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Space Transportation System Meteorological Expert

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ABSTRACT

Computers are being used today to build the expert systems of tomorrow. Expert systems are computer programs that are smart about a domain in the way that people are smart. Expert systems technology is being applied to weather forecasting to support Shuttle operations for launch and for ground processing at Kennedy Space Center (KSC), Florida. The Space Transportation System Meterological ExperT (STSMET) is a long term project, now in its third year, to capture general Shuttle operational weather forecasting expertise specific to our locale, to apply it to Shuttle operational weather forecasting tasks at the Cape Canaveral Forecast Facility (CCFF) at the Cape Canaveral Air Force Station (CCAFS), and to ultimately provide an on-line, real-time operational aid to the duty forecasters in performing their tasks.

The first domain addressed by the project has been summer thunderstorms. The effort to represent this knowledge and a control structure to reason about it has resulted in an approach that we call scenario-based reasoning. Other meteorological domains on our agenda are frontal weather phenomena, visibility including fog, and wind shear. We believe that scenario-based reasoning is also applicable to these other meteorological domains. The specific operational tasks to which to apply the general knowledge about summer thunderstorms are being identified during this phase of the contract.

The project is being developed using state-of-the-art hardware and software: a Symbolics Lisp Machine, Zetalisp and Automated Reasoning Tool (ART), an expert system shell.

Scenario-based reasoning appears to have applications outside of weather forecasting. The abilities of a scenario-based system to reason qualitatively, to reason over time, and to reason across scale are all applicable to planning in autonomous systems. With further research, we expect to add analogical reasoning to the abilities of scenario-based reasoning.

EXPERT SYSTEMS TECHNOLOGY

While advances in computer technology are most often associated with the development of new and powerful computers, the promise of expert systems technology lies in the new uses that can be made of both the new AI Lisp machines and conventional computers. We see the impact of this technology in three major areas. First, with the development of knowledge engineering as a field with a methodology, we are able for the first time to harness the personal knowledge that humans have acquired through years of experience. If we distinguish between public knowledge, private knowledge shared among experts, and personal knowledge (See Diagram 1.), conventional computing has addressed at most that knowledge which lies in the public domain. Automated text books and well understood (although complex!) decision trees are computational expressions of that public knowledge. What expert systems technology promises is the possibility of understanding, and either automating or assisting the private and personal knowledge of humans.

Second, expert systems technology offers us the means of dealing with the meaning of information. As information processing technology has brought increasing amounts of information to the fingertips of countless numbers of workers, the question of what to do and how to respond to that information has become increasingly problematic. It is one thing to know all of the facts and data concerning a particular situation; it is quite another thing to know what those facts and data mean, and to devise intelligent strategies for responding to them. Expert systems technology holds the promise of using computers to assist in this area. (See Diagram 1.)

Third, advances in expert systems technology have allowed us to envision new modes of interaction between humans and computers. The conventional model is to think of the computer as a machine which sits in the corner, takes large amounts of information as input, crunches or processes that information, and spits out "the answer". The vision that expert systems encourages is a vision of the computer as a genuine assistant to the human, serving to remind her where she was in her thought process if that thought process is interrupted, provoking her to consider the situation from multiple perspectives, reasoning to suggested conclusions in some instances, and explaining how those conclusions were reached.

We have begun to see the promise of expert systems technology in these three areas at KSC over the past two years in a project to improve the quality of weather forecasting for Shuttle operations at KSC.

	INFORMATION, FACTS, & DATA	PERSPECTIVES & STRATEGIES FOR USE OF KNOWLEDGE
PUBLIC KNOWLEDGE	Generally available textbook knowledge	Strategies taught in classrooms
SHARED KNOWLEDGE AMONG EXPERTS	Facts understood in special situations	Expert perspectives and strategies taught through apprenticing
PERSONAL KNOWLEDGE	Privately held knowledge never before communicated	Perspectives & strategies built upon intuitive fuzzy reasoning

Diagram 1. Types of Knowledge

STSMET

STSMET is a generalization of the Thunderstorm Weather Forecasting Expert System Project (described below) to provide a framework for continuing research into other meteorological phenomena and more powerful methods of reasoning, while at the same time moving previous work out of the laboratory into an operational role. By providing this framework, continuing research projects and projects on an operational track will benefit each other, but provide the necessary independence from each other. We feel that this is a realistic and necessary long term (ten years) approach to the problem of achieving competing goals from different funding sources.

Other meteorological phenomena being considered for continuing research are frontal systems, visibility including fog, and wind shear. All of these have operational impact. Only one other method of reasoning is being considered, analogical reasoning. Reasoning from first principles still appears to be beyond our ten year window. However, it is quite possible that all our effort will have an equivalent affect, a robust model (not necessarily numeric) with the requisite predictive power.

There are dimensions for continuing the research other than meteorological phenomena and reasoning. We have considered other geographic sites and other domains. The geographic sites could be very similar and the weather knowledge may actually be reusable. The geographic sites could be very different and only the empty shell would be reusable. Regardless of the similarity, there is also the hidden issue of the types and quality of weather data available. Shuttle landing sites are good examples. We have considered other domains such as planning in autonomous systems and also stock trading. They both possess characteristics appropriate to scenario-based reasoning which are discussed in a subsequent section. Space station and its subsystems are good examples.

