framework Overview (1):
▶ O-SCFT:
Self-consistency is the key to view quasi-stable universe. BIH, SMT, and MSA are three theories that construct O-SCFT.
▶ O-PDP:
Circular information flow in PDP is the key to view O-SCFT in the ever-changing environment.
▶ NDHB-Model/RT:
The entire system is constructed by a number of autonomous systems that shape the universe defined by O-SCFT by means of O-PDP.

1.3 MHP/RT: An Implementation of NDHB-Model/RT with Two Minds and Autonomous Memory System

1.3.1 Two Minds

Processes under O-PDP can be divided into conscious processes and unconscious processes. This has been studied in the domain of decision making for years. 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" (Kahneman, 2003; Evans & Frankish, 2009; Kahneman, 2011), a version of dual processing theory, consisting of System 1 and System 2. Figure 1.5 illustrates the workings of the two systems.

- **System 1:** The first type of process is a fast feed-forward control process driven by the cerebellum and oriented toward immediate action. Experi-

ential processing is experienced passively, outside of conscious awareness (one is seized by one's emotions).

- **System 2:** In contrast, 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).

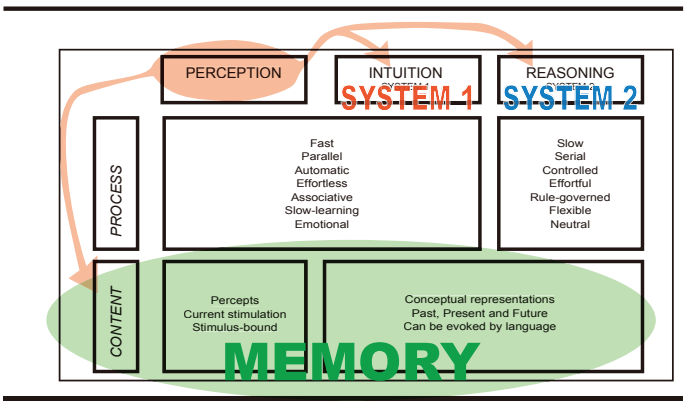


Figure 1.5: Two Minds (adapted from Kahneman (2003), shades are added by us)

1.3.2 Autonomous Memory System

Recent studies suggest that the memory system, shaded in green in Figure 1.5, 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.

1.3.3 MHP/RT: Model Human Processor with Realtime Constraints

By integrating autonomous memory system and Two Minds, we have developed a architecture model MHP/RT that 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 O-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.

Figure 1.6 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 1.6, green lines and orange lines indicate the path associated with System 1 and the one associated with System 2.

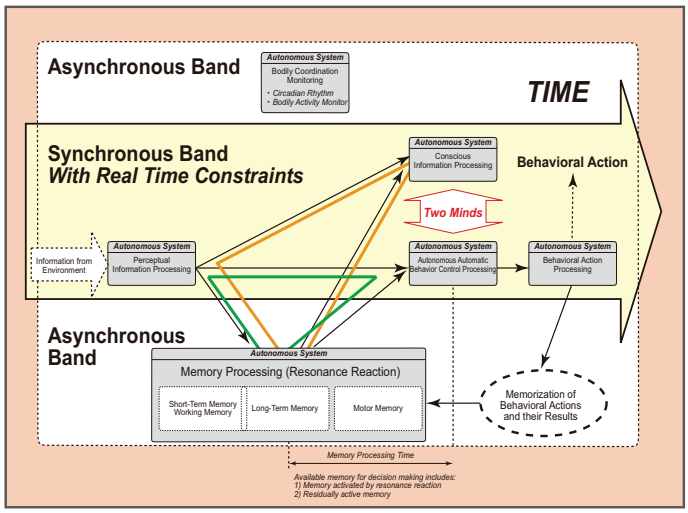


Figure 1.6: Outline of MHP/RT. Green lines indicates information for System 1-based processing and orange lines for System 2 based one. These two flows are synchronized before carrying out some behavior.

