Ontological Issues on Computer-based Training

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1 Introduction

The idea that the next generation computer-based training (CBT) systems should incorporate many innovative concepts in the acquisition, representation, and management of expert knowledge and common-sense knowledge is now widely accepted among the researchers.

The system which we call Smart Trainer is a CBT system including a set of simulators for facility of electric power systems. The development of Smart Trainer is partly motivated by the need for a powerful authoring system of Intelligent CBT systems. We think the specification authoring systems should be clarified in many viewpoints, for example, what role each component should play, to what extent the knowledge-bases should cover, to what degree of the fidelity of cognitive model should be pursued, and so on. In knowledge engineering, the research on a system of the concepts appeared in the domain of a knowledge-based system, called "ontology engineering"[Mizoguchi, 1995], attracts much attention of AI-researchers. So, to put the goal of the Smart Trainer in other words, we have been aiming at clarifying the ontology of CBT systems from the knowledge engineering viewpoint.

The expected advantages of explicit representation of ontology and its use are summarized as follows.

1. Because the ontology plays a role as fundamental scheme for authoring the contents, it provides authors with a right viewpoint for organizing training tasks of interest.
2. Because the functionality realized in a certain CBT system is explicitly specified by the ontology, the author can fully understand its capability in terms of human friendly primitives.
3. Once the educational knowledge and the contents of training tasks are organized under the ontology, they can be shared among authors.
4. The behavior of CBT can be self-explanatory in terms of ontology. In addition, it can be justified by the first principle behind the CBT ontology.

5. Because the functionality of CBT is represented in a right level of abstraction, it is easy to replace an out-of-date component of the system with one of the latest style.

In this paper, as a preliminary step to CBT ontology design, we briefly explain the principle behind the Smart Trainer. Let discuss little more generally about ontology and intelligent educational systems(IES) before going to CBT ontology.

2 Ontology Design for Intelligent Educational Systems

Building an IES(Intelligent Educational System) requires a lot of work. It is always built from scratch. Little functional components are reusable and we cannot compare or assess the existing systems. In order to design an IES, the designer has to know what an intelligent educational system is, that is, what functions are necessary for his/her goal of education, what components are necessary for what functionality, how to specify each component, what architecture is appropriate for the goal, how to control the behavior of the components, etc. Issues here include how much we know about these fundamental characteristics of an IES. Although there have been much philosophical discussion and implementation of IESs, there is little in between the two. What we usually see are very abstract discussions and idiosyncratic implementations[Wenger, 1987]. These discrepancies are mainly caused by the lack of knowledge engineering of IESs.

Knowledge engineering has been considered as a technology of building expert systems. It has contributed to eliciting expertise, organizing it into a computational structure, and building knowledge bases. While rule base technology has dominated until recently, a new technology based on knowledge modeling has appeared such as KADS project in Europe[Wielinga, 1983], PROTEGE project in USA[Puerta, 1992], and MULTIS project in Japan[Mizoguchi, 1992][Mizoguchi, 1995]. All these technologies are originated from the idea of Generic tasks[Chandra, 1986] and heuristic classification[Clancey, 1985]. The latest knowledge engineering technology comes up with an idea of task ontology which serves as a theory of vocabulary/concepts used as building blocks for knowledge-based systems[Mizoguchi, 1993, 1995]. We consider ontology consists of task ontology which characterizes the computational architecture of knowledge-based systems and domain ontology which characterizes the domain knowledge.

Task ontology provides us with an effective methodology and vocabulary for both analyzing and synthesizing knowledge-based systems which IESs belong to[Van Marcke, 1995]. Ontology is not only a pure theory in fundamental AI. Rather, it is becoming a research field called "Ontology Engineering"[Mizoguchi, 1996] like "Knowledge engineering" in expert systems. Ontology provides us with what we need to overcome the shortcomings the current IESs have we discussed above.

2.1 WHAT IS AN ONTOLOGY?

2.1.1 Simple definitions

Three simple definitions are given below.

(1) Ontology is a term in philosophy and its meaning is "Theory of existence".

(2) In AI, ontology is defined as "An explicit representation of conceptualization" [Gruber, 1992].

