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A KNACK FOR KNOWLEDGE ACQUISITION

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KNACK is a knowledge acquisition tool that generates expert systems for evaluating designs of electromechanical systems. An important feature of KNACK is that it acquires knowledge from domain experts without presupposing knowledge engineering skills on their part. This is achieved by incorporating general knowledge about evaluating tasks in KNACK. Using that knowledge, KNACK builds a conceptual model of the domain through an interview process with the expert. KNACK expects the expert to communicate a portion of his knowledge as a sample report and divides the report into small fragments. It asks the expert for strategies of how to customize the fragments for different applications. KNACK generalizes the fragments and strategies, displays several instantiations of them, and the expert edits any of these that need it. The corrections motivate and guide KNACK in refining the knowledge base. Finally, KNACK examines the acquired knowledge for incompleteness and inconsistency. This process of abstraction and completion results in a knowledge base containing a large collec- over

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19. ABSTRACT (Continued)

tion of generalized report fragments more broadly applicable than the sample report. (KR)

PREFACE

We would be remiss if we did not mention our co-workers in this project. Don Kosy, Gilbert Caplain, Beatrice Paoli-Julliat, and David Dong are members of the group and made significant contributions. Tom Mitchell reviewed an earlier draft of this paper. Rodney Perala of Electro Magnetic Applications (EMA) served as our domain expert. We would also like to thank Alex Stewart (HDL) for his support.

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SECTION 1

INTRODUCTION

A key issue in developing any expert system is how to update its large and growing knowledge base. A commonly proposed solution is the construction and use of a knowledge acquisition tool, e.g., KAS [Reboh 81], TEIRESIAS [Davis 82], ETS [Boose 84], MORE [Kahn 85], SALT [Marcus 85], SEAR [van de Brug 86], MOLE [Eshelman 86], KNACK [Klinker 87]. Such a tool typically interacts with domain experts, organizes the knowledge it acquires, and generates an expert system. A knowledge acquisition tool also can be used to test and maintain the knowledge base of the program it generates. A critical feature of such a tool is that a domain expert can use it to update a knowledge base without having to know about the underlying AI technology. A large knowledge base can be kept maintainable by organizing it according to the different roles that knowledge plays [Chandrasekaran 83], [Clancey 83], [Neches 84]. Knowledge roles, the organizational units of the knowledge base, are made explicit by defining a problem solving method.

KNACK is a knowledge acquisition tool that assists an expert in creating expert systems that evaluate the designs of electromechanical systems. KNACK gains power by exploiting a domain model and its understanding of the assumed problem solving methods for gathering information and evaluating designs, and the different roles played by knowledge in those methods. This enables KNACK to provide the control knowledge and the implementation details needed in the target expert system. It also helps to minimize the amount of information the expert must provide to define a piece of knowledge for the expert system.

Section 2 describes the expert systems generated by KNACK. Section 3 summarizes the characteristics of KNACK. Sections 3.1 through 3.5 explicate the steps of KNACK's knowledge acquisition approach.

SECTION 2

THE WRINGERS

Each of the expert systems produced by KNACK is called a WRINGER. The domain of the WRINGERs we have generated so far is nuclear hardening. Nuclear hardening involves the use of specific engineering design practices to increase the resistance of an electromechanical system to the environmental effects generated by a nuclear detonation. Designers of electromechanical systems usually have little or no knowledge about the specialized analytical methods and engineering practices of the hardening domain. The purpose of a WRINGER is to assist a designer in developing a hardened system and in presenting this design, together with a preliminary system evaluation, in the form of a report.

A WRINGER first gathers the information necessary for the evaluation of an electromechanical system. To accomplish this goal, a WRINGER uses strategies (discussed in section 3.3) to elicit information from the designer or to infer it. Every collected item is a value instantiating a concept of the hardening domain for a particular application. As it progresses, the gathering of information is driven by previously elicited information. This is a data-driven approach that modifies a WRINGER's behavior according to the information specific to each electromechanical system it is applied to. The collected information is evaluated by the WRINGER for validity, consistency, completeness, and possible design flaws. If indications of design flaws are found, a WRINGER points them out to the designer together with suggestions for improving the system design. Finally, when the designer is satisfied with the design of the system, a WRINGER instantiates all report fragments relevant to the particular application with the acquired values and generates a report describing and evaluating the system design.