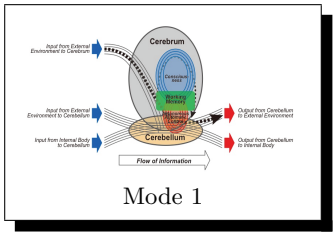
1.4 Basic Operations of MHP/RT

At a given time, T, MHP/RT's state is considered from the viewpoint "which part of MHP/RT is working" or "how MHP/RT is working."

1.4.1 Four *Operation* Modes of MHP/RT

In MHP/RT as illustrated by Figure 1.6, 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. Both systems work *synchronously* by sharing working memory. The former is called Mode 1, and the latter, Mode 2. However, in some situations, both work *asynchronously*, Mode 3, or independently, Mode 4; working memory may be shared weakly or used solely for one of these layers.

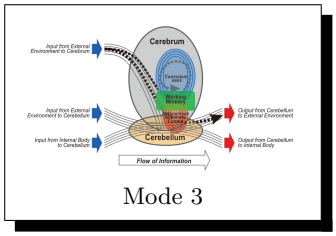
Mode 1 (System 1 controls behavior): When System 1 governs behavior, the updating rate of the cognitive frame is the fastest, and the system behaves unconsciously. The system refers to the memory that is activated via the resonance reaction, and the outcome of behavior is consciously monitored, which 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.



Mode 1

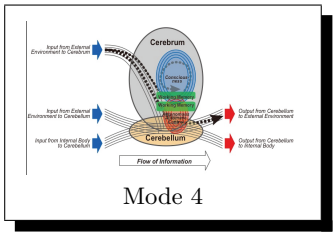
Mode 3 (System 1 and System 2 are weakly coupled): In some cases, it is not necessary to monitor the behavior with high frequency. As a result, System 2 may initiate tasks that are not directly relevant to unconscious behavior. In such a situation, consciousness is free from behavior that is tightly

embedded in the environment. 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. 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. And then, Mode 1 or Mode 2 takes over the operation. The shared information originates from perceptual encodings of the environment.



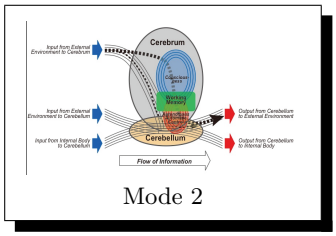
Mode 3

Mode 4 (System 1 and System 2 are isolated): 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 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 hods information available to the two processes but Mode 4 does not.



Mode 4

Mode 2 (System 2 controls behavior): When System 2 governs behavior, the systems try to behave according to the image System 2 created or meditate 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).



Mode 2

Mode 1, or System 1 control mode, would require least cognitive resources for stringing pieces of behavior in the ever-changing environment. On the other hand, Mode 2, or System 2 control mode, would consist of resource consuming activities including reasoning, recalling weak memory, etc. System 1 control may break down due to unexpected change in the environment, which would be detected by System 2's monitoring activity, leading to System 2 control mode for searching for procedures for escaping from the undesirable situation. Note that, in daily life, human beings are normally in System 1 control mode because human beings normally prefer effortless behavior, but occasionally forced to operate in System 2 control mode for the purpose of resuming "normal" System 1 control mode as soon and easily as possible.

1.4.2 Four *Processing* Modes of MHP/RT

Event

We concern with human activities. Essentially, conscious activities are carried out serially by using resources in a time-sharing fashion, whereas unconscious activities are in parallel. Figure1.7 shows the features of conscious activities carried out by social-activity ecological networks and individual-behavior ecological networks, and those of unconscious activities carried out by bodily-activity networks.

