Relationships between the methods of problem solving (retrieval, discovery, or search) and the kinds of acquired problem solving skills

課題解決型（解検索型／解発見型／解探索型）の実行と獲得される問題解決能力の関係

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Abstract: There are three methods for deriving a solution for a problem with which a person is facing, which are 1) retrieval of an existing solution from his/her own memory or from available external resources including human resources, digital resources, 2) clarifying the constraints to meet and discovering a solution that should satisfy them by exploring the problem space, or 3) deriving a solution by applying inference rules successively until the goal state is achieved. This paper describes the distinctive cognitive processes that respective methods should follow when deriving a solution. On the assumption that the ultimately needed problem solving skill would be the one which makes a person solve any problem by himself or herself without reliance on any external resources other than himself/herself, this paper discusses the implications of the respective methods of problem solving to acquiring the required problem solving skill.

概要：直面している課題に対する解決策は質的に異なる３つの方法で得ようとすることができる。１）既に存在している解決策を検索する（自分の記憶の利用、または、他の情報を利用）２）解が満たすべき制約を明らかにして、制約を満たす解を発見する、３）現状に対して手続き的知識を連鎖的に適用し解状態に到達する。これらの方法は異なった認知プロセスを伴うので、認知プロセスを動かすことによって獲得される知識やメタ認知スキルも異なる。本稿では、人間の記憶と行動選択プロセスに関する理論に基づいて、上記の３つの課題解決方法の特徴を、究極的に求められている自分自身の力のみで課題に立ち向かうことを可能とする「問題解決」能力の視点から、教育現場での実践の可能性を考察する。

Keywords: problem solving, problem solving skill, well-defined problem, ill-defined problem, MHP/RT, Multi-dimensional memory frame, routine expertise, adaptive expertise

1. Introduction

Problems are part of daily life. A problem can be defined as a situation in which people cannot immediately achieve their goals using routinely procedures. In order to solve their problems, people have to understand what the problem is, to find adequate resources, to undertake adequate actions, and to monitor the situation until the goal is reached, getting around impasses and other unexpected obstacles and undertaking corrective actions if and when necessary. Problem solving research has stressed the importance of past experience, prior knowledge, and one's ability to articulate goals and plans in skilled problem solving (e.g., Newell and Simon [1]; Meyer [2]). (e.g., Chi, Glaser, & Rees, 1981; Funke, 2010; Mayer, 1992; Newell & Simon, 1972; Sweller, 1998). In addition, problem-solving skills are considered crucial for successful participation in society. They are seen as one of the key precursors of success on the job and for engagement into lifelong learning [3].

The purpose of this paper is to give a characterization of problem solving activities from the viewpoint of well-definedness of problem, and to provide a detailed analysis of respective problem solving activities by using a cognitive architecture, MHP/RT, and discusses the nature of problem solving skills, required and potentially acquired, as a function of the degree of well-definedness of the problems.

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2. Problem solving activities

2.1 A definition

Following GPS (General Problem Solver) by Newell and Simon [1], problem solving is defined by a sequence of the following processes:

1. Recognize and represent the current state, or generate a representation of the current state. When the current state is the initial state to start a problem solving activity, the current state is replaced by "initial state",
2. Imagine and represent the states to achieve, or generate a representation including the top-level goal and intermediate subgoal states,
3. Select an action to move the current state to the next, which becomes the current state if the move is done successfully, and
4. Repeat until the top-level goal state is achieved.

In order for a person to carry out a PS activity by applying these PS processes, the following conditions have to be satisfied:

1. Be aware of the existence of goals to achieve and represent them unambiguously and precisely at an appropriate grain size,
2. Represent the current state as the initial state unambiguously and precisely at an appropriate grain size,
3. Have a repertoire of operators for transforming one state to another, and
4. Have a consistent set of criteria for selecting an appropriate operator among competing operators, which can be applied to the current state but cause transitions to different states.

2.2 Problem-solving in well-defined problem spaces

A problem space is defined by an initial state, a goal state, a set of intermediate states, and operators to move from one state to another if a set of conditions to move are satisfied.