In the fall of 1986 a first version of KNACK, reported in [Klinker 87], was used to develop two expert systems called WRINGERs. Both are dedicated to evaluating electromechanical systems' resistance to nuclear environmental effects. The first WRINGER generates a PROGRAM PLAN - the primary, top management report covering all phases of a project. Starting with several well chosen sample reports, it took one person-week to create the PROGRAM PLAN writer with KNACK. The average PROGRAM PLAN is organized in 237 fragments and contains 2248 words, 7.5% of which are values instantiating concepts of the hardening domain. The second WRINGER produces a DESIGN PARAMETERS REPORT - containing a detailed description of the electromechanical system. The basis for the expert system was a single sample report and a series of interactions with our EMP expert. It took three person-weeks to create it with KNACK. The average DESIGN PARAMETERS REPORT is organized in 455 fragments and contains 6675 words, 8.7% of which are values instantiating concepts of the hardening domain.

SECTION 3

KNACK

The present implementation of KNACK and the version used to generate the two WRINGERs assume that an expert can express knowledge in the form of a report. This implies that an expert knows what information is relevant to the task, how to evaluate this information, and how a designer presents this information. This assumption holds for a variety of evaluation tasks since, in general, someone who evaluates the work of others must have comprehensive and precise knowledge about that work.

The present implementation of KNACK refines the approach the previous version took to acquire knowledge. It combines existing AI techniques and uses them for knowledge acquisition. General knowledge about evaluating designs of electromechanical systems is incorporated into KNACK. In an initial interview process with the expert KNACK customizes that knowledge and builds a conceptual model describing the concepts and the vocabulary experts use in performing an evaluation task. KNACK also asks the expert for a sample report describing and evaluating some simple, but typical, electromechanical system.

Once the sample report is typed in, KNACK develops expertise in evaluating the designs of electromechanical systems by integrating the specific sample report with the conceptual model in successive interactions with the expert. This is a process of abstraction (constants in the report fragments of the sample report or strategies are variabilized) and completion (signs of incompleteness cause elicitation of additional report fragments or strategies). This integration process generalizes the sample report, making it applicable to different electromechanical systems. To demonstrate its understanding of the sample report, KNACK instantiates the generalized report with representatives of the concepts it detected for interactive review by the domain expert. The expert's feedback provides additional knowledge used by KNACK to correct its generalizations and refine the conceptual model.

Once the expert accepts KNACK's understanding of the sample report, KNACK elicits knowledge of how to customize the generalized sample report for a particular application. The expert defines strategies that a WRINGER will use to acquire values instantiating the concepts detected in the generalized fragments. As with the sample report, the expert does this by providing sample strategies. Strategies can be questions, formulas, inferences, and other forms. KNACK generalizes the strategies and displays some example instantiations of them for review and correction by the expert.

Finally, KNACK examines the resulting knowledge base for parts of the generalized report or strategies that indicate gaps or conflicts with the conceptual model. If a possible flaw is found, KNACK asks the expert to correct the report, the strategies, or the conceptual model.

The following detailed description of KNACK's knowledge acquisition approach is organized around an example of an actual KNACK case. It leads through the process of typing in a small part of a sample report, acquiring a partial conceptual model, generalizing the part of the sample report, defining strategies, and reviewing the acquired knowledge. In the interest of brevity, the excerpts used as examples are only a tiny fraction of a full KNACK case.

3.1 ACQUIRING THE SAMPLE REPORT AND THE CONCEPTUAL MODEL.

The sample report exemplifies what the expert intends the WRINGER to produce. It may be written specially for this purpose by a domain expert or group of experts, or selected from existing reports. Figure 1. illustrates a part of a sample report for the DESIGN PARAMETERS REPORT writer, evaluating the hardness of a specific electromechanical system to the EMP effect of a nuclear blast.[1] The report is typed in to a file by any person familiar with text editors. KNACK divides the report into fragments corresponding to paragraphs. In the tiny example of Figure 1. , this results in three report fragments.

1. ***11.2.3. EMP Leakage through Windows***
2. ***The Window is protected by a wire-mesh. The transfer inductance of the wire-mesh is 6.7e-10 Henries.***
3. ***The Power Cable penetrates the S-280C enclosure and induces 0.4 Volts on the Window of this enclosure.***

Figure 1. Part of a sample report.

