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*FRASES -- A knowledge representation scheme for engineering design

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ABSTRACT

Along with the rising complexity of design knowledge, knowledge management which includes knowledge acquisition, representation, control, and processing becomes a very difficult task. A good knowledge management scheme is needed to increase the reliability and efficiency of knowledge-based systems. In this paper an efficient knowledge representation scheme for engineering design applications called Frames and Rules Associated System Entity Structure (FRASES) is introduced. With FRASES, complex engineering design knowledge is organized into a hierarchical, entity-oriented tree structure to facilitate control and processing of knowledge. Exploiting well-defined axioms and operations of FRASES, the knowledge acquisition task, accomplished conventionally with time-consuming manual interviewing, can be efficiently automated.

INTRODUCTION

In the last decade the technology of knowledge-based systems has been widely used in solving various engineering problems such as system diagnosis, production scheduling, capacity planning, operation monitoring, design and synthesis, and performance evaluation. In general, the performance of a knowledge-based system is determined by its knowledge management scheme which includes techniques for knowledge representation, acquisition, and inferencing. Up to now, there is no accepted standard, common method for knowledge management in knowledge- based systems. The strategy for knowledge management is usually highly application-dependent. To assure high reliability and efficiency of knowledge-based systems, system designers are responsible to identify the characteristics of a design application and select the most appropriate knowledge management scheme.

Our efforts have focused on entity structure-based system design (Rozenblit and Zeigler 1988, Rozenblit and Huang, 1987). The system entity structure is a knowledge representation scheme that combines the concepts of decomposition, taxonomic, and coupling relationships (Zeigler 1984).

In the following sections we shall present a knowledge representation scheme called Frames and Rules Associated System Entity Structure (FRASES) for engineering design applications. The main objective of FRASES is to facilitate the knowledge management task in knowledge-based engineering design systems. The discussion of this paper will focus on issues of representation, acquisition, refinement, and inferencing.

KNOWLEDGE REPRESENTATION WITH FRASES

Knowledge-based systems are becoming increasing useful in solving complex engineering design problems. Each knowledge-based system may contain one or more knowledge bases for a specific application. For each knowledge base, a certain representation scheme is employed to organize the knowledge acquired from human experts. A good knowledge representation scheme not only efficiently represents all essential knowledge but it also facilitates the knowledge acquisition and inferencing processes. A good knowledge representation scheme for engineering design should be able to represent the following aspects of the design knowledge:

- structural/behavioral characteristic of objects
- taxonomy/decomposition of objects
- constraint checking and design synthesis rules
- generation of design alternatives procedures
- design verification and evaluation procedures

It should also facilitate knowledge management within the system. For example, it should assist in efficient knowledge acquisition, knowledge inferencing, and decision making. Finally, knowledge reflected by the representation scheme must be transparent to domain experts, knowledge engineers, and system users.

The requirement on high quality knowledge-based systems have made the knowledge representation become a major topic in AI research. Different schemes such as production rules (Newell and Simon 1972), frames (Minsky 1977), structure models (Dhar 1987), semantic networks (Quillian 1968), AND/OR trees (Nilsson 1971), and system entity structure (Zeigler 1984, Rozenblit and Huang 1987) have been defined for representing knowledge. These conventional representation schemes may not satisfy all requirements when applied to engineering design domain individually. Based on this observation, we augment the system entity structure into Frame and Rule-Associated System Entity Structure (FRASES). Combined with production rules and frames, FRASES sucessfully represents the knowledge required for engineering design into a hierarchical, entity-oriented knowledge base. FRASES is a superclass of the system entity structure that emcompasses the boundries, decompositions, and taxonomic relationships of the system being designed. All axioms (i.e., Uniformity, Strict hierarchy, Alternating mode, Valid brothers, Attached variables) and operations (i.e. Naming scheme, Distribution and Aggregation, Transformation, Pruning, Inheritance) defined for the system entity structure (Zeigler 1984) are also valid for FRASES-based representations.

In FRASES, an entity signifies a conceptual part of the system which has been identified as a component in one or more decompositions. Each such decomposition is called an aspect. In addition to decompositions, there are relations that facilitate the representation of variants for an entity. Called specialized entities, such variants inherit properties of an entity to which they are related by the specialization relation. A typical example of FRASES representation for a robot design is shown in Figure

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1. As shown in Figure 1, each FRASES entity is associated with an Entity Information Frame (EIF). Each Entity Information Frame is a frame object containing variable slots of:

$$< N,\ DATTs,\ DSF,\ CRS,\ CH >$$

where

N: is the name of associated entity or model
DATTs: are design attributes of N
DSF: is the design specification form
CRS: are constraint rules for pruning/synthesis
CH : children entities of N

DSF is a frame used to accept user's design objectives, constraints, and criteria weighting scheme specification. CRS contains pruning and synthesis rules for generating a system configuration. CH indicates the children nodes of the entity. To accomplish a design application, the knowledge given by an Entity Information Frame (EIF) will be extracted and processed by an appropriate inference engine during the design process.