A problem space is well-defined if the initial state, the goal state, and the intermediate states are represented unambiguously and precisely, and the conditions for move are defined appropriately. A person who solves a problem in a well-defined problem space (or if he/she is able to represent the problem as an instance of a well-defined problem space) would show a deterministic PS behavior for a given goal, i.e., he/she solves a problem to achieve the given goal starting from a specific initial state by successively applying a fixed sequence of operators, which may be most efficient in terms of, e.g., time, energy consumption, etc.

Card, Moran and Newell [4] suggests that the knowledge that a person acquires for carrying out routine goal-oriented tasks defined by well-defined problem spaces consists of Goal, Operators, Methods, and Selection rules (GOMS). Goal is represented as a rigid hierarchical goal structure, in which a goal is satisfied if and only if all of its subordinate sub-goals are satisfied. Method is defined by a specific fixed-ordered sequence of operators to accomplish a specific goal. Hierarchically, operators reside at the bottom layer of the goal structure, and methods are just above the operator-layer, each of which is considered as a label to identify a distinct sequence of operators, and associated with a goal at that level of hierarchy, in such a way as "goal G is accomplished by applying method M." Selection rule specifies a consistent rule to select a method among competing methods applicable for the current state. An operator's performance such as execution time is required to be independent of states in order for an operator to be qualified as Operator of GOMS. With these features, GOMS models are able to predict performance times of skilled users in carrying out routine goal-oriented tasks [5], [6].

If a person has a well-defined problem space for a given goal, his/her operator sequence is predictable. Models developed under ACT-R cognitive architecture [7], [8] can simulate cognitive processes involved in accomplishing goals by focussing on single goals successively and searching for production-rules defined by a set of pairs of conditions and actions (equivalent to operators in this context). They are stored in procedural memory and those that match the conditions concerning the currently focussed goal and the existence of required knowledge stored in declarative memory are possible to fire in the next cycle. A person who becomes an expert level of a domain can be viewed as one who has constructed an efficient set of production rules, called "routine expertise" [9]. GOMS model lies at one extreme of a well-defined problem space, where the strong condition for operator qualification is applied, i.e., an operator has to be independent of context, or an operator's performance has to be indifferent to which state it is applied, and due to this feature, it can predict performance times of a specific kind of problem solver.

For those who can use a well-defined problem space when he/she needs to accomplish a goal, it reduces just to cognitive activities to traverse the problem space. It may require times for representing current states, searching for the next operators that match the conditions to move with the current state, selecting the most appropriate one among a set of competing operators, and actually carrying out the selected operator.

2.3 Problem-solving in ill-defined problem spaces

A well-defined problem space can degrade to ill-defined problem spaces easily due to several reasons. One may have the abilities to transform an initially ill-defined problem space to a less ill-defined one. Once an ill-defined problem space is transformed to a well-defined one, one may traverse the well-defined problem space by successively firing production rules as modeled by the ACT-R cognitive architecture. Holyoak [9] names this class of expertise as "adaptive expertise", who is good at generate appropriate decoupling of the condition-action pairs of the production rules flexibly in the given situation to produce appropriate actions. Procedural knowledge represented as production rules are for traversing in a well-defined problem space. Given a top-level goal, one is required to find in his/her knowledge a well-defined problem space or somehow generate one. Once it is defined, PS activities can be considered as the activities for traversing in the problem space. PS skills should involve the skills necessary for transforming an ill-defined one to well-defined, or less ill-defined ones.

2.4 Turning well-defined problem into ill-defined ones

In the following, I will describe how well-defined problem may turn into ill-defined ones, and point out necessary cognitive skills for changing ill-defined one to well-defined one.

