PART 1

Theoretical Foundation for Dealing with Action Selection and Memorization

A Unified Theory of Action Selection and Memory

The purpose of this chapter is to provide a bird's-eye view of our project[1], the development of a framework for considering the behavior of human beings in the universe, nonlinear dynamic human behavior model with real-time constraints (NDHB-model/RT), and a cognitive architecture, "model human processor with real-time constraints" (MHP/RT), that is capable of simulating human being's daily decision making and action selection under NDHB-model/RT. The underlying idea is discussed in section 1.1.

1.1. Organic self-consistent field theory

1.1.1. *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 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

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1 The work discussed in this book is the result of a decade of collaboration between Makoto Toyota, cognitive architect, and Munéo Kitajima, cognitive scientist, the author of this book. The author is deeply grateful to Matkoto Toyota for his distinguished talent as a cognitive architect to imagine the complex working of the human brain. Throughout this book, "we" refers to "Makoto Toyota and Munéo Kitajima" unless it clearly implies people in general.

field. In this context, SCFT can be viewed as the "zeroth-order" expansion of the Hamiltonian in fluctuations. In reality, 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 study first- or second-order fluctuations.

1.1.2. *"Organic" SCFT*

We applied SCFT in physics to organic systems. Organic systems are those composed of human beings as their components. Any organic system can be represented as a model that considers a large number of individual human beings which interact with each other. In addition, individual "organic" human beings interact with "inorganic" physical environments as well, which is also 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 develops or evolves as a result of some fluctuations, a feature of the dissipative system – a fluctuation of the system caused by an environmental change could trigger the creation of a new order or catastrophe [PRI 85].
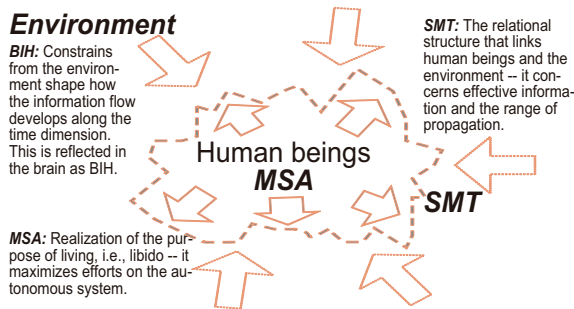
1.1.3. *Human beings considered in O-SCFT*

At the zeroth-order approximation implied by organic SCFT (O-SCFT), each human being interacts with the integrated environment consisting of inorganic components and organic components. Each human being is considered as *an autonomous system*, and interaction is best represented by *information flow* from the viewpoint of human being. Figure 1.1 shows the following three nonlinear constructs for representing human beings in O-SCFT:

1) Maximum satisfaction architecture (MSA) is about realization of the purpose of living, *libido* – it maximizes efforts on the autonomous system, i.e. each human being. It deals with how autonomous systems achieve goals under constraints defined by brain information hydrodynamics (BIH) and structured meme theory (SMT) [KIT 07], to be explained in what follows.

2) Brain information hydrodynamics (BIH) represents the constraints from the environment, which correspond to inorganic SCFT components. It defines how the information flow develops along the time dimension in the brain of individual human being [KIT 08].

3) Structured meme theory (SMT) represents the relational structure that links human beings, MSA, and the environment, inorganic SCF, to construct organic SCF. SMT concerns effective information and the range of propagation of information [TOY 08].

Environment

BIH: Constrains from the environment shape how the information flow develops along the time dimension. This is reflected in the brain as BIH.

SMT: The relational structure that links human beings and the environment -- it concerns effective information and the range of propagation.

Human beings
MSA

SMT

MSA: Realization of the purpose of living, i.e., libido -- it maximizes efforts on the autonomous system.

Figure 1.1. *Three fundamental constructs of O-SCFT*

1.1.4. *Scale mix*

Organic self-consistent field (SMT) provides a rather macroscopic viewpoint and considers the system in question as stable and obeys the law of increase in entropy (second law of thermodynamics), whereas BIH, corresponding to inorganic self-consistent field, provides a rather microscopic viewpoint where the universe is essentially a dissipative structure of a complex system that self-organizes as a hierarchical structure [PRI 85].

Gaia, the environment of the earth as a whole, is an extremely developed world with a complex hierarchical structure. Any phenomena in Gaia appear as the results of scale-mixed compounds of individual phenomena that coexist at different hierarchies characterized by their own scales in time and space. Any entities in the complex hierarchical structure that live across the multiple hierarchies should exist under a certain balance in the scale mix. Therefore, understanding human beings who live under MSA can be achieved by

considering their lives in a certain balance between organic self-consistent field, SMT, and inorganic self-consistent filed, BIH, established as a hierarchical structure.