(3) In KB community, ontology is defined as "a system of primitive vocabulary/concepts used for building artificial systems"[Mizoguchi, 1993]. Although these are compact, it is not sufficient for in-depth understanding what an ontology is. A more comprehensive definition is given in the next subsection.

2.1.2 Comprehensive definitions

Clarification of the differences among taxonomy, terminology, vocabulary, and ontology and explain axioms and axiom-equivalents is done here.

(1) Terminology

We need to discuss the labels of concepts after coming to an agreement on the meaning of them. Terminology is a theory of labels of concepts.

(2) Vocabulary

A set of words. Each word indicates some concepts, so it is similar to ontology. But vocabulary is language-dependent, so it lacks the universality. (We sometimes find a concept which we cannot find any one word in our language for it.) Vocabulary is weak in description of the relations among the terms in it. As for vocabulary, labels exist first, then what concept does each label indicate is discussed contrary to terminology.

(3) Taxonomy

Taxonomy is also similar to ontology. It is often a hierarchy of concepts in which each link is a is-a link or a part-of link. Roughly speaking, ontology is a taxonomy of concepts in which each concept is clearly defined.

(4) Ontology

Following Guarino(Guarino, 95), we use the convention in which capital letter "O" is used to distinguish the "Ontology" in philosophy from others. "Ontology" is a theory which can answer questions such as "what is existence", "What properties exist common to all the existence", "what properties can explain the existence", "How these properties explain the existence", etc.

(5) ontology

The design methodology is like one for Ontology, but the target is different from it. Not the "existence" but smaller and concrete thing such as enterprise, thermo-dynamics, problem solving, tutoring, etc. are discussed. We define an ontology as an explicit and unambiguous description of concepts and relations among them appearing in the target thing. Such ontologies exist as many as the possible target things. We do not have to use logic to describe it.

(6) Formal ontology

Axiomatic description of an ontology. It can answer questions on the capability of ontology.

(7) Axiom

Declaratively and rigorously represented knowledge which has to be accepted without proof. In predicate logic case, a formal inference engine is implicitly assumed to exist. But, anyone seldom mention it.

An axiom has two roles as follows in ontology description: 1) To represent the meaning of concepts rigorously. 2) Within the scope of the knowledge represented declaratively, to answer the questions on the capability of the ontology and things built using the concepts in the ontology.

Questions about the capability of ontology plays an important role in its evaluation and they are divided into the following two: 1) Questions on the formal properties of the ontology and things designed using ontology. 2) Questions on the behavior of the things designed using the ontology.

The former is called "competence" question and the latter "performance" question. Axioms written in predicate calculus are sufficient for answering the former. To answer the latter question, however, we often need procedural engines to interpret the meaning of concepts in the ontology because declarative knowledge with a formal prover cannot answer all the questions. To cope with such situations, we introduce axiom equivalents defined as follows:

(8) Axiom equivalent

An axiom equivalent is not a rigorous or declarative axiom based on formal inference engine, but it is partially declarative knowledge based also on interpretation by a procedural engine to answer performance questions. Axiom equivalent do not have to be formalized completely.

The difference between axioms and axiom equivalents is essential. "Axioms" can be also interpreted as "small number of rules which are represented in a declarative form and can derive all the facts from them". It is true they contribute to making the characteristics of technology clear and explicit if it is represented in a declarative form using axioms. This also applies to ontology. In fact, many researchers have been trying to represent ontology formally. However, we could say such an attempt neglects the reality. It is obvious that declarative and formal methodology cannot cope with the performance of the knowledge required by knowledge engineering. For example, if we adopted the first order predicate calculus, we have to abandon dealing with the knowledge such as "mathematical induction is sound for all the predicates". What we should do for knowledge engineering is to adopt not only formal approaches but also informal ones such as natural language representation and axiom equivalents based on procedural interpretation. This will enable ontology research to contribute to the future knowledge processing community.

2.2 TASK ONTOLOGY

2.2.1 What is a task ontology?

Task ontology is a system/theory of vocabulary for describing inherent problem solving structure of all the existing tasks domain-independently. It is obtained by analyzing task structures of real world problems. Design of task ontology is done in order to overcome the shortcomings of generic tasks[Chandra, 86] while preserving their basic philosophies. It does not cover the control structure but do components or primitives of unit inferences taking place during performing tasks. The ultimate goal of task ontology research includes to provide theory of all the vocabulary necessary for building a model of human problem solving process.

