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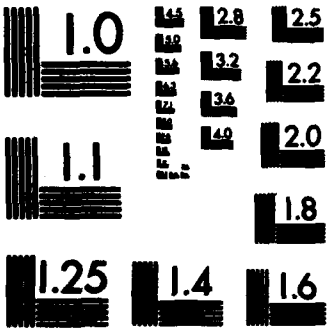

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report summarizes the first year of research on a project to produce formalisms, suitable for manipulation by computer, for the representation of specific concepts that are important for natural-language semantics, and to give an independent account of the meaning of such representations using the tools of formal logic. The major technical achievement of this effort has been the development of a logic which characterizes systems which represent and reason with information about their own beliefs. Other problems worked on include the development of semantic representations for comparative (CONT.)

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ITEM #20, CONT.: constructions in English and the analysis of deductive methods for commonsense reasoning.

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KNOWLEDGE REPRESENTATION AND NATURAL-LANGUAGE SEMANTICS

July 26, 1983

1st Annual Technical Report
Covering the Period June 1, 1982, to May 30, 1983

SRI Project 4488
Contract No. F49620-82-K-0031

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I OBJECTIVES OF THE RESEARCH EFFORT

Central to almost all aspects and applications of artificial intelligence is the representation and manipulation of large bodies of knowledge about the world. When viewed from the perspective of their ability to express facts about the external world, however, most knowledge representation schemes currently used in artificial intelligence are constrained by the limits of first-order logic. That is, they provide terms for referring to individuals, predicates for expressing properties and relations of individuals, and mechanisms that achieve some of the effects of propositional connectives and quantifiers. Much research effort has been expended on ways of organizing knowledge bases and developing information retrieval mechanisms; in terms of pure expressive power, however, existing representation systems are rather limited.

This issue is brought into sharp focus when one seriously attempts to analyze the semantic content of expressions in natural language, since many types of linguistic expressions seem to require something beyond first-order logic to represent their meaning perspicuously. Specifically, natural languages have special features for dealing with a variety of concepts that are central to our commonsense understanding of the world. For instance, linguistic systems of tense and aspect are intimately connected with commonsense conceptions of time. Adverbial modification, nominalization phenomena, and categorical distinctions among verb phrases appear to depend on such notions as state, event, and process. Predicate complement constructions frequently involve concepts of "propositional attitude" such as knowledge, belief, desire, and intention. The linguistic features of singular/plural and mass/count are used to sort out individuals, collective entities, and substances. In all these cases, either it is <u>not</u> clear how to express these concepts in first-order logic at all--or it <u>is</u> clear that they can be expressed in first-order logic only by very indirect means.

This project undertakes a program of basic research in knowledge representation, focusing on the represention of concepts needed for the semantic analysis of natural language. The objectives of the project are to produce formalisms, suitable for manipulation by computer, for the representation of specific concepts that are important for natural-langugage semantics, and to give an independent account of the meaning of such representations using the tools of formal logic.

II STATUS OF THE RESEARCH EFFORT

A. Development of Autoepistemic Logic

The major technical achievement of the first year of this effort has been the development of a logic that characterizes systems that represent and reason with information about their own beliefs. We call this logic "autoepistemic logic." The problem of representing and reasoning with information about the knowledge or beliefs of other agents has received much attention recently in artificial intelligence. Designing a system that can represent and reason with information about its own beliefs, however, poses some unique problems. The nature of the difficulties is suggested by an old philosophical puzzle: Why are sentences of the form "P is true, but I don't believe P" extremely odd, although sentences of the form "P is true, but he doesn't believe P" are not? Using the first person (making a statement about one's own beliefs) makes nonsense out of a sentence that is perfectly reasonable in the third person (making a statement about someone else's beliefs).

For a simple logical language for making statements about one's own beliefs, we were able to construct a very natural formal semantics and define sets of beliefs that are both sound and complete with respect to that semantics. (Roughly speaking, a set of beliefs is sound if it contains only statements that must be true whenever the premises of the set of beliefs are true, and it is complete if it contains all the statements that must be true whenever the premises of the set of beliefs are true.)

