Implementing a Problem Solving System for Physics based on Knowledge Map and Four Steps Problem Solving Strategies

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Abstract

In this paper, a problem solving system is implemented for Physics based on information-processing model in human being, Knowledge Map and four steps strategies designed for solving problems. According to structural knowledge and memory system, a Knowledge Map had been designed to integrate both knowledge hierarchy and knowledge schema. With Marshall's definitions of knowledge schema, four steps strategies are also designed in this paper. By using the knowledge map it will be able to accomplish the whole problem solving processes. Finally, there is an experiment system is constructed to be demonstration.

1. Introduction

There are many strategies for solving problems, such as Dewey purposed four steps for solving problems in 1910 and Polya provided another four stages for mathematical problems, they are understand problem, devise plan, carry out plan and look back in 1965.[9, 23] Recently Deek discovered almost all problem solving mechanism could be divided to four steps, which are Understanding and Defining the Problem, Planning the Solution, Designing and Implementing the Solution, and Verifying and Presenting the Results. [10]

To solve a problem not only strategies are necessary but related knowledge too. Knowledge elements store the knowledge exists in brain. To discuss how to use knowledge, memory system should be mentioned first. In 1981, Mayer proposed the information-processing model in memory system.[19] There are three major parts as Figure 1 shown following:

a. Sensory Memory (SM)
b. Short-term Memory (STM)
c. Long-term Memory (LTM)

To construct this memory system, a knowledge structure should be design first. This paper proposes a knowledge structure called Knowledge Map. There are two major elements existing in Knowledge Map: Knowledge Schema and Knowledge Hierarchy.

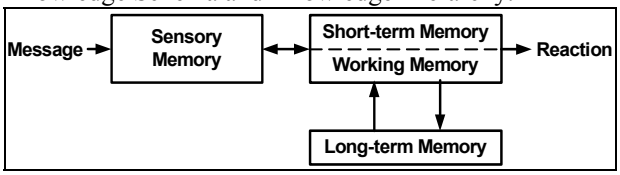

Figure 1. Information-processing model

In Section 2 some essentials of knowledge will described, such as concept, relation and representation Section 3 tries to develop a sort of knowledge representation for problem solving system, which is so-called Knowledge Map, integrated by both Knowledge Hierarchy and Knowledge Schema. Section 4 defines problem solving strategies and its operators, besides four steps for solving problem according to Marshall's schema theory are also designed in this Section. An experiment system is constructed in Section 5 for demonstrating the problem solving processes based on the Knowledge Map and Strategies Schema. There are a simple conclusion made and some possible future researches described in Section 6.

2. Essentials of Knowledge

The basic element of knowledge is concept. Novak and Gowin defined a concept as a designated label of regularity in events or objects [22]. That means a concept is a representative of something that could be used as an atomic unit of knowledge pieces. It could be noun phrase (for text), note, color, basic shape, or even single clothes. Here a concept is denoted as $\theta_i = e_N$, where e_N means a noun phrase, such as "Free Falling", "Kinematics", and so on. Some concepts belonging to the same specific domain can be gathered to a concept set, $\underline{\theta} = \{\theta_i\}$.

The aggregation of those knowledge pieces (concepts) called relation. Preece proposed eleven relations for semantic relationship in 1976; [24] Dansereau and Holley designed six links of network in 1978 and 1979; [7, 14] and Clifford conceived ten basic patterns of relationships for Frame Game in 1981.[5] In this paper, a relation is denoted as $\rho_j = e_V$, where e_V is denoted as verb phrase. Another way to present the relationship among concepts is called proposition. A unit of proposition displays an idea approximately.[13] Using the definition above, a proposition can be denoted as $\phi_k(\rho_j, \underline{\theta})$.

After elements of knowledge are well defined, the knowledge representation is then discussed. There are two types of knowledge representation: *declarative knowledge* and *procedural knowledge*. [13, 26]

a. Declarative Knowledge

b. Procedural Knowledge

The two knowledge types was proposed by Ryle in 1949 influenced some important theory, such as the Learning Theory proposed by Robert Gagné, Cognitive Theory proposed by John Anderson, and so on.[1, 2, 3, 11, 12, 26] Recently, some researches about neurophysiology also support this category of knowledge types. [20]

In declarative knowledge, there are three basic elements: *proposition*, *image*, and *linear ordering*. Proposition is the basic element of knowledge. It presents the relationship between concepts and usually do not need to preserve by sensory memory. Images and linear orderings are kinds of mental representation from sensory memory. Schema is the integrated element of declarative knowledge including proposition, images, and linear ordering. Rumelhart and Norman defined schema as a data structure stored in memory represents generic concept. [25]

3. Designing the Knowledge Map

The word *schema* comes from the Greek language. From ancient Greek, schema means "form", "shape", and "figure" [17]. Modern psychologists take the usage of schema as events, experiences, and situation [18]. Currently is wildly used for knowledge representation.