When we view a problem solving process based on search as a sentence of natural language, task ontology is a system of semantic vocabulary for representing meaning of the sentence. The determination of the abstraction level of task ontology requires a close consideration on granularity and generality. Representations of the two sentences of the same meaning in terms of task ontology should be the same. These observations suggest task ontology consists of the following four kinds of concepts:

(1) Generic nouns representing objects reflecting their roles appearing in the problem solving process,

(2) Generic verbs representing unit activities appearing in the problem solving process,

(3) Generic adjectives modifying the objects, and

(4) Other concepts specific to the task.

Task ontology for scheduling tasks, for example, looks as follows:

Nouns: "Scheduling recipient", "Scheduling resource", "Due date", "Schedule", "Constraints", "Goal", "Priority", etc.

Verbs: "Assign", "Classify", "Pick up", "Select", "Relax", "Neglect", etc.

Adjectives: "Unassigned", "The last", "Idle" etc.

Others: "Strong constraint", "Constraint satisfaction", "Constraint predicates", "Attribute", etc.

Verbs are defined as a set of procedures representing its operational meaning. So, they collectively serve as a set of reusable components for building IESs.

2.2.2 Roles of task ontology in IES

Roles of task ontology include:

(1) To provide vocabulary/concepts in terms of which one can compare and assess existing IESs.

(2) To formalize educational tasks.

(3) To specify the tutoring/training context which contributes to making it easy to put domain knowledge into a right context, since it provides us with abstract roles of various objects which could be instantiated to domain-specific objects.

(4) To provide reusable components for IES design and development.

(5) To enable translation of the knowledge-level description of the problem solving process into symbol-level executable code.

(6) To standardize communication protocol among component agents of IES in CSCL[Ikeda,95].

2.2.3 CBT ontology

Based on above consideration, the author and colleague have tried to build IES ontology[Mizoguchi, 1996]. Although the step we have made is not large, we believe that its implications to the future research in IESs area is not small. CBT ontology we discuss here uses the IES ontology as its core. We organize a set of concepts specific to training system under the IES ontology. Because of the space limit action, here we just show a part of the CBT ontology which we are building now(see [Mizoguchi, 1996] for a more detailed account of IES ontology). In the following two sections, we try to show the significance of the CBT ontology. First, we present brief overview of Smart Trainer which have been developed as a prototype of Intelligent CBT in section3, then, we will show the specification of Smart Trainer described with the CBT ontology in section 4.

3 Smart Trainer

Smart Trainer is a Computer Based Training System including a set of simulators in the area of Electric Power System.

3.1 Overview of Smart Trainer

The target task of Smart Trainer is mainly to recover the accidents of substations in the electric power system. When an accident happens, the electric power transmission will be interrupted, and the operators should recover it as quickly as possible. The operators should find the spot of the accident, continue to supply the electric power to some special places such as hospital, police station at once by borrowing some power from the other substations, find the causes of the accident and recover it within the limited time.

The goal of the training oriented by Smart Trainer is to improve capability of not only skill-based or rule-based reasoning but also knowledge-based reasoning[Rasmussen, 1983]. The set of the scenarios incorporated into Smart Trainer has been designed by the experienced trainers.

In order to let the trainee master the principled knowledge, Smart Trainer let them do practice first and then teach them the first principle behind it adaptively to their mistakes, and finally, check their learning result by practice again. With the cycle of practice->knowledge->practice, teaching process is going forward. This is a form of “learning by doing”.

Trainees can run the simulator in the way which they believe appropriate for the accident happened. If the wrong operation has been done, the system can teach them the right operation by the next three steps:

1. Asking the trainee some questions or ask him to do some other simulations related to the current one in order to know why he did the wrong operations. That is to say, the system wants to know what he knows and what he does not know.

2. Teach the learner the right knowledge according to step 1 in various ways and show him what dangerous events will happen according to the wrong operations taken by the learner with the simulators.