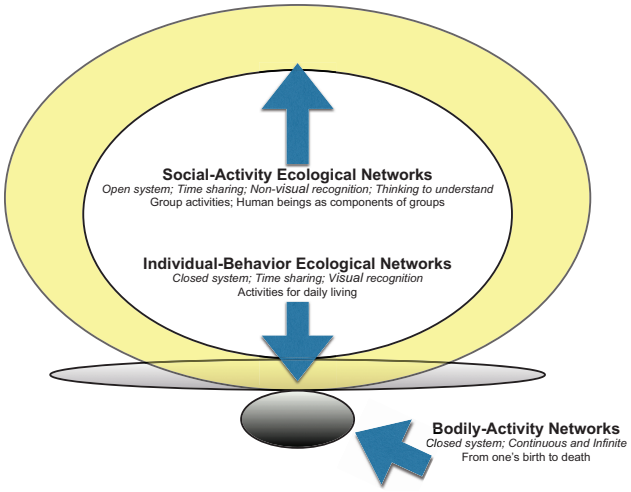


Figure 1.7: Multi-layered networks.

Figure 1.8 views this in a different direction. It shows factors that shape activities in a whole organic system focusing on different roles one is given at different times of individual lives. Basically, ones' time is divided into work and not-work times. In work time, one earns money and one pend it in not-work time. One's lives in work time are constructed by a sequence of work-events and those in not-work time are constructed by not-work events. Each event is processed by social-activity ecological networks, individual-behavior networks and bodily-activity networks. However, which networks process the event depends on the situation.

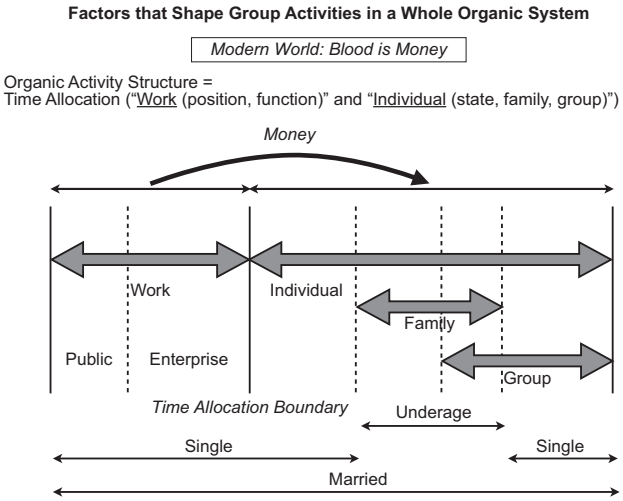


Figure 1.8: Factors that shape activities in a whole organic system.

It is important to introduce the concept of *event* for considering basic opera-

tions of MHP/RT. For MHP/RT, an event corresponds to a point on the time dimension where it can select an action from the alternatives under a specific environmental condition. The environment makes chaotic changes, and human beings, modeled by MHP/RT, are requited to develop an adaptive system that is capable of dealing with a set of events that happen in such an environment.

4-Process

At a particular time *before the event*, say T_{before}, one engages in conscious processes and 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 in Figure 1.9. System 2 carries out the processes surrounded by an orange round-cornered rectangle, whereas System 1 does those surrounded by a green one.

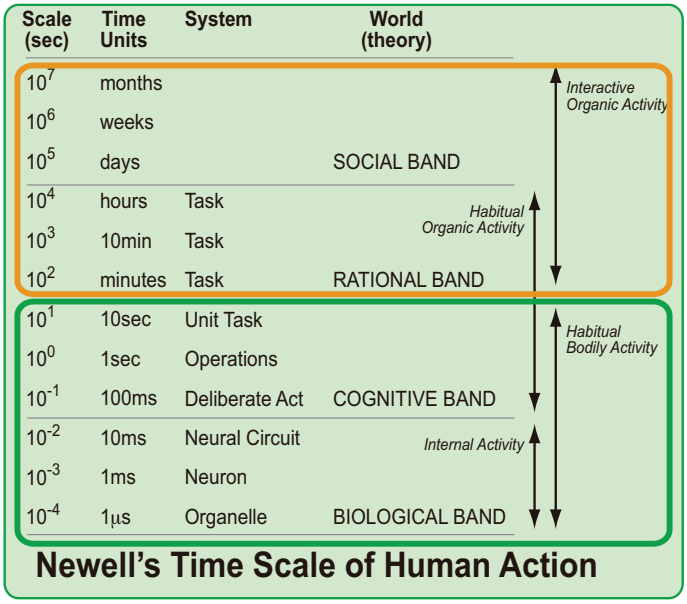


Figure 1.9: Newell's time scale of human action.