Marshall made a more precise definition of schema and defined four types of knowledge used for formatting and assessing schema. Marshall defined that a schema is a "vehicle of memory", which organizing similar experience of an individual [18]. To build and exam the schema, four knowledge types are assigned for schema:

a. identification knowledge

b. elaboration knowledge

c. planning knowledge

d. execution knowledge

Identification and elaboration knowledge compose together a framework, which allows the individual to form a tentative hypothesis about a situation, and then to test it by the following knowledge types, *planning knowledge* and *execution knowledge*. Planning knowledge is used to "make plans, create expectations, and set up goals and subgoals." The execution knowledge completes the steps of the plans.

In this paper, a concept with its related information is denoted a Knowledge Schema in Knowledge Map. Knowledge Schema also becomes one kind of high-level knowledge representation, which integrates information of natural categories, events, and text [13]. These information, which also called attributes, is symbolized as $attribute_j(\theta_i)$.

Another element of Knowledge Map is Knowledge Hierarchy, which presents the relations among Knowledge Schema. In 1969, Collins and Quillian made a typical experiment to prove information that stored in long-term memory is in network architecture.[6, 8] This experiment results suggest that people organize knowledge structurally and stored the features of the concept in different level of the hierarchical architecture as Figure 2 shown. The *Knowledge Map* designed in this paper integrated not only the relations in Concept Map but also the Knowledge Schema for corresponding concept.

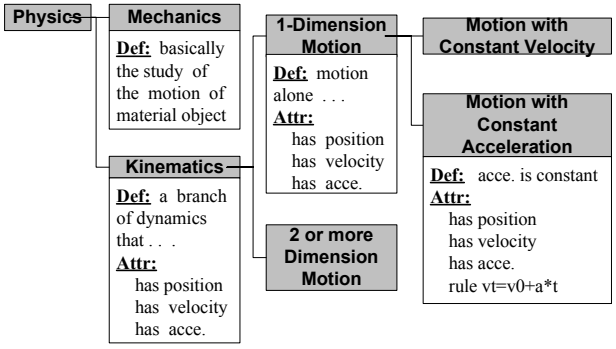

Figure 2. Knowledge Map with hierarchy form

4. Problem Solving Strategies from Schema

This paper also designs a four steps problem-solving solution by using four knowledge types proposed by Marshall [18]. Before the problem solving process is designed, the definitions of problem and its related strategies should be clarify and analyzed first.

A problem exists when someone has a goal and tries to find a way to reach the target [15]. Here, a problem is defined as a state of all the description of a problem, which containing the given resources that denoted as concepts $\underline{\theta}$, and the lacking ones that denoted as unknowns $\underline{x}=\{x_i\}$. So, a problem can be denoted as $\psi = \{\underline{\theta}, \underline{x}\}$, where $\psi \in \Psi$.

To construct a standard information-processing framework, a problem is constructed by some states: one end state, $\psi_D = \{\underline{\theta_D}\}$, which is the goal of a problem; one starting state, $\psi_S = \{\underline{\theta_S}, \underline{x_S}\}$, which is the initial description of the problem; and several intermediate states, $\psi_I = \{\underline{\theta_I}, \underline{x_I}\}$, which describes the possible solution paths of the problem [13, 21].

A problem is transformed from one state ψ_i to another ψ_{i+1} via operators, which could be denoted as $\tau_j(\psi_i) = \psi_{i+1}$. An operator that changed problem can also be seen as an edge between two states, that is $\tau_j = edge(\psi_i, \psi_{i+1})$. All operators are possibly used to transform problem is called operator space, $\underline{\tau_0} = \{\tau_j\}$. The set of operations in the solving procedure is called operator set, $\underline{\tau} = \{\tau_j\} \subseteq \underline{\tau_0}$. Therefore, the problem solving strategy is $\tau_j = \xi_k(\psi_i, \psi_D, \underline{\tau}) \in \underline{\xi}$ and the most common (heuristic) strategy is trying to reduce the distance from initial state to goal state

$$\tau_j = \xi_k(\psi_i, \psi_D, \underline{\tau}) = arg\ min\ distance(\tau_j(\psi_i), \psi_D),$$

where $\tau_j \in \underline{\tau}$.

According to the definitions of knowledge schema from Marshall, information-processing model in human being and problem solving strategies purposed in this paper, A model of four steps process for solving problem could be designed as Figure 3 shown: [4][16]

a. Problem Identification: $\xi_{idf}(\psi_i, \psi_D, \underline{\tau})$

b. Problem Elaboration: $\xi_{elb}(\psi_i, \psi_D, \underline{\tau})$

c. Problem Planning: $\xi_{pln}(\psi_i, \psi_D, \underline{\tau})$

d. Problem Execution: $\xi_{exc}(\psi_i, \psi_D, \underline{\tau})$.

5. Experiment System

In this Section, we use an example to demonstrate our experiment system. The experiment system is a Windows desktop application indicates the problem solving process by presenting the current situation in L.T.M. and S.T.M each step [27]. BTW, in each step we use different colors to make what actions are dealing with much clear to users. Finally a problem matrix is used for solving and getting results of each sub-problem just like Figure 6 shown.