3. Let the learner do the operations again after step 2 in order to master both the knowledge which is reactive to the accident and the right operation order as well as operation itself. Authoring tools has been designed and used to help the authors to make the authoring strategies more flexible.

Here we want to emphasize that the training we give to the trainee has the time-limitation just like in real accidents. Multi-media technique has been widely used in Smart Trainer to attain high fidelity, including the sound processor to create mock buzzer when an accident happens, the movie display to show the accident scene when the repairing man needs, the picture processor to create the static graphics of the various equipment ,and so on.

Next, we will discuss the target of Smart Trainer, process-oriented problem and organization of scenario in detail.

3.2 Target of Smart Trainer

About the design of Smart Trainer, we regard the conceptual level as important, and aim at developing the platform for making the training system of various business field. Smart Trainer is the CBT platform composed of four layers show in Fig1. It can cope with various domains by replacing the topmost layer(for example: the training system of recovering accident)[Jin, 1996].

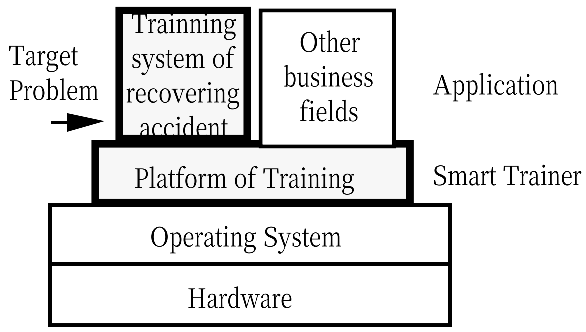

Fig. 1

Here we discuss the operations corresponding to the accidents in substation as a domain, and want to discuss a suitable conceptual level through the development of the platform which characterizes the training task properly. The target problems are situation of accident, working status of equipment, decision of disposition operations and so on. We select the available equipment according to the accident, the working status of equipment, the record of repairing machine, and use these selected equipment to maintain the system according to the rule of "the least influence to accident and the highest reliability of the system." In order to execute these operations properly, the operator should know the method of execution on the knowledge of principle and rule of the equipment and machine.

3.3 Process-oriented problem

One of the characteristics of a process-oriented problem is the continuity of its story. We propose the concepts of Backbone Stream and Rib Stream according to this characteristic. Here, we define the Backbone Stream which starts from an accident and ends to a suitable goal as a sequence of questions along with a scenario representing a sequence of operations, and it includes an accident case which should be experienced by the learners. Rib Stream consists a series of teaching behaviors for transferring the knowledge of the learning items included in a Backbone Stream to learners. The original knowledge in the background of operation and its teaching behaviors are written in the Rib Stream. Rib Stream conducts the learning process to associate principles behind each operation with a situation during the accident recovery procedure.

3.4 Organization of Scenario

The training scenario is organized by making use of Backbone Stream and Rib Stream after the construction of accident-cases and learning items.

The purpose of accident case is to teach the standardized sequence of operation orders and the principle knowledge behind it. Standard operation order is classified into two kinds, one is the operation order of normal state and the other is the operation order of emergency state. On the one hand, learners can learn the operation order of normal state(for example, shut down an equipment due to the inspection of machine) by drill&pratice easily. On the other hand, the operation order to cope with emergency state is very complicated and difficult to learn as a training task, because learners should identify the causes of the accident in limited time and the causes largely depend on the accident situations. In order to avoid magnifying the scope of accident and dissolve a supply hindrance rapidly by putting sound equipment to practical use, the learner should learn the disposition experience of the skilled operator and the record of repairing machine to investigate the cause of accident .

The target knowledge of Smart Trainer includes the knowledge of the equipment & machine in substation, the knowledge of the combination of equipment & machine in Electric Power System, and the knowledge of operating substation and its principles & rules.

The learning items are the instances of target knowledge of the operations corresponding to the accidents in substation. For example, the construction and usage of machine, the weakness of equipment, the loss and gain of disposition, and so on.

