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REASONING IN TIME AND SPACE: ISSUES IN INTERFACING A GRAPHIC COMPUTER SIMULATION WITH AN EXPERT SYSTEM FOR AN INTELLIGENT SIMULATION TRAINING SYSTEM

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ABSTRACT

Computer simulation and expert systems technologies have the same goal: the study of intractable, complex systems for which standard algorithmic methods of study are inadequate. An expert system can be interfaced with a graphic computer simulation to reason about physical systems. Such an expert system needs the ability to reason qualitatively about simulation objects. This reasoning includes temporal, spatial, and causal (cause and effect) reasoning. This paper describes an expert-system/graphic-computer-simulation interface for an Intelligent Simulation Training System (ISTS) which is currently under development. Important design considerations include the reasoning tasks involved, mechanisms for reasoning about physical systems, and machine perception of simulation data for use by the expert system. It is necessary to carefully design the interface between a graphic computer simulation and an expert system in order to realize automated, intelligent training related to physical systems.

1. INTRODUCTION

Computer simulation and expert systems technologies have the same goal: the study of intractable, complex systems for which standard algorithmic methods of study are inadequate. The success of each of these technologies depends on how well the simulation model or reasoning mechanism is fitted to the application domain.

A domain may lie anywhere between two extremes. At one extreme are domains in which the knowledge is ill-specified. It is hard to determine what the basic conceptual primitives are within the domain because the underlying theory is not sufficiently developed. At the other end of the spectrum are domains which have become so formalized and well-understood that efficient algorithms have been developed for problem solving. In the middle of the spectrum lie domains which are amenable to study via computer simulation and/or expert systems. These domains are sufficiently understood to be modeled, yet they cannot be approached algorithmically.

An expert system can be interfaced with a graphic computer simulation to reason about physical systems. Such an expert system needs the ability to reason qualitatively about simulation objects. This reasoning includes temporal, spatial, and causal (cause and effect) reasoning.

This paper describes an expert-system/graphic-computer-simulation interface for an Intelligent Simulation Training System (ISTS) which is currently under development. Section 2 describes the ISTS. Reasoning tasks which must be performed by the ISTS are outlined in Section 3. In Section 4, the requirements for computer reasoning about physical systems are enumerated. Section 5 includes discussion of expert-system perception of the simulation and prediction of future events. Finally, conclusions are drawn in Section 6.

2. INTELLIGENT SIMULATION TRAINING SYSTEM

2.1. Purpose

An Intelligent Simulation Training System (ISTS) is currently under development at the University of Central Florida (Department of Industrial Engineering and Management Systems; Dr. John E. Biegel, Principal Investigator). This system consists of a graphic computer simulation, an expert system, and a user interface (Biegel, et al. 1988b). The purpose of the ISTS is to instruct students in a particular domain in such a way that the instruction is tailored to the students' individual needs. Artificial intelligence technology is being applied in order to achieve this goal. It is desirable to have real-time processing capability in the final system.

The ISTS is being developed on a Symbolics 3630 LISP machine in Symbolics LISP (a superset of Common LISP). The ISTS is generic; suitable for any domain which can be described by a graphic computer simulation.

2.2. Description

The graphic simulation displays and manipulates objects within an "environment" which is represented in two dimensions on a color monitor. The simulation is driven and/ or modified by an intelligent tutor. It is a continuous, dynamic simulation, in which objects are moved on the screen in a time-dependent manner.

The user interface is the means by which the student (user) can communicate commands to the simulation objects (thus affecting the simulation scenario.) The student's objective is to manipulate the simulation objects in such a way that tutoring goals for the particular domain are met. At the same time, certain constraints should not be violated. The user interface is also necessary for viewing or changing other aspects of the ISTS, such as records of student performance in managing simulation objects.

The expert system is closely connected to the graphic simulation. Its purpose is to instruct the student and rate the student's performance in controlling the simulation objects. The expert system contains two expert components: the domain expert and the domain instruction expert. The domain expert contains knowledge of skills and methods to be taught within the domain. The domain instruction expert contains knowledge of skills and methods for teaching the particular domain (e.g. which topics to teach initially, etc.). These two modules comprise repositories for all of the domain-dependent information (except, of course, the simulation). This design allows the remainder of the system to be generic. Each time the ISTS is applied to a new domain, a domain-dependent knowledge base must be elicited (and a simulation must be developed). Other, domain-independent modules (e.g. the tutor, student model, evaluator, etc.) access and use the domain-dependent knowledge during inferencing. Therefore, the success of the whole system depends on the accuracy and sufficiency of the domain-dependent knowledge bases.