The knowledge representation in FRASES is distinguished from other knowledge representation schemes by the following features:

- Generation of Knowledge: FRASES is a generative representation scheme. Via transformations, new knowledge can be generated.

- Modularity: Axioms of strict hierarchy and alternation assure FRASES to be a hierarchical, modular knowledge representation scheme. This is essential for representing complex knowledge required in engineering design. Knowledge processing (e.g., modifications, updating, deleting) can be localized by focusing on an entity for which the processing is required.

- Efficiency: The characteristic of inheritance and uniformity highly reduces the size of a knowledge base required for the same design application. In FRASES all the attached attributes and substructures are inherited through the specialization of an entity. Every occurrence of an entity has the same Entity Information Frame and isomorphic substructures. The identical nodes located in different paths are updated automatically according to the axiom of uniformity.

- Flexibility: By using the top-down design methodology, the FRASES enables the users to specify design knowledge at the most appropriate design level and to refine the knowledge (or equivalent FRASES structure) as the technology evolves and changes.

KNOWLEDGE ACQUISITION WITH FRASES

Although a number of methodologies such as interviewing, protocol analysis, observing, induction, clustering, prototyping (Waterman 1971, Ritchie 1984, Kahn 1985, Hart 1985, Kessel 1986, Gaines 1987, Olson 1987, etc.) etc., have been proposed for knowledge acquisition, it is difficult to demonstrate their efficiency in engineering design applications. Different design applications require different strategies for knowledge acquisition and representation to avoid misunderstanding and/or loss of important knowledge from human expert. It is very difficult to acquire all aspects of design knowledge simply via the question/answer elicitation process. For example, the knowledge engineer may be unable to question all knowledge required for a design application; or the knowledge to be acquired may be too complicated to be asked in questions, or the human expert may misunderstand the knowledge engineer's questions. All the above situations may result in unnecessary, duplicate, conflicting, or confused knowledge. Acquiring complex knowledge with conventional acquisition methods is costly due to preparation, verification, organization, and traslation of information acquired from human experts. To avoid misunderstanding and/or missing of important facts, knowledge acquisition should be directed or supervised under a certain scheme. The scheme should help in: acquiring knowledge, detecting conflicts, identifying missing facts, and eliminating duplicate or unnecessary knowledge.

FRASES is a complete knowledge representation scheme for engineering design application, which conveys not only the static knowledge (structure and attributes) but also the dynamic knowledge (constraint rules for design, synthesis, verification and evaluation) required for design applications. By using FRASES, the complex knowledge acquisition task can be automated. At each design level, question patterns about decomposition and taxonomy knowledge of design objects can be generated automatically. If an Entity Information Frame (EIF) is missing, this fact will be detected and signaled to design experts. Appropriate verification procedures will be integrated for axiom examination and elimination of conflicting and/or duplicate knowledge. Acquired knowledge will be automatically translated into internal representation without human intervention. Knowledge acquisition assisted or activated by following the FRASES approach is called Knowledge Acquisition based on Representation (KAR). A simplified knowledge acquisition on robot design with KAR approach is shown in Figure 2. At each iterative acquisition, related querry rules are referred and interpreted based on the structural nature of FRASES to generate question patterns. Several advantages are expected from the KAR approach:

- Efficiency: Questions patterns required to acquire design knowledge for decomposition, taxonomy, pruning, and synthesis of systems are first predefined into querry rules. Based on the structure of FRASES, appropriate questions can be automatically generated to querry knowledge. KAR approach directly translates the acquired knowledge into FRASES representation. By exploiting the defined axioms and operations, the time-consuming acquisition task can be accomplished efficiently.

- Flexibility: FRASES is a flexible knowledge representation scheme. Simple modification of FRASES will fit other AI research applications such as object identification or consultantion systems. As shown in Figure 3, to identify an appropriate robot type for design application, alternative robot designs can be orgainized into a pure specialization FRASES with selction constraints associated with appropriate specialization entities.

- Controllability and Observability: FRASES will be implemented using extensive graphic facilities. The entity-oriented, hierarchical structure of FRASES allows the represented knowledge to be updated easily.