The sample report describes a particular electromechanical system. To generalize the sample report, making it applicable to other electromechanical systems, KNACK needs a conceptual model of the domain. To acquire the model, KNACK conducts an interview with the expert. The interview is driven by KNACK's understanding of the evaluation task. KNACK views evaluation as partly analytic (i.e., determine whether a system will function in a given environment) and partly constructive (i.e., improve a system design so that it will function in a given environment). This understanding has the following basis:

- An electromechanical system performs a set of functions and comprises a set of interrelated components.
- An environment produces a set of conditions under which an electromechanical system must function, each of which may affect system components via a set of media.
- The effect of a condition on system components may be modified by some provisions, each of which can comprise provision components which, in turn, can be affected by a set of conditions via a set of media.

KNACK implements these principles as generic questions to elicit knowledge about the domain concepts representing system *components*, *environments*, *conditions*, *media*, and *provisions*. The following sample interaction defines some of the concepts needed to generalize the sample report in Figure 1. . At this point in the interview, KNACK has already acquired part of the conceptual model.

How would you refer to possible provisions via which a SUBSYSTEM can meet the COUPLING condition produced by the EMP environment? ***enclosure, terminal protection device***

List some examples for a NAME of an ENCLOSURE: ***S-280C, metal box***

What are the terms describing the characteristics of an ENCLOSURE which affect its reaction to EMP? ***material, thickness, relative conductivity***

How would you refer to the provision components of an ENCLOSURE which affect its reaction to EMP? ***apertures, seams***

List some examples for a NAME of an APERTURE: ***window, cable entry panel***

How would you refer to possible provisions via which a WINDOW of an ENCLOSURE can meet the COUPLING condition produced by the EMP environment? ***wire-mesh, optical coating***

What are the terms describing the characteristics of a WIRE-MESH which affect its reaction to the COUPLING condition? ***transfer inductance***

The expert's responses are added to KNACK's internal representation of the conceptual model,

[1]In this and following figures, the expert's input appears in bold italics; the implementation details (for rules) and the prompts (of KNACK) appear in lowercase and uppercase. Default responses, enclosed by brackets, are used when the user types only a carriage return.

implemented as a semantic network. The nodes describe a taxonomy of concepts and concept properties used by domain experts to describe and evaluate electromechanical systems and their environments. The links encode structural and functional domain knowledge. Figure 2. shows part of the conceptual model corresponding to the above questioning session.

```
                                     PROVISION
ENCLOSURE                             .NAME = Wire Mesh                      ENVIRONMENT
 .NAME = S-280C,                              Optical Coating                 .NAME = EMP
         Metal Box                    .TRANSFER-INDUCTANCE
    |                                         ^                                  |
comprises                                     |                              produces
    |                                        via                                 |
    v                                         |                                  v
APERTURE                ------------- meets -----------------> COUPLING
 .NAME = Window,                                                                .PEAK-VOLTAGE
         Cable Entry Panel
```

Figure 2. Part of a conceptual model.

3.2 GENERALIZING THE SAMPLE REPORT.

KNACK interacts with the domain expert to generalize the sample fragments through a process of abstraction. The report's basic structure is extracted and fragments are parsed to detect text strings that match the entries in the conceptual model. The technique employs simple heuristics to infer the concepts each fragment mentions, based on detection of keywords and representative names of concepts in the fragment, combined with knowledge of relations between candidate concepts.

In the first aspect of this process KNACK looks for keywords (e.g., chapter, section, subsection, heading, itemize, enumerate, bold, underline), instances of keywords (e.g., 2. for chapter, 2.3.2. for subsection, (1) for enumerate), and the form of the input (only a few words in a line separated from the remaining text by blank lines). From this analysis KNACK generates a skeletal report defining the form of the sample report. It includes the outline and special formats (e.g., table of contents, itemizations, enumerations, filled or unfilled environments) encoded as commands for a document formatting system.

In the second aspect of the generalization process KNACK converts fixed report text into generalizations representing the concepts detected in the fragment. Cues to locate and identify concepts in a report fragment are numbers representing the value of quantitative parameters and non-numeric symbols denoting tokens of known concepts in the conceptual model.