2.4.1 Imagining goals is not trivial:

One may have difficulty in imagining a set of goals to achieve the top-level goal. For example, a foreign traveler stands in front of a ticketing machine with unfamiliar and strange interface to him/her by which he/she believes he/she is supposed to buy a train ticket. He/she is unable to generate intermediate goals to achieve the top-level goal, i.e., "he/she has a necessary ticket in his/her hand." This is the issue of mental models:

- the variety of mental models one has in the domain in question (mental model),
- the ability to switch from one mental model to another if the current one is estimated as ineffective (switching skill),
- the ability to create effective mental models from experience (model creation through experience)

2.4.2 Recognizing and representing state is not trivial:

In traversing *a well-defined problem space*, it is obvious where to attend to in the current state one has reached, and how to represent it because every state has already been represented unambiguously and precisely at the required level for selecting next operators. However, when goals are underspecified, one may find difficulty in controlling where to attend because a goal for the current state should provide the semantic context that helps him/her to parse the current state of the scene where he/she is in and comprehend it.

Comprehension requires background knowledge which is different from person to person. In addition, the ability to filter out the relevant objects from irrelevant ones may differ from person to person. Kitajima and Toyota [10] demonstrated that elderly participants who had inappropriate functioning of attention had difficulty in acquiring relevant information from rather complicated sign boards while performing a way-finding task. This evidence shows that even if one has a well-defined problem space in his/her long-term memory, it might be difficult for him/her to activate it for use in the problem solving activity. No effective retrieval cue is represented in working memory to activate task relevant well-defined problem space.

In this stage, an ill-defined problem space might change to a well-defined or less ill-defined one if one has the following:

- background knowledge to make him/her possible to represent objects in the current state appropriately for the given goal (background knowledge and comprehension skill),
- the ability to use the representation for defining to-be-searched-for objects (target objects) or evaluating the degree of relevance of attended objects (searching skill),
- the ability to pay attention to the relevant objects in the current state (attention skill)

2.4.3 Selecting next action is not trivial:

In traversing *a well-defined problem space*, next actions are selected by evaluating expected cost to be expended moving from the current state to the final goal state. Means-ends analysis or the hill climbing strategy is applied for this purpose. This is only possible when the problem space is strictly defined and one is able to manipulate it as a whole. In reality it is not possible if the size of problem space is large. One cannot foresee the entire problem space. In addition, one cannot fully specify the current situation. Under these conditions, one's action selection should not be rational but is controlled by the bounded rationality principle and the satisficing principle uncovered by Simon [11] and further studied by Kahneman [12] in generating situated next actions.

However, the farther one can foresee in the problem space, the lesser ill-defined the current problem space becomes. Kitajima and Toyota [10] demonstrated that elderly participants who had inappropriate functioning of planning had difficulty in estimating relevance of the acquired "right" information from sign boards to the current goal while performing a way-finding task because the current goal is underspecified. This evidence shows that even if one is able to attend to a right object, it might be difficult for him/her to estimate it as relevant for accomplishing the current goal which is not detailed enough to be matched with the representation of the right object.

An ill-defined problem space might change to a well-defined or less ill-defined one if one has the following:

- the ability to foresee the future states by performing mental simulation (planning ability),
- background knowledge to be used in the planning activity (mental model)

2.5 Cultural and individual differences

2.5.1 Differences in performance with *well-defined problem spaces*

There would be little differences between individuals and therefore cultures in the way how one carries out problem solving if he/she has a well-defined "tractable" problem space corresponding to the given problem and if one has adequate level of attention and planning cognitive functions. In this context, a problem space is tractable if it is small enough to manipulate the problem space as a whole. Otherwise, even if a problem space is well-defined, if the size of the problem space exceeds the threshold value that guarantees tractability, it enters into the realm where the bounded rationality and satisficing principles define how phenomena should emerge.

As said, there would be little difference in performance when one engages in a problem solving activity in a well-defined tractable problem space that would mirror his/her knowledge as a mental model with adequate level of attention and planning cognitive functions. There will be individual differences in how one manages the bounded rationality and satisficing principles.

