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ABSTRACT

As a person learns, his problem solving ability improves and one reason for this is the increased acquisition of "macro-rules" which make problem solving more efficient. An intelligent computer assisted learning (ICAI) system is being developed which automatically acquires the useful knowledge from the domain experts; as experts give the learning system instructions of how to solve given problems, the system extracts the strategic knowledge of problem solving from the instructions by generalizing them. The educational system then teaches and coaches students based on the acquired strategic knowledge by making a student give instructions instead of an expert, thus extracting a student's strategic knowledge. If macro-rules are prepared for various states, then the system is able to give an explanation of problem solving for various similar problems. The learning system described in this paper acquires strategic knowledge according to the model of explanation-based learning; the domain is physics at the high school level. Knowledge was prepared for the domain theory in terms of the knowledge: (1) for understanding the structure of a problem; (2) for inducing the appropriate formula from the problem structure; (3) for solving an equation; (4) for solving plane trigonometry; and (5) of a dictionary on the concepts/technical terms. The system makes the knowledge processing according to instructions on: attributes of objects; on defining attribute-value of an object as a variable; on a causal relationship among objects; and on equations. (AEF)

The method to acquire the strategic knowledge on problem solving

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Abstract: The aim of this study is to construct an Intelligent CAI(ICAI) with the function of knowledge acquisition by the theory of Explanation-Based Learning(EBL). In this paper, we describe a learning system which acquires strategic knowledge by EBG algorithm. In particular, the mechanism of an inference engine, the reasoning process to generate an expert's explanation and the method to acquire strategic knowledge are discussed. Moreover, the method to apply the acquired strategic knowledge is proposed.

1 Introduction

In general, as a human goes on learning, his problem solving behavior is improved. One reason for this improvement is considered to be that as a human acquires the knowledge called "macro-rules" which make problem solving more efficient. It is not an easy task to formalize macro-rules as meta-knowledge in a domain knowledge base for Intelligent CAI(ICAI)[1,2,5]. Therefore, we have been developing the ICAI which automatically acquires the useful knowledge from the domain experts. As the experts give the learning system instructions of how to solve given problems, the system extracts the strategic knowledge of problem solving from the instructions by generalizing them. Then, the educational system teaches and coaches students, based on the acquired strategic knowledge. By replacing a student as an expert, that is, by making a student give instructions instead of an expert, the system would extract a student's strategic knowledge.

To realize these issues, the aim of this study is to design and construct an ICAI with the function of knowledge acquisition by the theory of Explanation-Based Learning (EBL)[3,4]. This paper describes the mechanism of machine learning system which can acquire strategic knowledge on problem solving from the instruction-sequence given by an expert.

Chapter 2 examines the asserted knowledge in the problem solving process. Chapter 3 discusses the method to acquire the strategic knowledge. First, the configuration of the learning system that automatically acquires the strategic knowledge is described. Secondly, the type of expert's instructions are analyzed. Then, we discuss how the system interprets the expert's instructions, and how the system extracts the strategic knowledge. In Chapter 4, we propose how to use the acquired knowledge.

2 The asserted knowledge in the problem solving process

The domain which is handled in this study is the tasks of physics (the question on the composition and decomposition of vectors) at a high school level. The problem solving process in this subject matter includes the following steps:

Step1: To understand the sentences of a given problem.

Step2: To add extensional semantics information related to the sentences of a given problem.

Step3: To make the appropriate mathematical expressions related to some parts in the structure of a given problem.