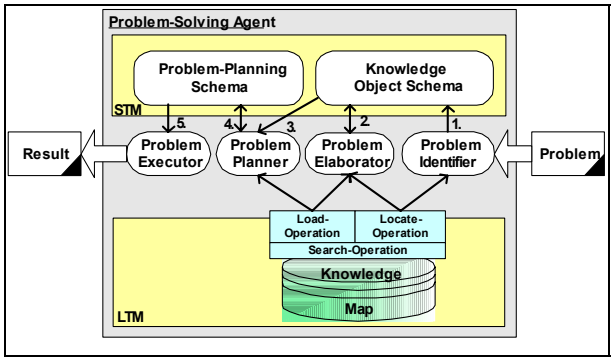

Figure 3. Four steps for solving problems

Our example question is

A paratrooper is free falling from a plane. He drops 44.1m in the sky and then opens the chute that gives him a constant acceleration of -2.0m/s^2. He reaches the ground at a velocity of 2.0m/s. What is the total time that takes this paratrooper from the plane to the ground?

As mentioned in previous sections, according to the four steps of problem solving in Section 4 (Figure 3), *Knowledge Map* designed in Section 3 (Figure 2) and memory system described in Section 1 (Figure 1), as Figure 4 represents in following sub-problem will be established by Physical Phenomenon firstly.

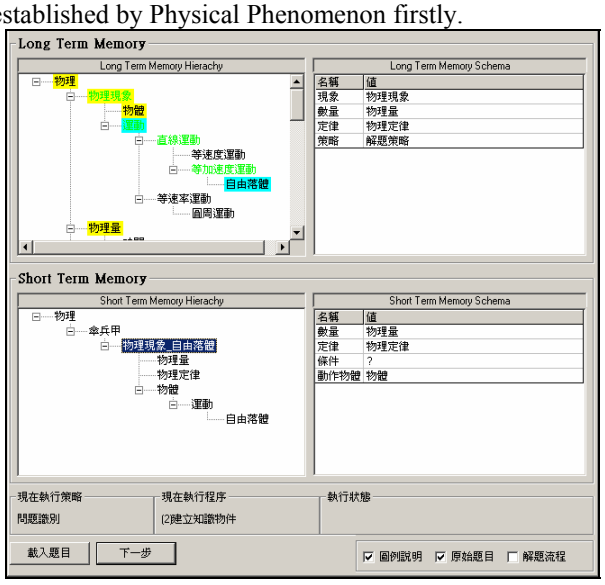

Figure 4. Establishing S.T.M. based on L.T.M.

After another sub-problem is added into the S.T.M. by keyword identification, the system is then begin the *Elaboration* step automatically just like Figure 5 shown above. Finally, when all information required for solving the specify problems have gathered from L.T.M. and the temporary Knowledge Map is constructed in S.T.M., a problem matrix, in Figure 6, comes from Knowledge Map then is created to resolve each (sub-)problem and the big one.

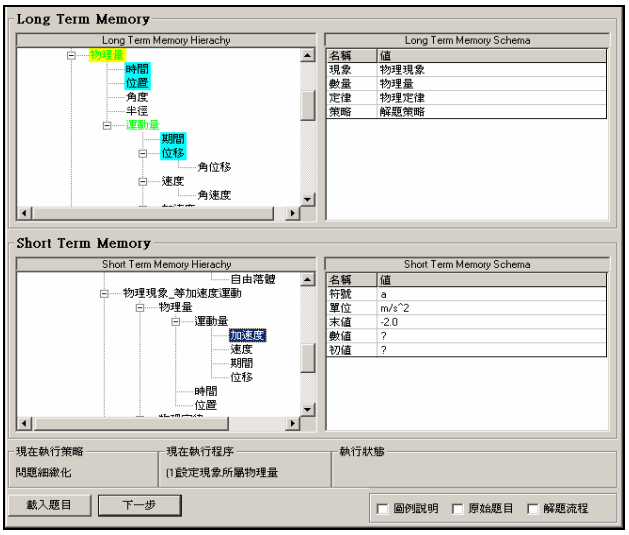

Figure 5. Elaborating Problem

6. Conclusions

This paper finished several goals, Knowledge Map, Problem Solving Strategies and Four Step Process of Problem Solving. Knowledge Map is a hierarchical knowledge structure constructed to integrate both advantages of Concept Map (relations) and Knowledge Schema (information). According to the definitions of problem, the problem solving strategies have been defined roughly but extendable when applying to problem solving processes.

With Marshall's knowledge schema, a corresponding four steps of problem solving process are designed. Finally a demonstration system based on Information-Processing Model is accomplished by using Knowledge Map to represent knowledge and four steps to resolve problems. However, more precisely definitions for strategies, what kinds of problem solving strategies exist and how they work should be our next research goal.

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Figure 6.Problem Matrix for solving (sub)problem(s).