2.5.2 Differences in performance with *ill-defined problem spaces*

There will be individual differences and cultural differences in performances for solving problems in ill-defined problem spaces. There should be individual differences because every one has his/her own background knowledge, which in effect should have different effects on the performance of transforming ill-defined

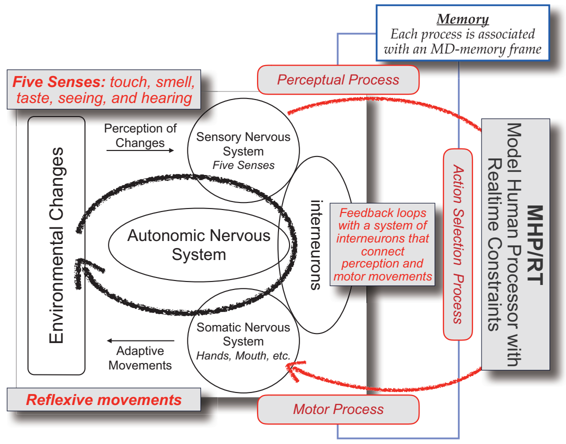

Fig. 1 Continuous cyclic loop of perception and movement.

problem space to a well-defined one. In addition, differences in cognitive functions of attention and planning would affect the detail of performance. It is known that these cognitive functions degrade as one gets older [13].

People who do not have confidence in transforming an ill-defined problem space to a well-defined one may not even try to make efforts to solve problems that they judge as ill-defined. The criteria for deciding problem as ill-defined would be different from person to person. People judge a problem ill-defined due to a variety of reasons and therefore the ways how to transform an ill-defined problem space to a well-defined one if they decide to make efforts to do could be diverse.

3. A closer look at selecting next action from cognitive architecture

This section introduces a cognitive architecture, MHP/RT (Model Human Processor with Realtime Constraints) [10], [14], that is capable of simulating action selection processes in *any* problem solving situation as described in the previous section phenemenologically. It consists of memory and action selection processes that describe in detail not only how action selections are carried out and what action will be performed but also how the results of action selections are stored in memory (see [15] for a full description of the architecture and its applications).

3.1 Cyclic processes of action selection and memorization

MHP/RT describes a cyclic process of action selection and memorization while one lives in the world, and the memory is gradually structured as multi-dimensional memory frames as one interacts with the environment. Constraints on behavioral processing are imposed by conscious and unconscious processes, and behavior must be synchronized with the ever-changing external and internal environments, which is a form of self-organization. With the cyclic processes of action selection and memorization, one develops his/her memory and shows distinct behavioral characteristics as one grows [16], [17].

MHP/RT and multi-dimensional memory frames will be introduced by considering how a vertebrate animal develops its neural network system through continuous cyclic loop of perception and movement by using Figure 1. 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. 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.

MHP/RT specify behavior generation processes that include the autonomous perceptual system associated with sensory neurons and the autonomous motor system associated with motor neurons. Interneurons process the input from the perceptual system with the conscious decision making process or the unconscious automatic action selection process. Each process in behavior generation defined by MHP/RT is associated with a Multidimensional memory frame. As such, behavior and memory are intimately connected with each other and the amount of the contents stored in memories are accumulated incrementally as the time goes by and the stored entities are strongly influenced by the detailed experience each individual has at each moment.

3.2 MHP/RT: Model Human Processor with Realtime Constraints

By extending a version of dual processing theories, Two Minds, proposed by Kahneman [12], [18], we have developed an architecture model Model Human Processor with Realtime Constraints, which is capable of simulating decision making and action selection in daily life [10], [14]. Two Minds consists of unconscious processes, System 1, and conscious processes, System 2. System 1 is a fast feed-forward control process driven by the cerebellum and oriented toward immediate action. In contrast, System 2 is a very slow feedback control process driven by the cerebrum and oriented toward future action.