The heuristics provide sufficient analytical power to acquire knowledge without turning to a sophisticated natural language interface. There are limitations though. The heuristics mistakenly identify some concepts and miss others. The errors are dealt with when the expert critiques instantiations of the generalized fragments as described in Section 3.4.

The generalization process results in a collection of generalized report fragments more broadly applicable than the sample report. A generalized report fragment describes a small possible piece of an actual report. It includes fixed text strings to be printed exactly as formulated by the expert, concepts to be instantiated by the WRINGER, knowledge about incorporating the gathered concept representatives into the report, and keywords specifying the type and form of the report fragment (e.g., simple paragraph, figure, table, and title). Generalizations are internal constructs for KNACK's use. Consonant with the research goal of reducing the knowledge engineering skills needed for knowledge acquisition, the expert sees only instantiated generalizations as demonstrated in section 3.4.

The sample report fragments in Figure 1. yield the generalized report fragments shown in Figure 3. . The angle brackets enclose concepts detected in a fragment.

1. SUBSECTION <ENVIRONMENT.NAME> Leakage through <APERTURE.NAME>
2. The <APERTURE.NAME> is protected by a <PROVISION.NAME> . The transfer inductance of the <PROVISION.NAME> is <PROVISION.TRANSFER-INDUCTANCE> Henries.
3. The <CABLE.NAME> penetrates the <ENCLOSURE.NAME> enclosure and induces ?<COUPLING.PEAK-VOLTAGE>? Volts on the <APERTURE.NAME> of this enclosure.

Figure 3. Sample of generalized report fragments.

In fragment 1, EMP is inferred to be a NAME of an ENVIRONMENT due to a unique match with the conceptual model. In general, a number is inferred to be a representative of some numerical characteristic of a concept. If the text adjacent to a number refers to a known concept and characteristic, the number is replaced with the corresponding concept. In fragment 2, WIRE-MESH matches the NAME of PROVISION and "transfer inductance" was encountered in the fragment text. Although more than one concept has the characteristic TRANSFER-INDUCTANCE, 6.7e-10 is inferred from context to be the TRANSFER-INDUCTANCE of a PROVISION. When helpful clues are not present in adjacent text, KNACK simply guesses the concept from the ambiguous set of matches. Such guesses can be mistaken and KNACK indicates this when the instantiated generalization is displayed for review by the expert (demonstrated in section 3.4). Fragment 3 of Figure 3. contains the guess <COUPLING.PEAK-VOLTAGE>.

Generalized report fragments also include conditions which determine when to include each fragment in an actual WRINGER report. KNACK uses simple heuristics to create the conditions from the concepts in the fragments and the conceptual model. Each report fragment constitutes an OPS5 rule [Forgy 81]. Figure 4. shows an English translation of the rule for report fragment 2 in Figure 3. .

```
If    an ENVIRONMENT with NAME EMP is known, and
      some COUPLING is known, and
      an APERTURE with NAME other than CABLE ENTRY PANEL is known, and
      a PROVISION with some NAME, and
          with some TRANSFER-INDUCTANCE is known, and
      the ENVIRONMENT produces COUPLING, and
      the APERTURE meets the COUPLING via the PROVISION,
then print: The <APERTURE.NAME> is protected by a <PROVISION.NAME>.  The transfer
            inductance of the <PROVISION.NAME> is <PROVISION.TRANSFER-INDUCTANCE>
            Henries.
```

Figure 4. Sample report fragment rule.

3.3 DEFINING AND GENERALIZING STRATEGIES.

Concepts in the generalized fragments must be instantiated with values describing a particular system design when a WRINGER evaluates a design and writes its report. KNACK asks the expert to define strategies for a WRINGER to acquire or produce the instantiation values. Experts define strategies in the same way that report fragments are defined, by typing in samples. Each strategy describes a way to determine a representative of a concept and includes instructions about valid possible values. Relying on previously elicited information and other prior knowledge, KNACK defines the circumstances in which these methods can be applied.