TWFES

The idea for applying expert systems technology to Shuttle operational weather forecasting first came up in 1983. The domain satisfied the then current rules of thumb. Conventional computer programs (such as numerical models) were not capable of performing the operational forecasting tasks. People performed the operational forecasting tasks regularly in the right amount of time, from five minutes to thirty minutes. Some people performed significantly better than others. People learned how to perform the operational forecasting tasks over a reasonably long period of time, about two years in this case. And, importantly, there was enough economic payoff to justify the large developmental costs. The economic leverage appeared to be in the two hour deorbit forecast for the Shuttle Landing Facility. Avoiding an unnecessary landing at Edwards Air Force Base with the significant costs associated with sending a team to Edwards and delaying ground processing was clearly a win.

However, it was not until 1985 that a feasibility study was funded. Arthur D. Little, Inc. was selected. Their recommendation was quite different than the two hour deorbit forecast. They suggested that the economic impact of severe weather caused by thunderstorms during the summer on day-to-day ground processing, while not as dramatic as the Shuttle landing, was also worth considering. Furthermore, the way that Duty Forecasters seemed to reason about summer thunderstorms could naturally be modeled in a machine. Then, once the ability for a machine to reason about summer thunderstorms was established, the knowledge could be applied to operational forecasting tasks.

The United States Air Force provides the Shuttle operational weather forecasting from the CCFF at the CCAFS. The Duty Forecasters achieve varying measures of expertise. They are, however, on fixed tours of duty. When they leave, much of their expertise leaves with them. Thus the first application of expert systems technology is to capture expertise and provide a sort of corporate memory. There are a variety of specialized instrumentation systems available to the Duty Forecasters in addition to conventional weather data. The Duty Forecasters perform time critical tasks and cannot readily assimilate all the appropriate data, especially prior and during severe weather. Thus the second application of expert systems technology is to assist the Duty Forecaster in selecting appropriate data and in interpreting it.

Phase One of the follow-on contract established that a machine can reason about summer thunderstorms. A demonstration prototype was built on a Symbolics 3640 Lisp machine hardware using Zetalisp and the Automated Reasoning Tool (ART), an expert system shell. Virtually identical hardware/software suites were used by Arthur D. Little, Inc. for development and by NASA for evaluation and use by domain experts. Phase One was completed in 1986.

Phase Two begins the development of a research prototype extending through 1988. This year has four major goals: the acquisition and refinement of more knowledge about summer thunderstorms, the identification of the appropriate operational tasks to which to apply the knowledge through additional knowledge engineering, an approach to measuring system performance for next year, and expert systems technology transfer into NASA. This year will also mark the completion of the Arthur D. Little, Inc. contract. Development will continue in-house at NASA. The following year will concentrate on the user interface and the data interface. Integration of the system into the CCFF will be necessary for performance testing in the summer of 1988.

Phase Three will be the development of a field prototype for use during the summers of 1989 and 1990. This phase addresses speed and reliability issues and performs extensive testing.

The architecture of the on-line runtime system is relatively simple. The kernel is discussed in the next section. The scenario editor is an off-line piece of software that has had several beneficial effects. It is also discussed in the next section.

This project clearly would not have been possible without the advances in computational resources (both hardware and software) made possible by thirty years of AI research. This project is one of many applications extending the scope of problems to which computers are applicable through the use of expert systems technology and symbolic processing.

SCENARIO-BASED REASONING

Scenarios are a linear sequence of events. In general they are modeled as AND/OR trees. Implicit in their content is reasoning across scale (geographic scale in TWFES). Explicit in their form is temporal reasoning. The control structure for reasoning about scenarios can be thought of simply as an agenda of scenarios with an update function and an anticipate function. Both functions interact with the world through events. Events in the scenarios have time windows associated with them, and events in the world have time tags associated with them. Events in the world cause the update function to add or advance scenarios on the agenda. Failure of an event to occur within its associated time window causes the update function to delete scenarios. Adding or advancing actions on the agenda cause the anticipate function to make requests to the world for the next event. Deleting actions on the agenda cause the anticipate function to withdraw requests to the world for a previously anticipated event.

Scenario-based reasoning is appropriate to tasks which are learned empirically. The tasks are characterized by the inability to consider all the available data before taking an action. This can be due to time criticality, a large volume of data, or both. Many tasks in the CCFF are characterized by both.

Scenario-based reasoning occupies a niche in time in predictive power just beyond predictions by simple extrapolation from observations and just short of predictions from robust but computationally expensive models. This is a one to six hour niche for TWFES.

A scenario editor is a powerful tool for acquiring this kind of knowledge from an expert, and relieves the knowledge engineer of considerable effort once the expert is trained in its use. It allows the expert to use the vocabulary of his domain. It enforces a uniformity of representation. A translation module isolates the runtime system from a particular representation in the editor following good software engineering practice to reduce coupling between functions.

SUMMARY

Today the solution to many classes of problems is made possible simply through applying faster and faster computers without any fundamental change in the problem approach. The class of problems in STSMET by their very nature require a fundamental change in the problem approach as exemplified by expert systems technology. The expert systems technology of tomorrow coupled with the increasing computational power available tomorrow will make it possible for STSMET to attack increasingly difficult problems in the weather forecasting domain.

REFERENCES

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