Figure 2 shows the outline of MHP/RT. MHP/RT focuses on synchronization between System 1 and System 2 in the information flow from the perceptual system from the environment at the left end to the motor system at the right end. Output from the perceptual system is diverted into three paths, one path leads to the conscious process of System 2, the other leads to the unconscious process of System 1, and the last one leads to the memory system. Information in memory activated by the input from the environment is become available to System 1 and 2. System 1 and 2 work in synchronous with each other but the memory process works asynchronously with System 1 and 2. The dotted oval shows the process of memorization of output from the motor process. These interactions between System 1 and 2, and memory are not seriously considered in the original Karhneman's Two Minds. Processes associated with unconscious System 1 are indicated by green lines. And those associated with conscious System 2 are

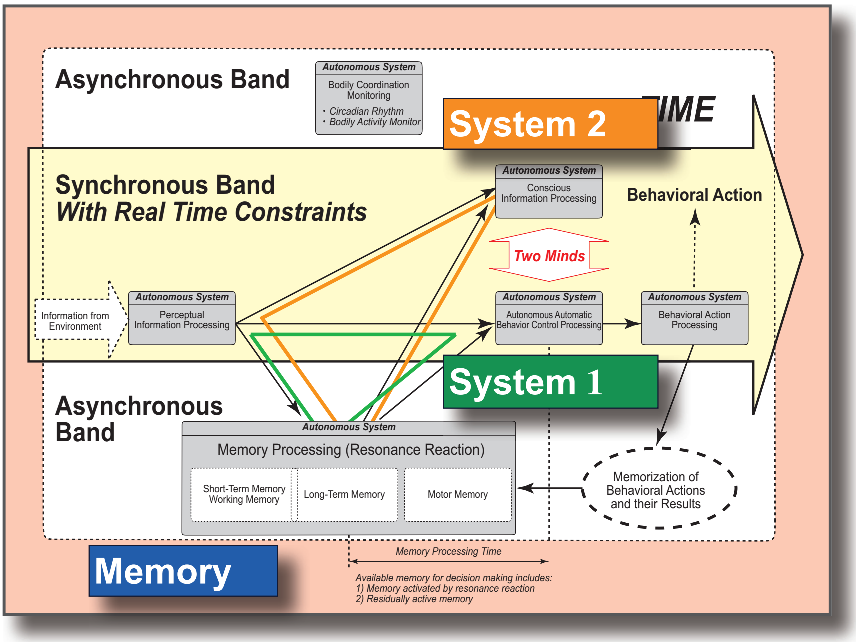

Fig. 2 Model Human Processor with Realtime Constraints.

indicated in orange lines.

3.3 MHP/RT's Four-Processes: Use and modification of memory

Figure 3 explains how MHP/RT works for a particular event, such as "taking a right turn at an intersection." At a particular time before this event, one engages in conscious processes and unconscious processes concerning the event to happen in the future. At a particular time after the event, one engages in conscious processes and unconscious processes concerning this event that has already happened in the past. What one can do before and after the event is strongly constrained by the Newell's time scale of human action [19]. System 2 carries out the processes surrounded by an orange round-cornered rectangle at the time range from 10 seconds, whereas System 1 does those surrounded by a green one at the time range from a hundreds of milli seconds to a few seconds.

MHP/RT works in one of four different modes. Two are before the event in which MHP/RT uses memory and the other two are after the event in which it modifies memory.

- **System 2 Before Mode:** MHP/RT consciously uses memory before the event for anticipating the future event which takes relatively long time.
- **System 1 Before Mode:** MHP/RT unconsciously uses memory just before the event, say 100 milli seconds before the event for automatic preparation for the future event.
- **System 1 After Mode:** MHP/RT unconsciously tunes the current network connections related to the past event for better performance for the same event in the future.
- **System 2 After Mode:** MHP/RT consciously reflects on the past event resulting in structural changes in memory.

3.4 How memory is constructed in System1 and 2 After Mode

Memory is created via working of autonomous nervous system that operates along the information flow from the sensory nervous system to somatic nervous system via interneurons under the time constraints that would reflect the environmental conditions at the time of operation. We can derive structural features by considering the fact that each autonomous system in MHP/RT has its own memory; each memory system records the traces of its working over time.

(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.