2.3. ELICIT

We are undertaking to develop an automatic knowledge acquisition module for elicitation of an expert system's domain-dependent knowledge base. This module will be called ELICIT: Expertise Learner and Intelligent Causal Inference Tool. ELICIT is intended to ease the process of using the ISTS in a new domain. It will serve as a front-end knowledge-based system which elicits and represents the domain-dependent knowledge base in such a way that it can be effectively used by the ISTS (Interrante. 1989).

In developing ELICIT, the main considerations center around the following:

1. What type of reasoning must an expert system perform to "understand" what is happening in the simulation?

2. What kind of language is needed to describe the succession of simulation events (and the implications thereof) in a qualitative manner for reasoning purposes?

3. What is the relationship between the certainty of the current state of the simulation and future uncertainty in reasoning about possible future events?

4. How should the expert system "perceive" the simulation?

In other words, what kind of knowledge must the expert system possess in order to be able to successfully interface with the simulation?

Although these issues are central to the entire ISTS project, they have surfaced during the development of ELICIT for the following reason. In order to design an automatic knowledge acquisition system, one must develop an internal language (description language) that is able to capture the information needed for adequate reasoning in the application. In the case of the generic ISTS, the application is this: "understand" the simulation to the point that expert performance in manipulation of simulation objects is possible. The expert system functions as an intelligent agent which is "looking on" as the simulation progresses, reasoning about the succession of simulation events, and responding by issuing commands to simulation objects.

3. REASONING TASKS

3.1. Analysis versus Synthesis Tasks

There is a broad range of reasoning tasks which an expert system can exhibit. The simpler of these tasks are interpretation, prediction, and diagnosis. Expert systems which perform these tasks are known as analysis systems. The majority of expert systems which have been developed are analysis systems. They are typically bottom-up, knowledge-sparse systems which do not rely on a domain model or a model of the knowledge base to perform inferences. Many pure production systems fit this category.

Unfortunately, most complex, real-world problems cannot be solved via analysis systems. This is particularly true of problems in which solution methods depend on models of physical systems. Most problems in the field of engineering fall into this category.

In addition to interpreting, predicting, and diagnosing; engineers design, plan, monitor, debug, repair, and control. Expert systems which are designed to teach expertise to novices perform the complex reasoning task of instruction. Synthesis systems perform these higher-level reasoning tasks. They are knowledge-rich, top-down, model-driven systems which rely on meta-knowledge and a sophisticated representation paradigm for inferencing. Relatively few synthesis expert systems have been developed.

3.2. ISTS Reasoning Tasks

The ISTS must perform complex, synthesis-type reasoning tasks. The system must monitor the simulation as it progresses. It must interpret a particular simulation scenario. It must predict the events that will occur in the future, based on the current scenario. The system must determine the roles which particular elements of the current scenario will play in upcoming events. It must plan methods for achieving domain goals, as well as for avoiding negative events. The system must monitor student actions and analyze these actions by comparing them to expert behavior within the same context. This expert behavior is generated by the ISTS by drawing upon the domain expert component. The system must be capable of "repairing" the scenario (carrying out plans to avoid upcoming negative events) when a student asks for help.

In short, the system must monitor and/or control the movement of simulation objects, as well as monitor student behavior. It must instruct the student in such a way that the instruction is unique to the state of the simulation as well as the particular student's needs. These are very complex reasoning tasks.

4. REASONING ABOUT PHYSICAL SYSTEMS

Inherent to an expert system which is capable of synthesis tasks is a method of representing the physical domain upon which the reasoning is based. In traditional engineering problem solving, this representation is quantitative. The representation consists of variables which represent state parameters, with numeric coefficients in equations. The equations represent relationships and constraints in the domain.