There are four processing modes:

- **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 2 After Mode:** Conscious use of long-term memory after the event, *i.e.*, System 2's operation for reflecting on the past event.
- **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.

Figure 1.10 illustrates the Four Processing Modes along the time dimension expanding before and after the event, which is shown as "boundary event" in the figure. 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.

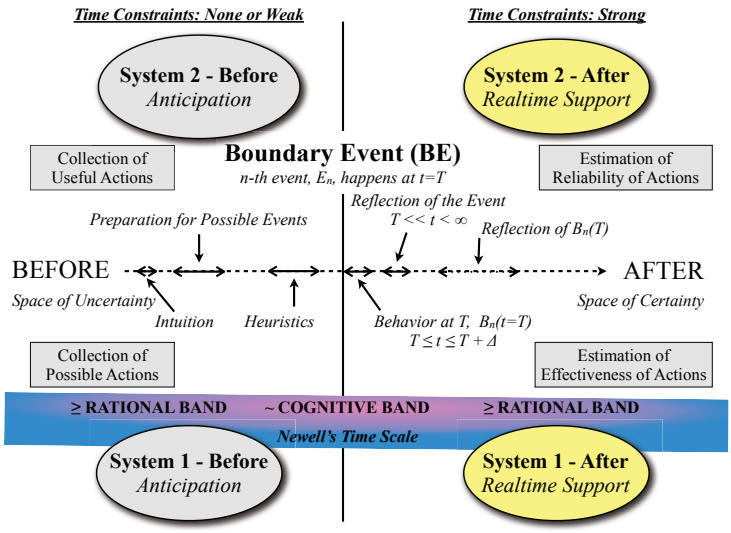


Figure 1.10: How the Four Processing Modes work

References 1.4

Damasio, A. (1999). *Feeling of What Happens: Body and Emotion in the Making of Consciousness*. Orlando, FL: Houghton Mifflin Harcourt.

Evans, J. S. B. T., & Frankish, K. (Eds.). (2009). *In Two Minds: Dual Processes and Beyond*. Oxford: Oxford University Press.

Kahneman, D. (2003). A perspective on judgment and choice. *American Psychologist*, *58*(9), 697–720.

Kahneman, D. (2011). *Thinking, fast and slow*. New York, NY: Farrar, Straus and Giroux.

Kitajima, M. (2012a). Cognitive Chrono-Ethnography (CCE): a methodology for anticipating future user needs. In *Work: A Journal of Prevention, Assessment and Rehabilitation (IEA 2012: 18th World congress on Ergonomics - Designing a sustainable future)* (Vol. 41, pp. 5251–5258). Amsterdam, The Netherlands: IOS Press.

Kitajima, M. (2012b). *Organic Self-Consistent Field Theory.* http://oberon.nagaokaut.ac.jp/ktjm/organic-self-consistent-field-theory/index.html.

Kitajima, M., Akamatsu, M., Maruyama, Y., Kuroda, K., Katou, K., Kitazaki, S., ... Kajikawa, T. (2009). Information for Helping Drivers Achieve Safe and Enjoyable Driving: An On-Road Observational Study. In *Proceedings of the Human Factors and Ergonomics Society 53rd Annual Meeting 2009* (pp. 1801–1805). Santa Monica, CA: Human Factors and Ergonomics Society.