These objects are then used independently in Systems 1 and System 2 of Two Minds, 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 are processed in the next cycle, representation of the objects may serve as the common elements to combine the System 1 memory and the System 2 memory to form an inter-system memory.

3.5 Multidimensional frame as a distributed memory system

We call this memory the Multi-Dimensional (MD)-memory frame as defined below:

- **PMD (Perceptual Multi-Dimensional)-frame** constitutes

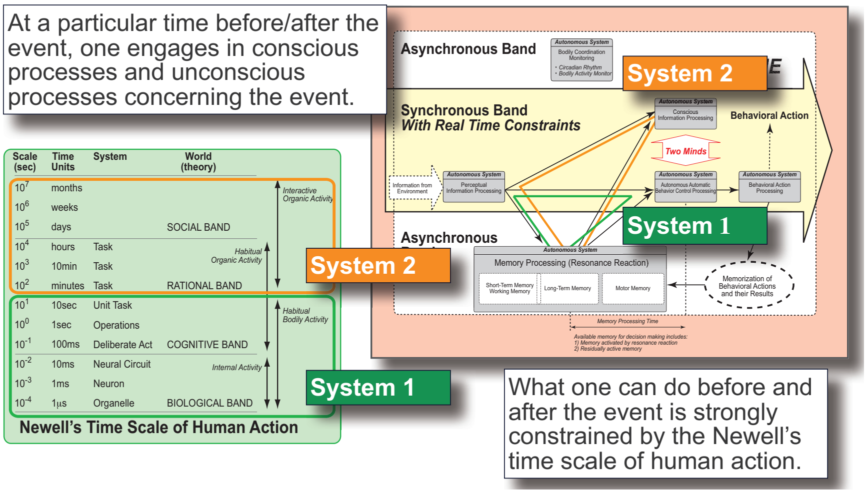

Fig. 3 Four-processes and time constraints.

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 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.
- **WMD (Word Multi-Dimensional)-frame** is the memory structure for language. It is constructed on a very simple one-dimensional array.

MHP/RT specifies how one uses and modifies memory, and the contents of memory at the time of use specifies what MHP/RT can do and does. As MHP/RT works, the contents of memory change according to the results of performance of MHP/RT.

3.6 Evolution of the "MHP/RT + MD-Frames" system

Figure 4 focuses on formation of a cyclic network of relations between perceptual development and motor development.

The first step is to segment out an object by detecting edges by using perceptual information represented in multiple dimensions including haptic cognition, visual cognition, and so on, which is superficial but information density is very high. The characteristics of the object are specified through its use in behavior, which is serial in nature and therefore information density is low. Once a word symbol is attached to the object, it works as a pointer to the object. Since a symbol connotes the use context of the object it represents, the network of symbols that will be constructed in the future is inevitably influenced by existing symbols.

Each object is represented as a symbol in the correlation matrix in the form of a cyclic network of relations. A symbol node is recognized as the pre-existing symbol node when the contents of perception and body movement coincide with the ones associated with the existing symbol. Then the recognized symbol will be incorporated in the growing network.

4. Problem solving activities viewed from MHP/RT

This section discusses how problem solving activities are described from the viewpoint of MHP/RT's action selection processes and memory processes. There are three methods for deriving a solution for a problem with which a person is facing, which are 1) retrieval, 2) inference, or 3) exploration. In the following subsections, each method is elaborated by combining the description in Section 2 and Section 3.

4.1 Solving a problem by retrieval

Solving a well-defined problem: Given a problem statement, irrespective of whether it is generated internally or provided externally, a person represents both the goal state to achieve and the initial state that he/she is in unambiguously and precisely enough to retrieve the description of the action sequences that should intervene the both ends of the states *from his/her memory*. Therefore, this problem is considered as a well-defined problem.

