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AN EXPERT DISTRIBUTED ROBOTICS SYSTEM WITH COMPREHENSION AND LEARNING ABILITIES IN THE AIRCRAFT FLIGHT DOMAIN

D.L.WALTZ, R.T. CHIEN, G. DE JONG

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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Investigators:

D. L. Waltz, R. T. Chien, G. DeJong

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1. Introduction

The goal of our research is to build an expert distributed robotics system with comprehension and learning abilities in the aircraft flight domain. We are focusing on knowledge representation, knowledge use, and knowledge acquisition.

In the areas of representation and use we are concentrating on two aspects of this problem, (1) temporal and event representation, and (2) mechanism modeling. An adequate representation for the temporal, causal and spatial relationships between events is essential for a system that is to understand complex mechanical and electrical devices. To this end, we are constructing a natural language understanding system called NALATIK (NAtural LAnguage Temporal Inference and Knowledge system) [Spoor83] which will find or infer such relationships and be able to answer questions involving them. In a companion effort, we are also working on systems that convert high level sensory input into descriptions in terms of events and actions. In the mechanism modeling area, we are building a question answering system for fault diagnosis of an aircraft gas turbine engine, and we have developed some initial understanding models for a generic refrigeration system in terms of such concepts as heat-transfer and circulation.

We are developing an artificial intelligence laboratory which will eventually have an array of modular components which allow the building of integrated systems with learning, natural language processing, perception, and manipulation capabilities. The emphasis here is both on building compatible components and on actually combining them.

We have been investigating the use of meta-planning for an air traffic control system. This planning method uses generalized plans to do the preliminary planning, and then applies correction mechanism to modify the plans in order to "fine tune" them. This method drastically reduces the amount of searching required for planning and should also lead to a less domain specific planning system.

Our work on knowledge acquisition addresses a major obstacle to the implementation of a large expert distributed robotics system, namely the actual construction and updating of their knowledge base. Humans obtain their expertise in a particular domain through years of instruction and of personal experience, and their knowledge of the domain is constantly being updated and refined as it is used. To capture this idea in an expert system, we are constructing two systems that implement Explanatory Schema Acquisition [DeJong82], a knowledge based learning technique. The first is in the domain of Natural Language Processing, and the second is a robot system that will learn new task schemata.

2. Projects Update

2.1. Progress on the NALATIK System

At the current time construction of the the NALATIK system (NAtural LAnguage Temporal Inference and Knowledge system) is well underway. The two lowest levels (the time interval level and the event level) have been designed and implemented for the first time in INTERLISP [Teitelman78], on a XEROX 1100 Scientific Information Processor. The time interval level represents pure temporal information, consisting of intervals and instants in time, linked in a relational network. The event level describes primitive events, and their relationships to time intervals and points. Events also are linked to one another and to spatial and causal information at the event level. A complete description of this system may be found in [Spoor83].

2.2. Progress in Mechanism Modeling

We have been working on a frame based knowledge representation system for modeling and troubleshooting in the aircraft gas turbine engine domain. Rough models of the operation of the inlet duct and compressor have been designed incorporating the ideas of Rieger on representing causality [Rieger75], and of de Kleer on qualitative reasoning [de Kleer75].

We have developed some initial understanding models for a generic refrigeration system in terms of such concepts as heat-transfer and circulation. With the help of these models, we can analyze any schematic of a refrigeration system and identify the relevant components which are pertinent to an operation, such as circulation. We can then easily construct the circulation subsystem as an abstraction.

In a more abstract direction, we have established a systematic process of substructure recognition which facilitates mechanism understanding. By simplifying the physical model through composition of substructures which perform a unit function, and treating the substructure as a single new functional component, the amount of physical detail can be greatly reduced and a composition hierarchy can be imposed over the physical model. Furthermore, this hierarchy enables explanation at various levels of detail. Substructure recognition is based on satisfaction of semantic constraints on component parameter relations, as well as syntactic constraints on the physical structure; recognition can vary in different contexts.

Finally, in the direction of diagnoses, we are studying an important subclass of multiple failures, called "dependent failure" cases, in which a primary failure can trigger subsequent secondary failures. Two new concepts are introduced into this diagnostic approach: (1) the observed symptom, which serves as input the diagnosis process, is a time-sequence of "qualitative" events, and (2) occurrences of secondary failures are treated as timely events which can be explicitly reasoned from mechanism models. To reason about dependent failures, we construct state-transition models which are capable of encoding component knowledge such as time-related constraint characteristics and failure causalities. Based on the structure knowledge and component models, a qualitative reasoning process, called "predictive analysis", is developed to analyze the time-elapsed behavior of a fault-asserted mechanism. With the ability to reason with deep-level mechanism model, a computer-based real-time diagnosis system has been implemented to reject or to justify fault hypotheses by qualitatively matching predicted mechanism behaviors with observed time-elapsed symptom.

2.3. Progress on the Modular AI System

A relatively new project has been launched to design a robotic system that understands what it sees, touches, or otherwise senses, and can learn actions and names of concepts from what it is shown. In order to accomplish this task, the system must have goals driving perception, a rich set of predicate schemas which will render the system capable of finding the correct level of understanding, and an appropriate decision mechanism which gives the system the ability to choose among the predicate schemas given its goals.