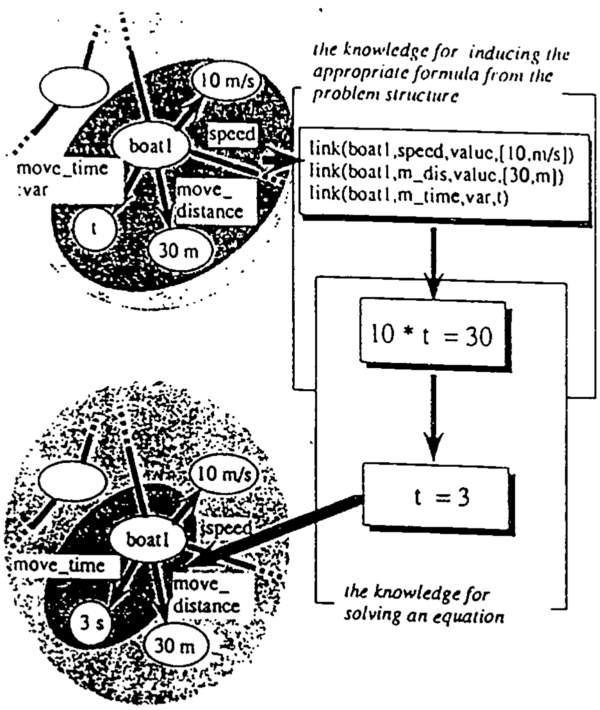

Figure 1: The relationship among the knowledge

```
basic_ope(70,
 [link(Obj1,S1,hensuu,[V,M/S]),
  link(Obj1,MT,value,[T,S]),
  link(Obj1,MD,value,[X,M])],
 [link(form5,relation,value,[S1,MT,MD])],
 [link(Obj1,S1,equ,[X=V*T,M/S])],
 []).

link(form5,relation,value,
   [sin_speed,sin_move_time,sin_move_dist]).
link(form5,relation,value,
   [sin_h_speed,sin_move_time,sin_move_h_dist]).
link(form5,relation,value,
   [sin_v_speed,sin_move_time,sin_move_v_dist]).
```

The knowledge for inducing the appropriate formula from the problem structure

```
basic_ope(203,
 [link(Obj1,Attri,equ,[X=V*T,U])],
 [],
 [link(Obj1,Attri,value,[V1,U])],
 [shiki(X=V*T,V1)]).
```

The knowledge for solving an equation

Figure 2: The internal expression for the domain knowledge

Step4: To solve the expressions, and calculate the values corresponding to the attributes of the objects.

We assume that the solution of a given problem is obtained by repeating the steps from Step2 to Step4. In order to construct the system which handles such a problem solving process, the following knowledge was prepared for the domain theory.

(1) The knowledge for understanding the structure of a problem.

(2) The knowledge for inducing the appropriate formula from the problem structure.

(3) The knowledge for solving an equation.

(4) The knowledge for solving plane trigonometry.

(5) The knowledge of a dictionary on the concepts/ technical terms.

Figure 1 shows the relations among (2),(3) and (4) in this system. The figure shows that the formulas related to three variables of speed, time, and distance can be applied to part of the problem structure, that is, "the speed of boat1 is 10 m/s" and "the distance to which boat1 moves is 50 m", and new information, that is, how long it takes for boat1 to move across the river is added to the structure of the problem. Figure 2 shows the internal expression for the domain knowledge in this system.

3 The method to acquire the strategic knowledge on problem solving

3.1 The configuration of the learning system

When the leaning system is given a problem by an expert, the system learns how to solve it from problem solving statements specified by the expert. The system tries to find an appropriate equivalent operator-sequence by analyzing this process and generalizes them. Simply, the system extracts strategic