An expert system, however, needs a qualitative representation of the domain. This reduces the information about the domain to the essential features of the problem. This information reduction eases the task of focusing during problem solving. Appropriate focus is necessary for efficient problem solving in expert systems which perform complex reasoning tasks. Time, space, and causality must be represented to capture important concepts for reasoning about a physical system.

4.1. Temporal Reasoning

Temporal reasoning is a mechanism for drawing inferences about objects whose behaviors are time-dependent. Time may be represented discretely or continuously. Shoham states that a theory of time must provide:

1. A description language for stating the true and false predicates at various points in time and for comparing scenarios at different instances of time to determine relevant changes.

2. A way of reasoning about acceptable or unacceptable changes (a way to constrain the allowable type of change) in the description language (Shoham. 1988).

4.2. Spatial Reasoning

Spatial reasoning cannot be separated from temporal reasoning when drawing inferences about a physical system which contains moving objects. It is necessary to know where objects are at a certain instance of time as well as where objects are expected to be at some future instant. Spatial reasoning (as well as temporal reasoning) can be absolute or relative. In absolute spatial reasoning the object's position is compared to a fixed origin. Relative spatial reasoning deals with the position of one object as compared to that of another object (or objects).

4.3. Causal Reasoning

Reasoning about objects in a physical system requires more information about the relationships among objects than temporal or spatial information alone. It is necessary to have information about how the behavior of one object affects the rest of the physical system. A model must be employed in reasoning about domains which are related to physical systems.

A causal model represents cause-effect relationships among objects in a domain. Causal reasoning involves deduction of the global behavior of a system based on cause and effect behavior of its individual components. In this way, the system supports top-down reasoning about the domain represented by the model.

Another benefit of a model is that it serves as an organizer of domain knowledge. Related bits of knowledge are grouped together with the object to which they correspond. Reasoning about a particular object or relationship is efficient since all knowledge related to the object or relationship is stored in one place. Furthermore, knowledge-rich, top-down methods such as causal modeling exhibit noise immunity and they are relatively easy to extend and modify.

Causal models are necessary for expert systems which perform synthesis reasoning tasks in domains which involve physical systems. Knowledge of cause and effect is necessary in order to explain or predict the behavior of physical systems. Without causal information it is difficult, if not impossible, to have the understanding necessary for reasoning about the state of a physical system and for predicting events within that system. A causal model provides knowledge of the consequences of particular actions on components of the system. Causal reasoning provides information about when and why changes occurred in the system by maintaining a history of dependencies among system state changes.

Elements of the expert system (causal) domain model should be analogous to simulation objects. In this way, a cross-reference exists between the expert system model and the simulation model. The expert-system/graphic-computer-simulation interface must be designed to take advantage of this cross-referencing. Figure 1 illustrates the type of information which must be passed through the interface.

The simulation passes object position and object speed information to the expert system when requested (see Section 5). The expert system issues commands to the simulation to change object movements.

4.4. ISTS Reasoning about Physical Systems

The graphic computer simulation makes use of time-dependent equations to determine where to depict objects within a scenario (i.e. on the CRT) at any given time. These equations are necessarily quantitative. They express the "physics" of the domain. Unfortunately, these equations cannot support efficient, knowledge-based reasoning related to the simulated domain. The processing requirement would be prohibitive for drawing inferences on

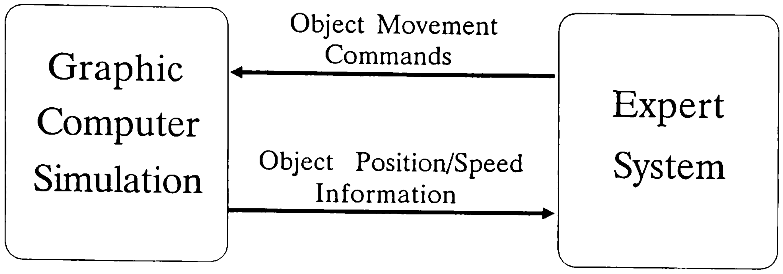

Figure 1: Simulation/expert-system interface.

this basis because of:

1. the complex reasoning tasks involved,
2. the many simulation objects that may exist in one scenario, and
3. the lack of a real-time processing capability.