This project ties together vision, natural language processing, learning, tactile sensing, and problem solving. Three major areas are involved. The first is determining the link between language and perceptual events [Waltz82]. The second is centered around the predicates themselves

[Miller76]. The last is the actual system implementation, constraining the domain, and associating vision, taction, and language. This includes associating what is seen with the natural language input, and modeling action and the automaton itself.

2.4. Progress in Meta-Planning

We have recently been investigating the applicability of Wilensky's ideas on Meta-Planning [Wilensky81] in real-time control as would be applicable in an air traffic control system. We feel that many of the features of Meta-Planning are useful in this domain especially the explicitness of knowledge about planning (the Meta-Knowledge), which makes plan modification much simpler.

2.5. Progress on the Event Sequence Processor/Explanatory Schema Acquisition System

The event sequence processor/explanatory schema acquisition (ESA) system has three sub-parts, the parser, the event sequence processor, and the learning subsystem. Most of our work and progress to date has been on the event sequence processor part; however, we have recently obtained a copy of the RUS Parser from Bolt, Beranek and Newman [Mark80], and have been coordinating efforts with the NALATIK group in installing it on our VAX11/780. Currently input to the event sequence processor is being translated to a conceptual dependency form (the input format used by the event sequence processor) by hand. The implementation is in INTERLISP and runs on both the VAX11/780 and the XEROX 1100.

The event sequence processor takes input in conceptual dependency form [Schank73] and builds a conceptual model of what is actually happening in the event sequence. A major part of the design of this section of the event sequence processor/explanatory schema acquisition system was coming up with a satisfactory schema representation and writing the support functions. The representation adopted both for schemata and the event sequence model is a graph paradigm. INTERLISP code which makes the conceptual representation to graph translation has been developed for both the VAX and the Xerox machines[1]. Another difficult problem which has been solved for this system is the schema activation problem, the problem of selecting the proper schema or schemata for the given input. A graph-matching algorithm to select schemata from CD input has already been implemented on our system.

The event sequence processor subsystem is currently receiving the most attention, and it is very near completion. As soon as it is done, work can begin on implementing the learning portion of the project.

2.6. Progress on the Robot Learning System

Our project aims to give our robot arm a goal-directed controlling program with ESA-based learning. We have split the problem into two parts and attacked both simultaneously. The first part was to write the action sequence command interpreter, a program which runs on the PDP11/40 and controls the robot arm [Harrington83]. The second part was to write the program to run in INTERLISP on the VAX11/780 which would do the actual learning and would send action sequences to the control program running in the PDP11/40. In order to simplify the reasoning in the INTERLISP learning program, we chose a simple action sequence command language for the communication with the control program, a command language consisting of only five commands: hmovex, hmovey,

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[1] The Xerox machines were not yet available at the beginning of the project; future work will be exclusively on the Xerox 1100's and 1108's.

hmovez, hmover, and hmoveg. These five commands control movement along the three Cartesian coordinate axes (x, y and z), rotation of the gripper, and the opening or closing of the gripper. In order to further simplify the learning program, we restricted the orientation of the gripper (the direction of the axis of joint 6 in the Stanford Manipulator robot arm) to be pointing down at all times. This restricts the Stanford Manipulator to 4 degrees of freedom, but this is sufficient for the tasks we have set out for this first version program.

The action sequence command interpreter (written in Pascal on the PDP11/40) has already been completed. The major problem is controlling the six joint Stanford manipulator such that the gripper follows a straight line trajectory. The control method is one of successive approximations; the control program measures where the gripper is and where it should be, any difference between the two positions is considered as error. The control algorithm then selects the appropriate motor commands such that the error is reduced to zero after approximately 14 program iterations.

Work on the other half of the system, the learning program on the VAX11/780, is also progressing. We have selected constructive solid geometry representation for the internal representation of the objects the system will be manipulating, and have written the routines for manipulating these representations. The original schemata for the basic actions are currently undergoing revisions to make collision detection and avoidance simpler.

3. Publications

3.1. Air Force Sponsored Publications

DeJong, G., "Acquiring Schemata Through Understanding and Generalizing Plans," Proceedings of the Eighth International Joint Conference on Artificial Intelligence, Karlsruhe, West Germany (1983).

DeJong, G., "An Approach to Learning from Observation," Proceedings of the 1983 International Workshop on Machine Learning, Allerton, IL (1983).

DeJong, G., "Artificial Intelligence Implications for Information Retrieval," Proceedings of the Sixth Annual International ACM SIGIR Conference, Washington, D.C. (1983).

DeJong, G. F. and D. L. Waltz, "Understanding Novel Language," The International Journal of Computers and Mathematics with Applications, Vol. 9, No. 1, 131-147 (1983).

Harrington, P. V., "HARRY: A Pascal Control System for the Stanford Manipulator," M.S. thesis, Department of Electrical Engineering, University of Illinois at Urbana-Champaign (1983).