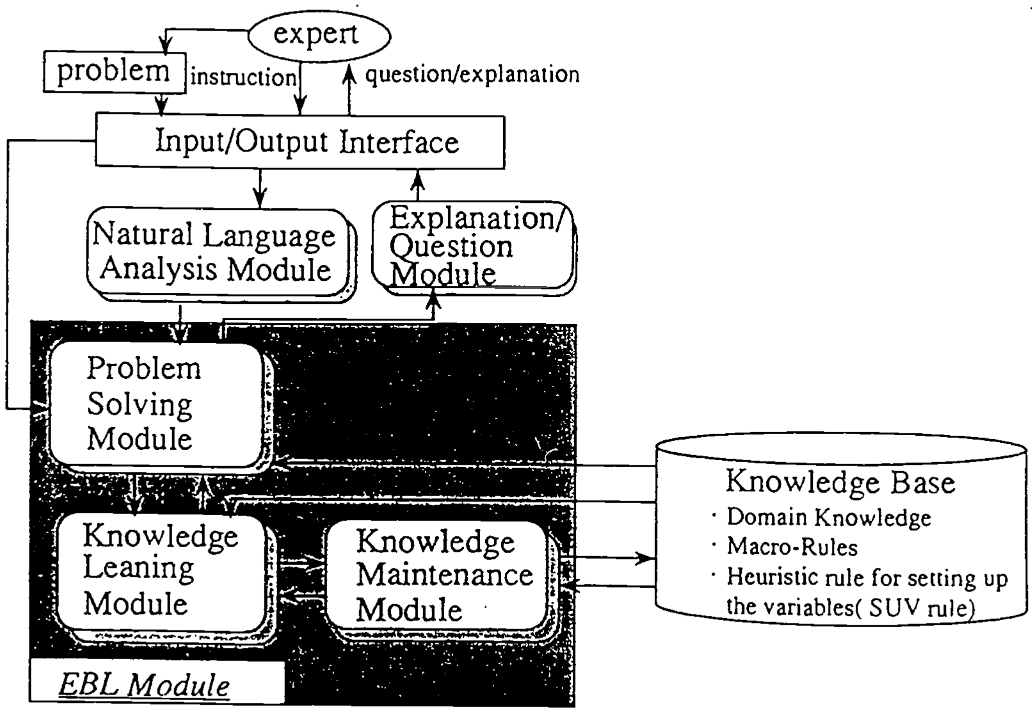

Figure 3: The configuration of the system to acquire the strategic knowledge

knowledge, which improves its problem solving performance, from expert's instructions. In this study, the strategic knowledge is the one that facilitates to solve problems efficiently with prediction, which is related to planning and intention. **Figure 3** shows the configuration of this learning system. The system consists of five modules and a knowledge base. "*Natural Language Analysis Module* " translates expert's instructions into the internal expressions which the system can interpret. "*Problem Solving Module* " builds up an explanation-tree. The instructions given by experts are classified into four different forms. Through the expert's instruction process, the system traces what kinds of knowledge is used by the expert. "*Explanation/Question Module* " has two functions. One is to explain what kinds of knowledge is used in expert's instructions. This function is displayed in a window on the screen. The other function is to confirm what attribute an expert asserts as a variable, to ask what its value means in the expression. This module is driven, whenever the system is given instructions for the former, and can't understand the expert's instructions for the latter. "*Knowledge Learning Module* " builds up a generalization-tree to acquire strategic knowledge. "*Knowledge Maintenance Module* " tunes up the acquired knowledge in the domain knowledge base.

This learning system acquires two kinds of knowledge. One is "**macro-rules**" acquired with EBG algorithm, and the other one is "**heuristic rules for setting up the variables**", which we call "**SUV-rules**". Heuristic rules for setting up the variables is the knowledge to set up attribute-value of an object, which the expert wants to know, as a variable in a particular situation.

3.2 The method to interpret Instructions

In this section, we describe how to construct an explanation-tree from a sequence of instructions given by experts. With a production system, the system tries to find the appropriate equivalent operator-sequence by analyzing an expert's instruction. The inference engine of the production system uses two kinds of working memories; the first one is to identify an instruction(ii_wm) and the second one is to generate an explanation-tree(ex_node). The ii_wms are used in a process to understand one instruction, when the system regards its instruction as the sub-goal. The ex_nodes represent a set of the knowledge, which have already known, in a state of the solving process. **Figure 4** shows an internal expression of ex_nodes in the system. The 1st argument of ex_nodes is a node number. The 2nd argument shows the

ex_node(1, link(boat1, move, value, river1), [],[],n,y).
ex_node(4, link(river1, sin_speed, value, [4, m/s],[],[],n,y).
ex_node(11, link(river1, give_an_effect,value,boat1),[1,4],[b,50],n,y).
ex_node(19, link(boat1, sin_speed,hensuu,[vh, m/s],[],[],hensuu,y).

ex_node(1st, 2nd, 3rd, 4th, 5th, 6th)

1st : a node number
2nd: knowledge
3rd: node numbers of precondition nodes in a list form
4th: an applied rule for the precondition nodes
5th: whether its knowledge is explained by experts or not
6th: the usablity in the next reasoning

Figure 4: The memory to generate an explanation-tree(ex_node)

knowledge about the attribute, its types of value, and the value of the object. The 3rd argument holds node numbers of precondition nodes in a list form. The 4th argument shows an applied rule for the precondition nodes. The 5th argument in ex_nodes shows whether its knowledge is explained by experts or inferred by the system itself. The 6th argument represents whether the Inference Engine (IE) can use this node or not from now on. For example, ex_node 11 in the figure 4 includes the fo''owing contents; the knowledge that "a river influences a boat" is resolved by using basic-rule 50 for 1 and 4 nodes, this node is inferred by the system in the process of identifying a given instruction, and IE can use this node in the next reasoning process. **Figure 5** shows the method to generate an explanation-tree. The system tries to convert the problem sentences into the appropriate internal expressions, which are translated by "Natural Language Analysis Module", as the initial state in ii_wm. At this time, the ex_nodes are a state of an empty list. When an expert gives instructions to the system, the system fills ii_wms with all information of the present ex_nodes and the expert's instruction. Then, the system regards the expert's instructions as the sub-goal, and understands its instructions by using a production system. The system continues to infer by means of the deep-first search algorithm. So, the system keeps a record of the intermediate hypothesis, until the system could find a given sub-goal. Moreover, to avoid a wasteful search, the system keeps the information of success or failure for each nodes. When the meaning of instruction is understood, the system adds the knowledge, which hasn't been ever included in ex_nodes, to ex_nodes in the forms of figure 4. The system repeats this cycles until experts inputs "finish the work",