Autoepistemic logic turns out to be quite similar to logics that have been proposed to model what is called "nonmonotonic reasoning." Commonsense reasoning is "nonmonotonic" in the sense that we often draw, on the basis of partial information, conclusions that we later retract when we are given more complete information. The following example is frequently given to illustrate the point: If we know that Tweety is a bird, we will normally assume, in the absence of evidence to the contrary, that Tweety can fly. If, however, we later learn that Tweety is a penguin, we will withdraw our prior assumption. If we try to model this in a formal system, we seem to have a situation in which a theorem P is derivable from a set of axioms A, but is not derivable from some set A' that is a superset of A. The set of theorems, therefore, does not increase monotonically with the set of axioms; hence this sort of reasoning is said to be "nonmonotonic."

Some of the most interesting recent attempts to formalize nonmonotonic reasoning are nonmonotonic logics developed by Drew McDermott and Jon Doyle [McDermott and Doyle, 1980; McDermott, 1982]. These logics, however, all have peculiarities that suggest they do not quite succeed in capturing the intuitions that prompted their development. By comparing McDermott and Doyle's logics with autoepistemic logic, we have been able to diagnose the reasons for their peculiarities and show how they can be eliminated.

Our work on autoepistemic logic is described more fully, focusing on its relation to nonmonotonic logic, in SRI Artificial Intelligence Center Technical Note 284, "Semantical Considerations on Nonmonotonic Logic," which accompanies this report.

B. Semantic Representation of Natural-Language Comparative Constructions

A second area we have begun to study in the first year of the project is the development of semantic representations for comparative constructions in English--e.g., "London is closer to Paris than to New York." At some level, such information could be represented almost

trivially, as in (CLOSER LONDON PARIS NEW_YORK), but this ignores two important issues. First, it makes no connection between this fact and the same information expressed in more concrete terms: "The distance between London and Paris is less than the distance between London and New York." Second, it ignores the details of the way English expresses comparisons (e.g., the connection between "close" and "closer") so that it does not generalize to more complex expressions such as "London is closer to Paris than the information in our database indicates."

We have made considerable progress in the past year in understanding how to represent the information expressed by natural-language comparatives, but this research is still incomplete. One of the first priorities for the next year will be to complete this research and bring it to publication.

C. Analysis of Techniques for Commonsense Reasoning

A very important constraint on knowledge representation formalisms is that it must be feasible to draw inferences automatically from them. That is, a general-purpose knowledge representation should be adequate to implement the knowledge base of a commonsense reasoning system. To better understand these requirements, we have carried out a survey and analysis of rule-based methods of automatic deduction for commonsense reasoning. The results of this analysis were presented in an invited lecture at the 1982 National Conference on Artificial Intelligence. One of the goals of the second year of the project will be to write up and submit the results of this analysis for publication.

III FUTURE PLANS

We have already mentioned in the previous section two of our goals for the second year of the project: (1) completing our research on semantic representations for English comparative constructions and submitting it for publication, (2) writing up and submitting for publication our survey and analysis of deductive methods for commonsense reasoning. The other major effort of the second year of the project will be to work on representation of commonsense information about time and events. We have begun preliminary studies in this area, and it appears that analyzing how adverbs and the tense and aspect system of English work will give us significant insights into how people organize their thinking about time and events.

IV PUBLICATIONS

Robert C. Moore, "Semantical Considerations on Nonmonotonic Logic," (in preparation).

This paper has been completed and will be submitted for publication, probably in the journal, Artificial Intelligence, after comments have been received from a number of colleagues.

V CONFERENCE PRESENTATIONS

Robert C. Moore, "Deductive Methods for Commonsense Reasoning," invited lecture, National Conference on Artificial Intelligence, Pittsburgh, Pennsylvania, August 18-20, 1982.

Robert C. Moore, "Semantical Considerations on Nonmonotonic Logic," to be presented at the Eighth International Joint Conference on Artificial Intelligence, Karlsruhe, West Germany, August 8-12, 1983.

VI PERSONNEL

The research on this project has been carried out by Robert C. Moore. The supervisor has been Nils J. Nilsson. Outside consultants to the project have been: Professor C. Raymond Perrault, University of Toronto; Professor Patrick J. Hayes, University of Rochester; Professor Drew V. McDermott, Yale University; and Dr. Raymond Turner, University of Essex, U.K.

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McDermott, D. [1982] "Nonmonotonic Logic II: Nonmonotonic Modal Theories," Journal of the Association for Computing Machinery, Vol. 29, No. 1, pp. 33-57 (January 1982).

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