In this case, the processes shown in Figure 4 plays an important role for converting the problem statement to the one used for retrieval. For solving the problem, he/she is required to just carry out the retrieved sequence of actions. This practice should strengthen the retrieved memory trace that connects the represen-

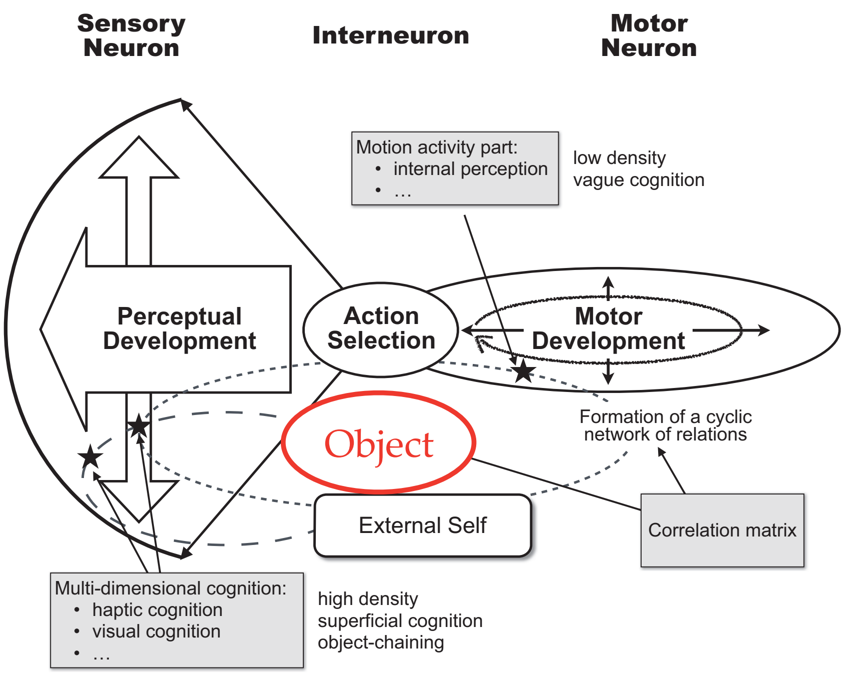

Fig. 4 Development of the sensory nervous system and the somatic nervous system, and interneurons connecting them with action selection process.

tation of the initial state and the goal state. System 2 Before Mode is used when retrieving the sequences of actions, and System 1 Before Mode is used to actually solve the problem. System 1 or 2 After Mode strengthen the memory that has used in the activity. In this way, he/she actually learns from the problem solving practice to strengthen the memory traces of successful performance.

Problem solved *without* problem solving activities: Given a problem statement, a person uses *external memory* to retrieve solutions. The description of the problem statement is used literally as it is, and he/she expects to reach any "solutions" that someone has already created for the problem. Since the solution is external, the person is required to follow consciously the sequences of actions as the solution specifies. In other words, the problem is solved by borrowing the others' thinking (cognitive) process, and he/she just perceives the state of the problem and moves eyeballs and hands as the description of what to do in the perceived situation. He/she could use System 1 After Mode for tuning neural networks to just finished activities or deliberate reflection in System 2 After Mode. Only when he/she does them, he/she can learn from the practice, otherwise he/she just memorizes the episode, "the problem was given, and successfully solved by retrieving solutions from the Web." The link between the problem and the solution may or may not be established. The problem may not be solved by using his/her memory when encountered it again in the future. Learning is very limited compared with the former case.

4.2 Solving a problem by inference

Given a problem statement, irrespective of whether it is generated internally or provided externally, a person represents both the goal state to achieve and the initial state that he/she is in unambiguously and precisely enough to retrieve the inference rules, or pieces of procedural knowledge, to carry out the necessary state transitions. This is the way of problem solving modeled as production systems like ACT-R [7], [8] or Soar [19], [20].