Kitajima, M., Kumada, T., Akamatsu, M., Ogi, H., & Yamazaki, H. (2005). Effect of Cognitive Ability Deficits on Elderly Passengers' Mobility at Railway Stations - Focusing on Attention, Working Memory, and Planning. *Gerontechnology*, *3*(4), 231.

Kitajima, M., Kumada, T., Ogi, H., Akamatsu, M., Tahira, H., & Yamazaki, H. (2008). Usability of Guide Signs at Railway Stations for Elderly Passengers – Focusing on Planning, Attention, and Working Memory. *Ergonomics*, *44*(3), 131–143. (in Japanese)

Kitajima, M., & Naito, K. (Eds.). (2010). *The Science of Consumer Behavior*. Tokyo: Tokyo Denki University Press. (in Japanese)

Kitajima, M., Nakajima, M., & Toyota, M. (2010). Cognitive Chrono-Ethnography: A method for studying behavioral selections in daily activities. In *Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting* (pp. 1732–1736). Santa Monica, CA: Human Factors and Ergonomics Society.

Kitajima, M., Shimada, H., & Toyota, M. (2007). MSA:Maximum Satisfaction Architecture – a basis for designing intelligent autonomous agents on web 2.0. In D. S. McNamara & J. G. Trafton (Eds.), *Proceedings of the 29th Annual Conference of the Cognitive Science Society* (p. 1790). Austin, TX: Cognitive Science Society.

Kitajima, M., Tahira, H., & Takahashi, S. (2010). A Cognitive Chrono-Ethnography study of visitors to a hot-spring resort, Kinosaki-onsen. In M. Kozak (Ed.), *Proceedings of the 5th World Conference for Graduate Research in Tourism, Hospitality and Leisure* (pp. 436–445). Ankara, Turkey: Detay Anatolia Akademik Yayincilik Ltd.

Kitajima, M., Tahira, H., Takahashi, S., & Midorikawa, T. (2012). Understanding tourist's *in situ* behavior: a Cognitive Chrono-Ethnography study of visitors to a hot spring resort. *Journal of Quality Assurance in Hospitality and Tourism*, *12*, 247–270.

Kitajima, M., & Toyota, M. (2011a). Four Processing Modes of *in situ* Human Behavior. In A. V. Samsonovich & K. R. Jóhannsdóttir (Eds.), *Biologically Inspired Cognitive Architectures 2011 - Proceedings of the Second Annual Meeting of the BICA Society* (pp. 194–199). Amsterdam, The Netherlands: IOS Press. doi: 10.3233/978-1-60750-959-2-194

Kitajima, M., & Toyota, M. (2011b). *Practical Guide to CCE (Cognitive Chrono-Ethnography) – A Study Methodology of Human Beings' Behavioral Ecology Based on Cognitive Science.* Tokyo: ON-BOOK.ltd. (in Japanese)

Kitajima, M., & Toyota, M. (2012a). Cognitive Chrono-Ethnography: A Methodology for Understanding Users for Designing Interactions Based on User Simulation with Cognitive Architectures. In *Biologically Inspired Cognitive Architectures 2012 - Proceedings of the Third Annual Meeting of the BICA Society* (pp. 193–198).

Kitajima, M., & Toyota, M. (2012b). Decision-Making and Action Selections in Two Minds. In *Biologically Inspired Cognitive Architectures 2012 - Proceedings of the Third Annual Meeting of the BICA Society* (pp. 187–192).

Kitajima, M., & Toyota, M. (2012c). The Role of Memory in MHP/RT: Organization, Function and Operation. In *Proceedings of ICCM 2012: 11th International Conference on Cognitive Modeling* (pp. 291–296).