In order to organize the teaching materials, we build the system of knowledge along the sequence of operation process (Backbone Stream :task-oriented organization), and the system of learning items along the order of teaching(Rib Stream: topic-oriented organization). During the learning of Backbone Stream, if the learner makes a mistake, the Rib Stream can help him/her not only remedying his/her mistake but also making him/her understand and master the knowledge in it firmly. After the Rib Steam achieves its purpose, it will return to the point of the Backbone Stream where the learner made his/her mistake, and then the Backbone Stream will be resumed. Thus, with the crossing of Backbone Steam and Rib Stream, intersection of subjects and items, the teaching process goes on.

In our prototype of Smart Trainer, we make the training scenario of the operations corresponding to the accidents in substation by arranging the accident cases and learning items, organizing teaching materials, combining the Backbone Stream and Rib Stream according to the learner's level and the complication, difficulty of accident's disposition. The whole image of our scenario is repeating the cycle of "training->knowledge learning->training". In the first training of the cycle, the system let the learner dispose the accident on his/her own way, and when the mistake is taken placed, the system will give him/her some hints or the knowledge to solve the problem. In the second training, the system check the learner whether he/she has mastered the knowledge firmly or not.

In the following section, we will show a part of the CBT ontology.

4 Toward an Ontology for Computer-Based Training

Through the development of Smart Trainer, CBT ontology comes in sight little by little. Needless to say, it will take a long time and needs great effort to come up with the complete figure of it . In this section, we discuss some topics related to CBT ontology as much as space permits.

4.1 Representation of training process

A training task is organized into three concepts, that is, a situation, a Rib Stream, and a Backbone Stream. Note that these concepts can be realized only when one see the target task from the viewpoint of training. The Backbone Stream corresponds to a sequence of thinking process required to attain the goal of a target task, for example, to recover from an accident. It consists of an ordered set of situations which trainee would face in training. The situation is represented as a frame, for example, ask-question-about-the-symptom frame in which the system asks a trainee of the implication of the symptom observed. The situation serves as a primitive which can be connected to a knowledge-oriented learning task, which is represented as a Rib Stream. A set of Rib Streams is organized under the learning goal, for example, "to introduce new knowledge" "to correct buggy knowledge", "to practice a skill", and so on. In principle, once the learning goal of the Rib Stream is attained, the trainee can go back to the situation which initiated the Rib Stream.

The problem solving required for performing the target task should be represented explicitly. In the domain of Smart Trainer, we can see two types of problem solving process, that is, diagnosis of the malfunction and planning of recover operation. In our project, the structure of the problem solving concepts is also organized as "task ontology of target task."

4.2 Representing domain concept

There are two viewpoints to represent the domain of the training, that is, the educational viewpoint and the pure-domain viewpoint. From the former viewpoint, the domain concepts should be captured based on how trainees treat the topics in training context. On the other hand, from the latter, the concepts should be represented in the form of executable knowledge-representation. For example, the behavior of the target system can be simulated by using the representation. These two viewpoints, in principle, should be integrated into CBT ontology. We have investigated the domain from both viewpoints through the development of Smart Trainer and set up the following presuppositions on the author's properly.

1. The authors can easily organize the domain concepts along the training task structure, which consists of situations, Rib Streams, and Backbone Streams.
2. It is also easy for authors to augment each concept with multi-media material, because the structure could clarify the educational context of each material.
3. The authors can specify the need of simulation of the target plant in association with each learning situation.

We are currently building CBT ontology based on the presuppositions.

4.3 Representation of questions

By investigating the structure of a concrete training process incorporated in Smart Trainer, we found a meaningful educational intention of an author behind the question-answer frame. For example, a question in the form of one from many choices can be rich source of information needed for learner modeling. In most cases, we can expect a diagnosis is attached to each choice by authors. So the conceptualization of the questions is also quite important for CBT ontology. By characterizing a question, CBT ontology could clarify its underlying role, that is, how the learner model should be modified in response with learner's answer to the question.

The first stage of ontology design is to clarify the competence of the underlying ontology. The competence can be figured out easily if one can imagine the set of questions for which the ontology can derive the answer. In the following, we show the competence of “author's intention of question” as a pair of a question and answer for it. Words with capital letters denote the concepts defined in CBT ontology.

Competence of “author’s intention of question.”

Q: What does the author want to know about the learner’s status with the question?