- Cost-Effectiveness: Unlike the conventional schemes which

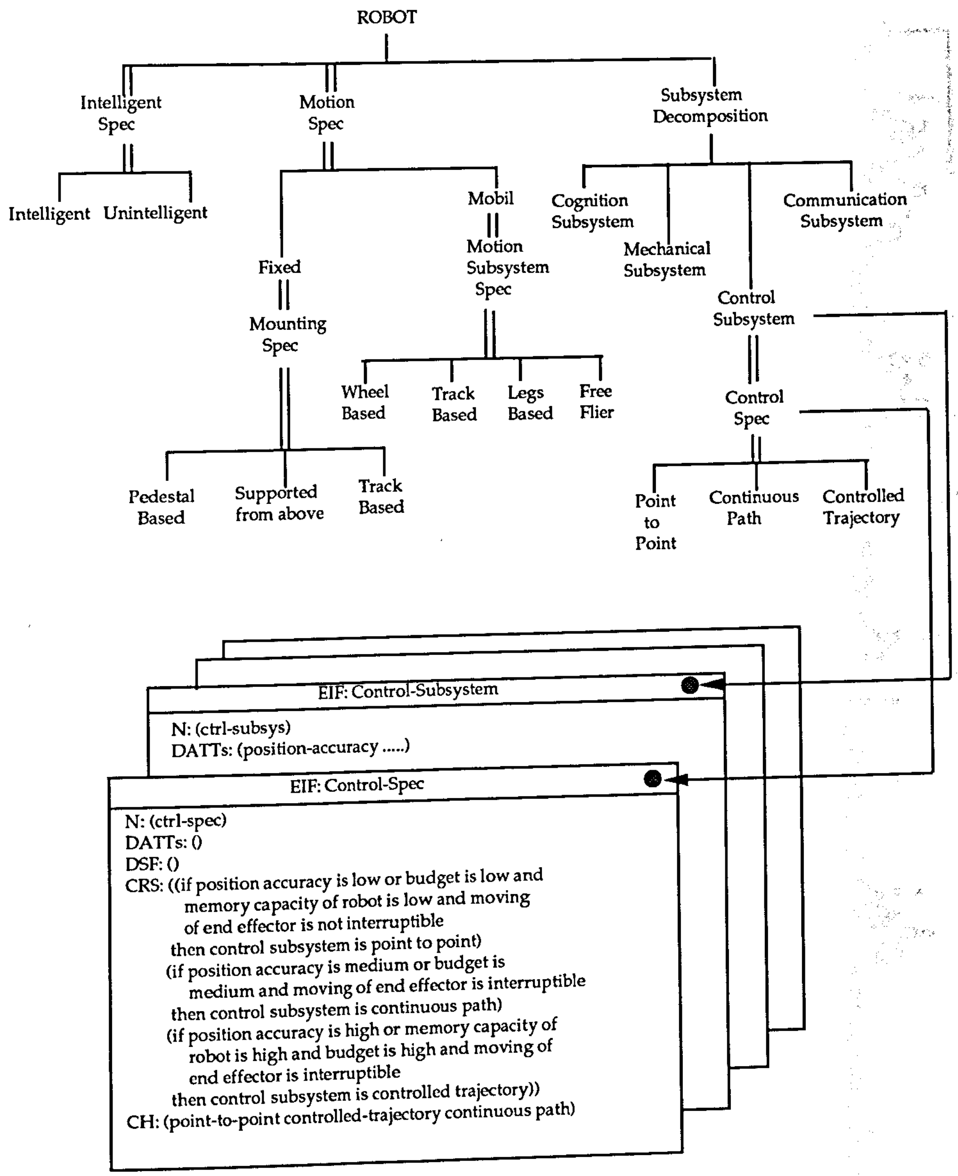


Figure 1 Robot design in FRASES

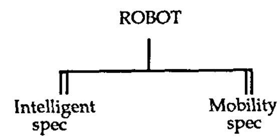
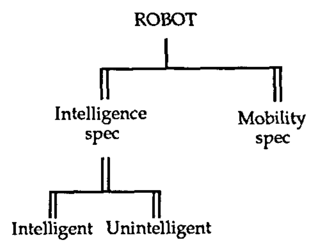
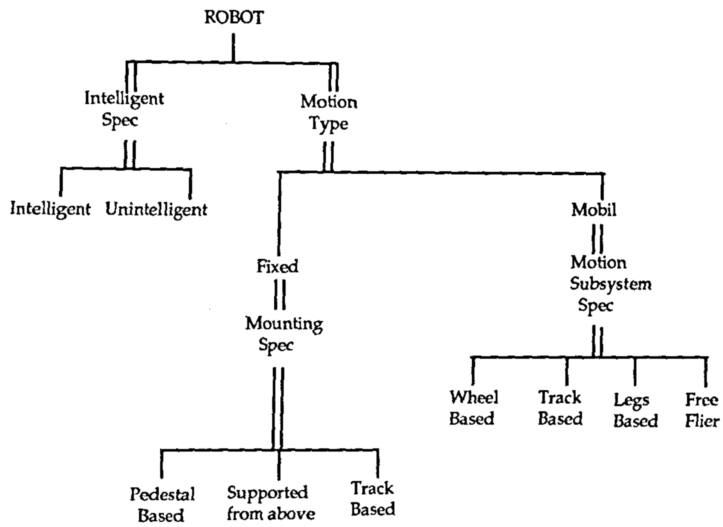
Expert/KAR Interaction	System Internal Conversion
1.) What is your design domain (a list)? => (robot)	1.) ROBOT
2.) Can you classify robots based on certain specialization (a list)? => (intelligence mobility)	2.) 
3.) What are those alternatives when you classify robots based on intelligence (a list)? => (intelligent unintelligent)	3.) 
4.) What is the rule for selecting an intelligent robot (IF-THEN clause)? => (if degree of autonomy is high or medium then the robot is intelligent)	4.) ROBOT.EIF.ATTs = (autonomy) ROBOT.EIF.CRS = (if ROBOT.autonomy = high or ROBOT.autonomy = medium then select ROBOT.Intelligence = Intelligent) . . . .
n.) Can you decompose a robot based on certain aspects (a list)? => (cognition-subsystem communication-subsystem control-subsystem . . . .)	

Figure 2 KAR with FRASES for robot design



Intelligent-Spec.EIF.CRS:
((if desired autonomy is high or medium then select Intelligent Robot)
(if desired autonomy is low then select Unintelligent ROBOT))

Motion-Type-EIF.CRS:
((if budget is low and working area is less than 25 square feet or
arm carrying capacity is larger than 1000 lbs
then select Fixed ROBOT)
(if budget is high and working area is larger than 25 square feet or
arm carrying capacity is less than 1000 lbs
then select Mobil ROBOT))

Mounting-Spec.EIF.CRS:
((if Motion-type is fixed and power consumption is low and
working area has a solid ground then select Pedestal-Based mounting)
(if Motion-type is fixed and power consumption is medium and
degree of freedom is low and working area has a soft ground
then select Support-from-above mounting)
....
)

Figure 3 Object identification with FRASES always require human intervention in knowledge acquisition, verification, translation, and organization, the knowledge acquisition task is automated with KAR. The fast turnaround of knowledge acquisition highly reduces the development cost of knowledge-based systems.

DESIGN PROCESS AND VERIFICATION WITH FRASES