We examined the types of instructions which experts asserted in the problem solving process on this subject matter. As a result, we found that the following four types of instructions are included in the explanation to solve problems.

(1) Instructions on attributes of objects, or its attributes and values.

(2) Instructions on defining attribute-value of an object as a variable.

(3) Instructions on a causal relationship among objects.

(4) Instructions on equations.

The system makes the knowledge processing corresponding to these four types of the instructions, and as a result of it, the system can identify the expert's problem solving process. The identification of the instruction types (1), (2), and (3) adopts the method mentioned above. The system has a function to transform the expert's equation into an equivalent equation when an expert gives the instruction type of (4) to the system. "Instructions on defining attribute-value of an object as a variable" is slightly different from the knowledge processing of (1), (3), and (4). Even though experts have the knowledge to set up attribute-values of an object as a variable in a particular situation, the system doesn't have it. So the system acquires the knowledge of SUV-rules from this instruction.

3.3 The method to acquire macro-rules

In this system, we explored the method of generalization with EBL algorithm. In general, a target concept to learn is given in the framework of EBL. When the system can solve a problem by expert's

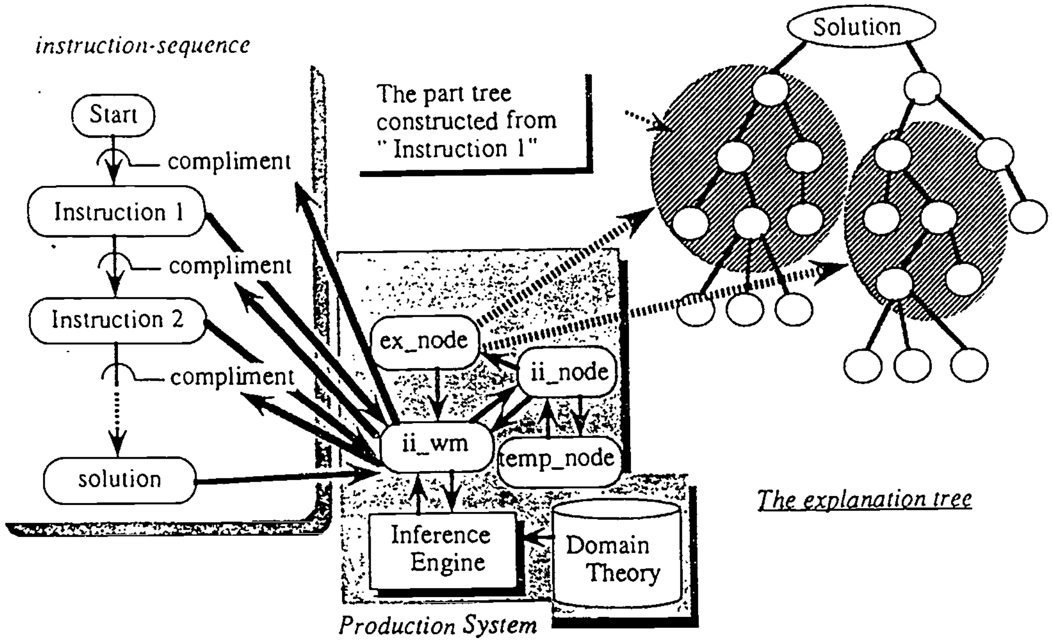

Figure 5: The method to construct the explanation-tree

instructions, the solution becomes the target concept. The given problem itself becomes a training example. The system regards one instruction given by the expert as a trigger to resolve sub-goals. Then, the instructions given by an expert work as bias, and the system constructs an explanation-tree. The system generalizes it within the domain theory. The operationality criterion in this system is the procedure which extracts the macro-rule from rule-sequences within the scope of causality. So the system can extract macro-rules from an example problem. Figure 6 shows a problem and the example of instructions. Figure 7 shows the example of the extracted macro-rule and SUV-rule.