A: The learner’s ABILITY to RECOGNIZE the SITUATION to apply RULE
The learner’s TENDENCY to follow the SKILL-LEVEL BEHAVIOR
The learner’s LEVEL-OF-MASTERING of the SKILL to cope with the SITUATION

Q: What is implied by the learner’s response R.

A: The learner’s LACKED-KNOWLEDGE/INCORRECT-KNOWLEDGE which caused the INCORRECT-BEHAVIOR for the SITUATION

By using the competence, ICBT system could

GUIDE the FOCUS-OF-ATTENTION on CONSOLE-OF-SIMULATOR to make him/her NOTICE the MEANINGFUL-SIGNAL

GIVE a HINT to REMIND the learner of the CAUSE-OF INCORRECT-ANSWER

SELECT an APT RIB-STREAM

….

Thus, the definition of the concept “question” in CBT ontology can be viewed as a source of the competence shown above. The concept of “question” is composed of :

Question
+ Problem (see below)
+ Response (see below)
+ Intention

Problem
+ Situation
+ list of Related-Knowledge-Unit

Response
(a) type: One-from-many-choices / Some-from-many-choices / Order-a-set-of-items / Order-a-set-of-items-selected-from-many-choices / Allow-do-simulate .....
+ choices

"+" and "(a)" denote "part_of" and "attribute", respectively.

4.4 Ontological representation of Smart Trainer

Here we show the rough sketch and the definition of the behavior of Smart Trainer by using CBT ontology. Words with capital letters denote the concepts defined in CBT ontology.

Rough sketch:

Smart Trainer is a typical TRAINING system in the DOMAIN of electric power system. The GOALS of TRAINING is to improve the learner's MEMORY CAPABILITY(LONG-TERM MEMORY), DEDUCTIVE THINKING CAPABILITY and PROBLEM SOLVING CAPABILITY. The COMMUNICATION SEQUENCE is CASE-ORIENTED, the TEACHING-MATERIAL-KNOWLEDGE and learning items are organized by the method of BACKBONE-STREAM and RIB-STREAM. COMMUNICATION is SYSTEM-DRIVEN basically, breaking by DOING

SIMULATION, learning's HELP and system's advice as HINT or EXPLANATION according to the LEARNING's STATE like PHASE in TRAINING PROCESS and so on. SIMULATION is used for training, and system provides FEEDBACK.

Behavior:

ASK the LEVEL of learner and CONFIRM it by PRE-TEST
SELECT a BACKBONE STREAM with an accident-case
GIVE a PROBLEM in the BACKBONE STREAM
ALLOW the learner DO-SIMULATION
ASSESS learner's RESULT
UPDATE LEARNER MODEL
IF LEARNER makes a mistake
THEN
    ASK the learner some QUESTIONS to find mistakes
    SELECT a suitable RIB-STREAM
    SUGGEST learner to apply the PRINCIPLE or RULE
    SUGGEST learner to DO SIMULATION
    GIVE the learner some HINTS or EXPLANATION
RETURN to the beginning of this accident-case
……
ASK the LEVEL of learner and CONFIRM it by PRE-TEST
SELECT a BACKBONE STREAM with an accident-case
GIVE a PROBLEM in the BACKBONE-STREAM
ALLOW the learner DO-SIMULATION
ASSESS learner's RESULT
UPDATE LEARNER MODEL
IF Learner's RESULT is Good
THEN COMPLIMENT
SELECT next accident case
……
IF LEARNER's ACTION is ASK_FOR_HELP
THEN SYSTEM's ACTION is PRESENT
(one_of: EXPLANATION(PRINCIPLE or RULE for the BEST RESULT)
            HINT
            SIMULATION
            ENCOURAGEMENT)

5 Concluding Remarks

The characteristics of Smart Trainer as a CBT is adoption of the notion of “learning by doing” for encouraging the trainee to carry out knowledge-based reasoning. We try to make the system components reusable so that it can be not only used in one substation but also in the others, not only in the domain of electric power system, but also in the other systems.

Currently, we have been formulating CBT ontology and initiate to rebuild Smart Trainer based on it. The most important part of CBT ontology is training task ontology to represent how to train the learners. At the workshop, we will present CBT ontology in more detail.

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