Maran, L. R., D. T. Spoor and D. L. Waltz, "Encoding the Natural Language Meaning of Time - Toward a Conceptual Model for Temporal Meaning," Working Paper 37, Advanced Automation Research Group, Coordinated Science Laboratory, University of Illinois (1983).

O'Rorke, P., "Reasons for Beliefs in Understanding: Applications of Non-Monotonic Dependencies to Story Processing," Proceedings of the 1983 National Conference on Artificial Intelligence, Washington, D.C. (1983).

Spoor, D. T., "A System for Reasoning about Time and Events," M.S. thesis, Department of Electrical Engineering, University of Illinois at Urbana-Champaign (1983).

Waltz, D. L., R. T. Chien and G. DeJong, "An Expert Distributed Robotics System with Comprehension and Learning Abilities in the Aircraft Flight Domain," Technical Report T-116, Advanced Automation Research Group, Coordinated Science Laboratory, University of Illinois, Urbana, IL (1982).

Waltz, D. L., R. T. Chien and G. DeJong, "An Expert Distributed Robotics System with Comprehension and Learning Abilities in the Aircraft Flight Domain," Technical Report T-123, Advanced Automation Research Group, Coordinated Science Laboratory, University of Illinois, Urbana, IL (1983).

3.2. Other Related Publications

DeJong, G., "Automatic Schema Acquisition in a Natural Language Environment," Proceedings of the 1982 National Conference on Artificial Intelligence, Pittsburgh, PA (1982).

DeJong, G., "On Communication Between AI and Lingustics," in Perspectives in Cognitive Science, D. Farwell, S. Helmrich, and W. Wallace (Eds.), Linguistics Student Organization, University of Illinois, Urbana, IL (1982).

Dorfman, M., "Toward a Reader-Based Model of Narrative Understanding," Working Paper 38, Advanced Automation Research Group, Coordinated Science Laboratory, University of Illinois (1983).

Farwell, D., S. Helmrich and W. Wallace (Eds.), Perspectives in Cognitive Science, Linguistics Student Organization, University of Illinois, Urbana, IL (1982).

Pollack, J. and D. L. Waltz, "Natural Language Processing using Spreading Activation and Lateral Inhibition," Proceedings of the Conference of the Cognitive Science Society, Ann Arbor, MI, August, 50-53 (1982).

Segre, A. M., "An Expert System for the Production of Phoneme Strings from Unmarked English Texts using Machine Induced Rules," Proceedings of the First Annual Conference of the European Chapter of the Association for Computational Linguistics, Pisa, Italy (1983).

Segre, A. M., "A System for the Production of Phoneme Strings from Unmarked English Texts," M.S. thesis, Department of Electrical Engineering, University of Illinois at Urbana-Champaign (1983).

Waltz, D. L., "Artificial Intelligence," Scientific American, 247, 4, 118-133 (October 1982).

Waltz, D. L., "Event Shape Diagrams," Proceedings of the National Conference on Artificial Intelligence, Pittsburgh, PA, August, 84-87 (1982).

Waltz, D. L., "The State-of-the-Art in Natural Language Understanding," in M. Ringle and W. Lehnert (eds.), Strategies for Natural Language Processing, Hillsdale, NJ: Erlbaum Associates, 3-36 (1982).

Waltz, D. L. and M. Dorfman, "The Holes in Points," The Behavioral and Brain Sciences, forthcoming (1983).

Waltz, D., M. Genesreth, P. Hart, G. Hendrix, A. Joshi, J. McDermott, T. Mitchell, N. Nilsson, R. Wilensky and W. Woods, "Artificial Intelligence: An Assessment of the State-of-the-Art and Recommendation for Future Directions," AI Magazine, to appear (1983).

4. Personnel

There are three investigators on the project: Professor David Waltz (principal), Professor R. T. Chien, and Professor Gerald DeJong. Besides these investigators eight graduate students have contributed to the project: Dave Spoor, Raman Rajagopalan, Patricia Halko (advisees of Professor Waltz), Paul O'Rorke, Alberto Segre (advisees of Professor DeJong), Adam Pajerski, William Frederick, and Michael Houghton (advisees of Professor Chien).

5. Interactions

There has been close work with three other groups within the Coordinated Science Laboratory: ONR N00014-75-C-0612 (Jordan Pollack and Anthony Maddox), NSF IST 81-17238 (LaRaw Maran, Jerry Morgan, Richard Dinitz, Marcy Dorfman, and David Farwell), and AFOSR 82-0317 (Narendra Ahuja). Paul Harrington, a Bell Laboratories fellowship recipient, also worked on tasks associated with this project.

6. Inventions and Patent Disclosures

There have been no inventions or patents stemming from this research.

7. Other Statements

Please find enclosed copies of the papers by Spoor and by O'Rorke mentioned above in section 3.1.

8. References

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[Waltz82] D. L. Waltz, "Event Shape Diagrams," Proc. National Conf. on Artificial Intelligence, Pittsburgh, PA, August 1982, 84-87.

[Wilensky81] R. Wilensky, "Meta-Planning: Representing and Using Knowledge About Planning in Problem Solving and Natural Language Understanding," Cognitive Science 5, (December 1981), 197-233.