4 Application of the acquired strategic knowledge

In this chapter, we discuss the meaning of acquiring strategic knowledge on problem solving with the EBL technique and the method of its application.

The learning system acquires the strategic knowledge from expert's instructions. This acquired knowledge is reflected as the template knowledge in a student model for an ICAI.

As mentioned in Chapter 1, by making a student give instructions instead of an expert, the educational system would extract a student's strategic knowledge. So, when the educational system diagnoses a state of a student model, and supports the student's learning activity, the strategic knowledge is reflected. By adding the acquired macro-rules to the system, the quality of explanation in the tutoring module is improved. If macro-rules are prepared for various states, then the system is able to give an explanation of solving for various similar problems. The system gives some rough explanations to the student who understands well how to solve problems, and details to the student who doesn't understand it well. Then, the system tries to select the more effective instructional strategy.

5 Conclusion

In this paper, we described the mechanism of a machine learning system which can acquire the strategic knowledge on problem solving from the instruction-sequence given by an expert. By using this system, the strategic knowledge of domain knowledge base for ICAI can be acquired as meta-knowledge, that is "macro-rules". Moreover, we referred to application of the knowledge acquired by EBL. Now, we have

PROBLEM

A boat with a speed of 4 m/s goes across the river with a speed of 3*root(3) m/s. It is 80 m width. Now, the boat goes up the upper stream. Its angle is 30° for the flow direction of the river. Then, it arrives at the opposite side of the bank. Supposing that the position of the opposite bank locates at the position of b.

(1) In which direction does the position of b locate from the position of a and how far is it from the position of a to the position of b ?

ANSWER

Put the speed of vertical direction of boat as v_{1y}
$v_{1y} = 4 * \cos 30$
$v_{1y} = 2$

Put the speed of horizontal direction of boat as v_{1x}
$v_{1x} = 4 * \sin 30$
$v_{1x} = 2 * root(3)$

Put the time which boat moves as t
$2 * t = 80$
$t = 40$

Put the distance which boat goes forward horizon as x
$x = (3 * root(3) - 2 * root(3)) * 40$
$x = 40 * root(3)$

The boat arrives at the point of downstream with 40*root(3) m far from the position of a

Figure 6: The example problem and the example of instructions for its problem

```
macro_ope(2,
 [link(Obj1,sin_dir,value,_802),
  link(Obj2,give_an_effect,value,Obj1),
  link(Obj1,com_move_time,value,[_834,S]),
  link(Obj1,sin_h_speed,value,[_866,M/S]),
  link(Obj1,com_move_h_dist,hensuu,[_890,M]),
  link(Obj2,sin_h_speed,value,[_922,M/S]),
  link(Obj1,com_h_speed,hensuu,[_954,M/S]),
  link(Obj2,_974,value,+)],
 [link(dir_h,relation,value,[sin_dir,_974,_802,-]),
  link(com_vh_veloc,relation,value,
      [_974,sin_h_speed,_1076,com_h_speed]),
  compare(_866,_922),
  shiki(_954=_922-_866,_1126),
  link(form5,relation,value,
      [com_h_speed,com_move_time,com_move_h_dist]),
  shiki(_890=_1126*_834,_1178)],
 [link(Obj1,com_move_h_dist,value,[_1178,M])],
 [[[b,160],link(Obj1,_974,value,-)],
  [[b,100],
   link(Obj1,com_h_speed,equ,[_954=_922-_866,M/S])],
  [[b,205],
   link(Obj1,com_h_speed,value,[_1126,M/S])],
  [[b,72],
   link(Obj1,com_move_h_dist,equ,[_890=_1126*_834,M])],
  [[b,203],
   link(Obj1,com_move_h_dist,value,[_1178,M])]]).
```

(a) Macro-rule

```
suv_ope(1,
  [link(Obj1,sin_speed,value,[_762,M/S]),
   link(Obj1,sin_angle,value,[_786,D])],
  [make_vaiable([Obj1,sin_v_speed],_892)],
  [link(Obj1,sin_v_speed,hensuu,[_892,M/S])],
  []).
```

(b) SUV-rule

Figure 7: Macro-rule and SUV-rule

been constructing an ICAI based on the theory of EBL[6]. As the next research step, the examination of an operationality criterion to select the acquired macro-rules, and the development of three-agents interaction system for ICAI by using the acquired knowledge must be explored.

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