KNACK asks the expert to define at least one strategy for each concept in the report fragments. A strategy can acquire representatives by asking questions, interpreting a graphical design description, asking the designer to fill in the slots of a table or diagram, or asking the user to choose from the items in a menu. It can infer representatives by directly applying specific domain knowledge, computing numeric values using formulas, or referring to a database. Figure 5. demonstrates KNACK gathering the knowledge needed for a question strategy to instantiate the TRANSFER-INDUCTANCE characteristic of a WIRE-MESH PROVISION.

```
How can the TRANSFER-INDUCTANCE of a WIRE-MESH PROVISION be determined?

[constant, question, inference, table, menu, graphics, formula, database,
postpone, quit] [ QUESTION ]:

What will be the question text........: What is the transfer inductance of the wire-mesh

What are the possible answers.......... [ NUMBER ]:
What is the default answer............. [ 6.7e-10 ]: unknown
What will be the status of the answer.. [ NOT-MANDATORY ]:
```

Figure 5. Defining a question strategy.

KNACK parses the text of the question in an attempt to generalize it. It knows that WIRE-MESH is a representative of a NAME of a PROVISION. But a strategy must be discriminating enough to result in the instantiation of the right concept. KNACK uses heuristics to make the text of a question strategy more specific. Since the conceptual model states that an APERTURE meets a COUPLING condition via a PROVISION, KNACK extends the text of the generalized question to:

> What is the transfer inductance of the <PROVISION.NAME> provision of the <APERTURE.NAME> aperture

The specialization of the question text is guessed by KNACK and can be wrong or unnecessary. Section 3.4 describes how KNACK displays the result of the generalization process and takes advantage of the expert's editing.

3.4 DEMONSTRATING UNDERSTANDING OF THE SAMPLE REPORT AND STRATEGIES.

KNACK predicts and exemplifies the performance an expert can expect from the WRINGER he is working to create. It instantiates the concepts of the generalized fragments with known concept representatives taken from the conceptual model and displays several differently instantiated examples of each generalized report fragment. The expert edits any examples that make implausible statements about the domain. KNACK treats such events as incorrect use of the knowledge base and interprets the corrections as new knowledge to update the generalization and improve the conceptual model. For example if the expert indicates that values from the conceptual model combine too loosely, KNACK adds a constraint to the model, restricting possible combinations. A correction also can imply that an uncertain guess of KNACK's about the identity of a concept is wrong, leading to its retraction and the introduction of a new, initialy less probable guess. Applying the new knowledge, the generalization is instantiated again and display of several examples gives the expert immediate feedback on the effects of the knowledge base modification.

KNACK extends the conceptual model whenever the editing adds variability between examples that it cannot parse. Extensions can be new concepts, new characteristics for known concepts, and restrictions on existing relations between representatives of two concepts. The model serves as a collection of examples suggesting guesses for KNACK as to the form of the extension. The following examples illustrate the editing process with some of the generalized report fragments of Figure 3..

The generalization of the first fragment in Figure 3. is a subsection heading. KNACK displays different instantiations of the <ENVIRONMENT.NAME> and <APERTURE.NAME> concepts detected in that fragment. The expert edits the examples by restricting them to the EMP ENVIRONMENT and to

APERTUREs other than CABLE ENTRY PANEL. The correction is used to refine KNACK's conceptual model.

11.2.3. EMP Leakage through Windows

11.2.3. Thermal Leakage through Windows

11.2.3. EMP Leakage through Cable Entry Panels

Corrections? [NONE]: ***point the mouse to EMP in example 1 and command that this value only be used, point the mouse to Cable Entry Panels in example 3 and command that this value never be used***

Continuing this example, KNACK knows that ENVIRONMENTs produce COUPLING, and that no other relation links ENVIRONMENT to any other concept. KNACK extends the conceptual model in adding the restriction that ENVIRONMENTs other than EMP do not produce COUPLING. This extension of the conceptual model is internal to KNACK and does not require asking the expert for confirmation. But when KNACK attempts to add another restriction, that a CABLE ENTRY PANEL APERTURE does not meet COUPLING via a PROVISION, it cannot decide with certainty which relation to restrict because more than one relation interrelates APERTURE with other concepts. KNACK guesses a restriction to one of the known relations involving APERTURE. It assumes that its guess is right, until a correction of an instantiation later in the interaction indicates the opposite. KNACK then revises its earlier decision and restricts another relation.