1.2. Development of brain architecture model under the NDHB model/RT

We are not only interested in how individual human beings' brains process information, originated either from external or internal environment, but also by 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 *parallel distributed processing* (PDP) is the fundamental mechanism for developing brain architecture [MCC 87]. Since PDP is considered under O-SCFT, we prefixed "O (organic)" to PDP, O-PDP, 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 somehow reflect the experience of 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. *The guideline for architecture selection*

O-PDP represents the working of the entire organic system as a whole, in which a number of autonomous systems function in the ever-changing real 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 our architecture. Figure 1.2 depicts this schematically. It is quite reasonable to consider this as the optimum solution that resides at the intersection of the trace of evolution of human beings and the system architectures that are capable of reproducing the characteristics of current human beings.
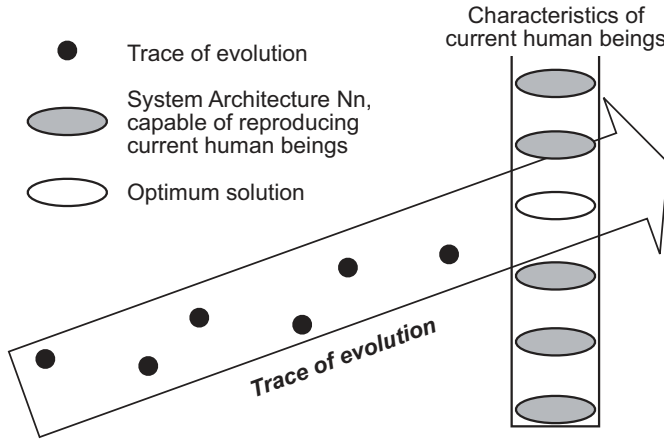

Figure 1.2. *The guideline we adopted for selecting our architecture*

1.2.3. *Development of cross-networks of neurons in the brain*

As Swanson [SWA 11] explains, cross-networks of neurons in the brain develop in a systematic way to show the three-layered structure of the interneurons system (Figure 1.3). Interneurons intervene in the sensory nervous system that is responsible for processing sensory information and in the somatic nervous system that is associated with the voluntary control of body movements via skeletal muscles to form a complex paired structure of perception and motion. They consist of direct feed-forward connections from perception to motion, and more complex connections with feedback loops using the interneurons to form three distinguishable layers.

Body movement is constructed by selecting executable motions and sequencing them in such a way that it adapts to the current 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 the deoxyribonucleic acid (DNA) body plan. A body movement could be associated with multiple different purposes. Therefore, meaning to particular body movement is given *consciously* as a compound social ecology. In this way, PDP by McClelland and Rumelhart [MCC 87] is naturally integrated with evolutionary view described by Swanson [SWA 11].
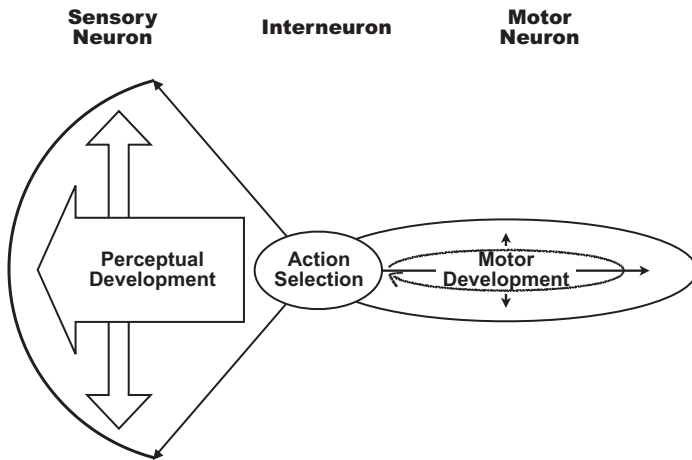
Figure 1.3. *Development of the sensory nervous system and the somatic nervous system, and interneurons connecting them with the action selection process (adapted from [KIT 15a])*

According to Damasio [DAM 99], a vertebrate animal develops its neural network system in the following way. It starts with the development of the paired structure consisting of the sense of touch and reflexive movements associated with it. Then, the sense of smell and the sense of taste, and, finally, the sense of seeing and the sense of hearing develop their associations with reflexive movements. From the beginning, the perceptual stimuli from the five senses form a paired structure with their associated reflexive movements. In addition, the association tends to become bidirectional for the purpose of establishing selective sensing, which is a paired structure with feedback between perception and movement. 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.
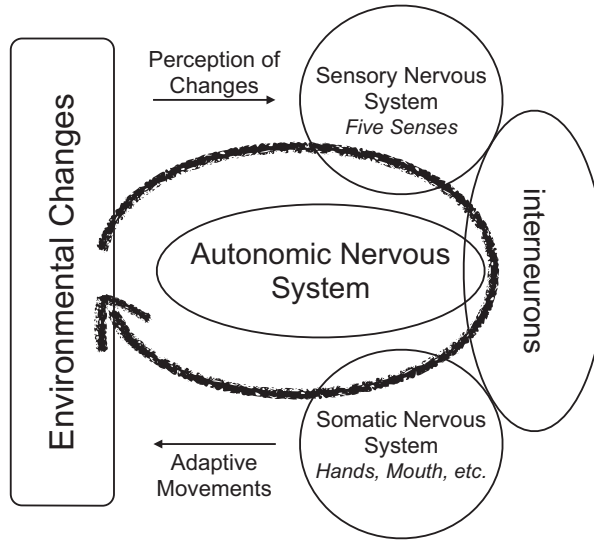
Figure 1.4. *Continuous cyclic loop of perception and movement (adapted from [KIT 14a])*

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 the NDHB-model/RT (see Chapter 2) as an architecture model that consists of a number of autonomous systems including the perceptual system, conscious system (System 2), unconscious system (System 1), memory system, behavior control system, and so on. A number of theories have been constructed as the project develops. Respective theories take different viewpoints for observing a variety of phenomena generated by the single mechanism of O-PDP.