In this case, it is assumed that a person has procedural memory, which connects Perceptual Multi-Dimensional-frame with Behavior Multi-Dimensional-frame with the help of Relation Multi-Dimensional-frame. The inference rules are successively applied to transform the current state to the next until the goal state is achieved. System 2 Before Mode is used for planning and System 1 Before Mode is used to execute individual production rules. System 1 After Mode is used to strengthen the successfully applied production rules in Behavior Multi-Dimensional-frame and declarative memory in Relation Multi-Dimensional-frame. System 2 After Mode might be used to create a new set of production rules that are expected to function more effectively for the kinds of situations defined by the just solved problem. Ultimately, the person becomes able to carry out the same task more and more efficiently, very fast without error; it is said that he/she has acquired routine expertise for the kinds of tasks executable by applying well-learned procedural knowledge [9].

The states that appear while solving the problem are represented unambiguously and precisely enough to retrieve production rules from procedural memory, Behavior Multi-Dimensional-frame, and factual knowledge from declarative memory, Relation Multi-Dimensional-frame, triggered by Perceptual Multi-Dimensional-frame that is activated by external perceptual stimuli. *Therefore, the performance of problem solving activity would depend on the contents of memory and the functioning of perceptual sensors.* These should be influenced by the kinds of experiences one has had from his/her birth. This is obviously affected by the culture and the circumstances one is in in everyday life while one grows up. This suggests the external environment should be of crucial importance for fostering this kind of problem solving skill.

4.3 Solving a problem by exploration

Given a problem statement, a person can only represent both the goal state and the initial state vaguely, and therefore it is not possible for him/her to retrieve anything directly relevant to solve the problem. This is the case where he/she is faced with an ill-define problem as described in Section 2. He/she needs to create effective retrieval cues, "Object" in Figure 4, to find any action that should move the current state to another along the unknown successful path to the goal, whose representation should become less vague as one proceeds. This is equivalent to make the initial vague representation of the goal clearer; to convert the ill-defined problem to a less ill-defined or hopefully a well-defined one.

The notion of resonance is relevant for this to happen. Memory system in MHP/RT is regarded as an autonomous system, which means that memory should not be a passive database system to return data on request from the action selection process. The MHP/RT's memory system receives input from the autonomous perceptual system and resonates with the other autonomous systems, i.e., conscious system (System 2 of Two Minds) and unconscious system (System 1 of Two Minds) to make available the currently activated portion of memory. The mechanism of resonance is used to make available any relevant portion of Behavior Multi-Dimensional-frame to the action selection process of MHP/RT. System 2 Before Mode and System 1 Before Mode use this resonance mechanism to select plan and next action.

The selected action may succeed or fail, or result in uncertain outcome to fall into an impasse.The processes are totally exploratory but the memory traces of the executed actions will be created with the flag of success/failure. The memory trace with successful performance will be strengthened because it is associated with rewards. Ultimately, the person becomes able to handle the same situation flexibly with less ineffective search; it is said that he/she has acquired adaptive expertise [9] for the kinds of ill-defined tasks with a variety of well-developed Behavior and Motion Multi-Dimensional-frame available through resonance with Perceptual Multi-Dimensional-frame.

Development of flexible and rich memory is necessary for acquiring adaptive expertise through a variety of experience with reality (not virtual). It is often felt that a solutions for an ill-defined problem is discovered suddenly or the solution emerges spontaneously. It is because the critical process underlying the discovery is memory resonance. However, the richness of memory should affect the possibility of successful discovery should happen; construction of memory structure that integrates perception and body movement with high reality is important, and again a variety of experience with reality is important for fostering this problem solving skill.

5. Conclusions

This paper suggested that when faced with a problem, either it is given externally or generated internally, it could be carried out either by retrieval, search, or discovery method, each of which is associated with distinct cognitive processes for action selection and memorization. Respective methods should have different implications to development of problem solving skills. Retrieval method would be effective when his/her own memory is used; search method is effective for advancing efficient use of inference rules; discovery method is crucial for turning ill-defined problem to well-defined one which should be critical for problem skill development. The importance of experience was emphasized for fostering problem solving skills. Some aspects of experience needs to be carefully designed in education, society, or wherever a person carries out some activity for the purpose of fostering problem solving skills by considering the distinct features in terms of cognitive processes involved in the different kinds of problem solving activities.

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