A mechanism is needed for analyzing the state of the domain qualitatively and making decisions on this basis (as much as possible). This is similar to what human experts do. After a certain amount of experience, e.g., a human air traffic controller can "eye" an undesirable situation developing on a radar screen and perform the necessary actions to correct the situation. The expert controller needs little quantitative information in order to do this.

To build this capability into a computer, the expert-system domain model must include qualitative causal, temporal, and spatial reasoning mechanisms. Objects affect each other in time and space during the simulation. These effects cause events to occur which are also time- and space-dependent. Events, in turn, affect simulation objects and cause other events to occur. There is a network of complex, interdependent interactions which may be event-to-event, object-to-object, object-to-event, or event-to-object relationships. The domain model and associated heuristics must represent these interactions qualitatively.

5. UNDERSTANDING THE SIMULATION AND PREDICTING THE FUTURE

5.1. Expert-System Perception of the Simulation

Important questions arise in the design of the expert-system/computer-simulation interface. The graphic simulation provides a wealth of information from which the expert system can draw for reasoning. As stated previously, it is too time consuming to examine and attempt to use all of the simulation data in this process. What data is most useful for reasoning purposes? In a system which performs complex reasoning tasks such as the ISTS does, some data is more significant than other data. Furthermore, the significance of a particular datum changes with time. How often should the simulation data be examined in this time-dependent application? In other words, when should the expert system's data be updated by more current simulation data? There is a tradeoff here between processing time and accuracy.

Currently, a method is being developed for allowing variable time increments between accessing of simulation data, depending on the state of the simulation. At times when objects are widely spaced and no critical events are imminent, the time interval between "glances" at the simulation should be relatively large. At other times, for example, object collisions may be imminent and more frequent accessing of simulation data will be necessary. The goal is to develop a situation-dependent type of machine perception for the expert system.

5.2. Implications in the Prediction of Future Events

In order to judge the frequency for accessing simulation data, it is necessary for the expert system to be able to predict future events based on the current state of the simulation. To this end, a modal logic is being employed. This mechanism will enhance the expert system's ability to monitor and control simulation objects. The expert system's ability to pass this information on to the student user during instruction will be enhanced as well. Information about the aspects of the simulation which provoked particular expert-system responses will be represented explicitly in the expert system.

6. CONCLUSION

Computer simulation and expert systems technologies are used to study similar systems: intractable, complex systems for which standard algorithmic methods of study are inadequate. A problem-solving tool which draws upon both technologies should prove to be very powerful.

However, much work needs to be accomplished in designing an interface mechanism for intertwining these technologies. This paper defined some of the necessary design features of such an expert-system/computer-simulation interface which are being incorporated into ELICIT: Expertise Learner and Intelligent Causal Inference Tool. Important considerations include the reasoning tasks involved, mechanisms for reasoning about physical systems, and machine perception of simulation data for use by the expert system. Systems such as the ISTS provide a deeper understanding of the application domain by adding reasoning ability to a graphic computer simulation. It is only with this "deep" understanding that automated, intelligent training related to physical systems can be realized.

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REFERENCES

Biegel, J.E., Draman, M., Nadoli, G. and Brooks, G.H. (1988a). Control and inferencing paradigms for an Intelligent Simulation Training System. In: Proceedings of the First Florida Artificial Intelligence Research Symposium (M.B. Fishman, ed.). Florida AI Research Symposium, Orlando, Florida, 254-256.

Biegel, J.E., et al. (1988b) Input and instruction paradigms for an Intelligent Simulation Training System. In: Proceedings of the First Florida Artificial Intelligence Research Symposium (M.B. Fishman, ed.). Florida AI Research Symposium, Orlando, Florida, 250-253.

Bobrow, D.G. (ed.). (1985). Qualitative Reasoning about Physical Systems. MIT Press, Cambridge, Massachusetts.

Boose, J.H. (1986). Expertise Transfer for Expert System Design. Elsevier Science Publishing Co., Amsterdam, The Netherlands.

Interrante, L.D. and Biegel, J.E. (1989). Automatic knowledge acquisition for an Intelligent Simulation Training System. In: Proceedings: Annual Conference of the International Association of Knowledge Engineers. Systemsware Corporation, Kensington, Maryland.

Shoham, Y. (1988). Reasoning about Change. MIT Press, Cambridge, Massachusetts.

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