Since the generalized fragment represents a subsection heading and KNACK assumes that the topic within a subsection will not change, KNACK constrains the remaining fragments of the subsection to the EMP ENVIRONMENT and APERTUREs different from CABLE ENTRY PANEL. For example, KNACK displays the following instantiations of the third generalized report fragment shown in Figure 3. :

The Power Cable penetrates the *S-280C enclosure and induces 0.4 Volts on the* Window of this enclosure.

The Signal Cable penetrates the S-280C enclosure and induces 0.4 Volts on the Window of this enclosure.

The Power Cable penetrates the *Metal Box* enclosure and induces 0.4 Volts on the Window of this enclosure.

Corrections? [NONE]:

0.4 is assumed to be a PEAK VOLTAGE of a COUPLING. Correct? [YES]:

KNACK asks the expert for confirmation because it knows from its generalization, shown in Figure 3. , that its guess for the concept representing the number "0.4" might be wrong.

3.5 CHECKING THE KNOWLEDGE BASE FOR INCOMPLETENESS AND INCONSISTENCY.

KNACK's knowledge acquisition approach described in the preceding sections generalizes a specific sample report. This results in a knowledge base the generated WRINGER expert system can use to evaluate a range of electromechanical systems. However, the sample report covers only one simple system and inevitably lacks concepts necessary to evaluate a broad range of systems.

For this reason, KNACK searches the knowledge base for report fragments or strategies that indicate gaps or conflicts with its conceptual model. This review of the knowledge base is most relevant at the end of the acquisition process, because an apparent gap found during the process might be filled in later in the process. When a conflict was detected or an indication of a gap was found, KNACK asks the expert to correct either the fragment, the strategy, or the conceptual model. In cases where the conceptual model is changed, KNACK reviews all fragments or strategies that use the changed concept or relation to propagate the change through the knowledge base automatically, making guesses when ambiguities arise. On the other hand, when the expert adds or changes report fragments or strategies, KNACK processes them through the integration of the conceptual model, display of examples, strategy definition, and checking. The remaining part of this section demonstrates some of the heuristics KNACK uses to identify incompleteness and inconsistency in its knowledge base.

A flaw is indicated if a concept or a representative for a concept was introduced into the model but never used. For example, the conceptual model contains the concept FUNCTION, which is not integrated with any report fragment. KNACK reminds the expert of that.

The knowledge base might be incomplete if the conceptual model indicates a relation between two concepts, but every fragment containing one concept consistently contains the other one:

> A SUBSYSTEM meets a COUPLING condition via an ENCLOSURE. No report fragment was defined dealing with SUBSYSTEMs without ENCLOSUREs. Do you want to define one now? [YES]: *no*

Gaps exist whenever the expert inadvertently leaves out some concepts or representative values for them. For each concept figuring in relations with several others, KNACK asks for possible extensions to that set:

> A COUPLING condition affects SUBSYSTEMs via a CABLE. Do you know any other media for a COUPLING condition to affect a SUBSYSTEM? [NO]: *antenna*

This introduces a new concept: ANTENNA. KNACK integrates new concepts into the model using the process described in section 3.1. KNACK then examines the generalized sample report to find fragments mentioning the ANTENNA concept. As the conceptual model previously did not include knowledge about ANTENNAs, any occurrences in the sample report fragments were treated as fixed text in the generalizations. KNACK now variabilizes the new concept in those fragments and displays instantiated examples. If there are no fragments mentioning the new concept, KNACK looks for related concepts in the conceptual model. It then integrates the new concept with fragments dealing with the related concept and displays instantiations for confirmation by the expert.

SECTION 4

CONCLUSION

This paper introduced the approach KNACK takes to acquire knowledge for evaluating designs of electromechanical systems. An important goal in this research is that domain experts interacting with KNACK do not need knowledge engineering skills. However, KNACK must generate the highly structured knowledge base of the WRINGER expert systems. To bridge this gap, KNACK takes advantage of some presupposed knowledge about evaluating electromechanical systems. The general knowledge is used to acquire a conceptual model of the domain during an initial questioning session. The conceptual model gives KNACK the leverage to generalize a sample report and sample strategies, and to display several instantiated generalizations. The expert's corrections of the instantiated generalizations provide additional knowledge with which KNACK extends the conceptual model. Finally, KNACK examines the resulting knowledge base to check for incompleteness and inconsistency.

SECTION 5

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