After the design knowledge is built into FRASES representation, the system is ready to aid in the design process. A set of design objectives and constraints are accepted through the Design Specification Form (DSF) interface. These user- specified requirements and constraints are employed to derive design configurations. From the view point of problem-solving, aspect and specialization nodes of the system entity structure are the states of the solution space. The process of design generation can be interpreted as a search directed by constraints associated with these states. The mechanism which drives this search is called pruning (Rozenblit and Huang 1987). The resultant design is accomplished by forming a path made of these states through a process of analysis, synthesis, and evaluation. A number of production rules are attached to each state to direct the search. The type of rules can be either selection or synthesis. This depends on the type of a node. The synthesis rules are associated with the aspect node. The selection rules are associated with the specialization node (Rozenblit and Huang 1987). Generally speaking, design constraints are classified into two categories, static and dynamic (Rozenblit and Hu 1988). Without the aid of verification tools such as analytic methods or simulation, the dynamic constraints can not be used for configuration pruning. To save time, all possible design configurations should be generated all at once instead of reapplying searching techniques time after time. As mentioned before, simulation is employed for our design verification. If there exists more than one design configuration, the trade-off design evaluation using techniques of multi-criteria decision making will be activated to suggest the most appropriate design based on the criteria weighting specified in the Design Specification Form (Rozenblit and Hu 1988).

CONCLUSION

Because knowledge-based systems explicitly represent and reason with knowledge supplied by human experts, they offer considerable promise in modern engineering design. This paper has presented a knowledge management scheme used in our system called Knowledge-Based Design Support Environment (KBDSE). A flexible and efficient knowledge representation scheme called FRASES was introduced for representing complicated modern engineering design knowledge. The hierarchical, entity-oriented FRASES representation not only facilitates the knowledge acquisition but also eases control and processing of design knowledge. Knowledge management with FRASES, the time and cost spent in acquisition, verification, translation, organization and application are highly reduced.

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