Kitajima, M., & Toyota, M. (2012d). Simulating navigation behaviour based on the architecture model Model Human Processor with Real-Time Constraints (MHP/RT). *Behaviour & Information Technology*, *31*(1), 41–58. doi: 10.1080/0144929X.2011.602427

Kitajima, M., & Toyota, M. (2013). Decision-making and action selection in Two Minds: An analysis based on Model Human Processor with Realtime Constraints (MHP/RT) . *Biologically Inspired Cognitive Architectures*, *5*, 82–93. doi: http://dx.doi.org/10.1016/j.bica.2013.05.003

Kitajima, M., & Toyota, M. (2014a). Hierarchical Structure of Human Action Selections – An Update of Newell's Time Scale of Human Action. In *Submitted to BICA 2014.*

Kitajima, M., & Toyota, M. (2014b). The Role of Consciousness in Memorization : Asymmetric Functioning of Consciousness in Memory Encoding and Decoding. In *Submitted to BICA 2014.*

Kitajima, M., & Toyota, M. (2014c). Topological Considerations of Memory Structure. In *Submitted to BICA 2014.*

Kitajima, M., Toyota, M., & Shimada, H. (2008). The Model Brain: Brain Information Hydrodynamics (BIH). In B. C. Love, K. McRae, & V. M. Sloutsky (Eds.), *Proceedings of the 30th Annual Conference of the Cognitive Science Society* (p. 1453). Austin, TX: Cognitive Science Society.

Kitajima, M., Toyota, M., Yoshino, K., Matsumoto, S., Tahira, H., & Miyaji, R. (2011). Relationship Between Episodic Memory Formation and Two Minds. In *Proceedings of the 33rd Annual Conference of the Cognitive Science Society* (p. 2095). Cognitive Science Society.

McClelland, J. L., Rumelhart, D. E., & Group, P. R. (1987). *Parallel distributed processing: Explorations in the microstructure of cognition: Psychological and biological models (a bradford book)* (Reprint ed.). The MIT Press. Retrieved from `http://amazon.co.jp/o/ASIN/0262631105/`

Prigogine, I., & Stengers, I. (1984). *Order out of chaos.* William Heinemann.

Someya, E., Kitajima, M., Tahira, H., & Kajikawa, T. (2009). Project B*B: Developmental processes of fan loyalty for the professional baseball team 'The Hokkaido Nippon-Ham Fighters'. In *Proceedings of the 2009 North American Society for Sport Management Conference (NASSM 2009)* (pp. 364–365).

Squire, L. R., & Kandel, E. R. (2008). *Memory: From mind to molecules* (2nd ed.). Roberts & Co. Retrieved from

http://amazon.co.jp/o/ASIN/0981519415/

Suto, S., & Kumada, T. (2010). Effects of age-related decline of visual attention, working memory and planning functions on use of IT-equipment. *Japanese Psychological Research*, *52*, 201–215.

Swanson, L. W. (2011). *Brain Architecture*. Oxford University Press.

Toyota, M., & Kitajima, M. (2010). MHP/RT: Model Human Processor with Real Time Constraints. In S. Ohlsson & R. Catrambone (Eds.), *Proceedings of the 32nd Annual Conference of the Cognitive Science Society* (p. 529). Austin, TX: Cognitive Science Society.

Toyota, M., Kitajima, M., & Shimada, H. (2008). Structured Meme Theory: How is informational inheritance maintained? In B. C. Love, K. McRae, & V. M. Sloutsky (Eds.), *Proceedings of the 30th Annual Conference of the Cognitive Science Society* (p. 2288). Austin, TX: Cognitive Science Society.

Yoshino, K., Matsumoto, S., Someya, E., & Kitajima, M. (2011). Happiness and heart rate response: a case of fan services at japanese professional baseball games. *Natural Science*, *3*, 255–258.

Yoshino, K., Suzuki, K., & Tahira, H. (2009). Project B*B: A physiological approach to assess and promote fan service in a professional baseball game of 'The Hokkaido Nippon-Ham Fighters'. In *Proceedings of the 2009 North American Society for Sport Management Conference (NASSM 2009)* (pp. 366–367).