STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA

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RESEARCH ON INTELLIGENT QUESTION-ANSWERING SYSTEMS

By

BERTRAM RAPHAEL

STANFORD RESEARCH INSTITUTE
333 RAVENSWOOD AVENUE
MENLO PARK, CALIFORNIA 94025

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Approved: C. A. ROSEN, MANAGER
Applied Physics Laboratory

TORBEN MEISLING, EXECUTIVE DIRECTOR
Information Science and Engineering

ABSTRACT

This report summarizes two years of research effort that included studies of computer memory organization, formal theorem-proving techniques, the application of theorem-proving techniques to new problem domains, and the use of limited natural language input to a question-answering system. The principal accomplishments of the project were (a) the discovery of some interesting ways of relating formal theorem-proving to practical question-answering and problem-solving tasks, and (b) the implementation of a system of computer programs that demonstrate the approach and facilitate further research.

This report describes briefly the areas of research covered, and then presents abstracts of four papers that contain extensive description and technical detail of the work.

CONTENTS

I INTRODUCTION

For two years, Stanford Research Institute has been engaged in studies of computer memory organization, fact retrieval, and logical deduction techniques that can lead to effective automatic question-answering systems.* This work has resulted in (a) the discovery of some interesting ways of relating formal theorem-proving in the first-order predicate calculus to practical question-answering and problem-solving tasks, and (b) the implementation of a large system of computer programs that demonstrate the capabilities of the approach used and facilitate further development and experimentation. This work will be continued under other sponsorship.

The results from this project will be reported in several technical publications, some of which are currently in preparation. This final report consists of a brief summary of the research performed, and abstracts of some papers that contain further details.

*Although the author of this report was responsible for project supervision, most of the work on theorem proving and information structuring was performed by C. C. Green and R. Y. Yates. Dr. L. S. Coles developed the interface with natural language.

II SUMMARY OF RESEARCH

The principal areas investigated during this project were computer memory organization, formal theorem-proving techniques, the application of theorem-proving techniques to new problem domains, and the use of limited natural language input to a question-answering system.

A. Memory Organization[†]

Our efforts in this area were directed toward developing an information structure for representing the computer's "knowledge" of its environment. Early in the project we experimented with general property-list representations for both specific facts and general logical deductive rules. Subsequently, the decision was made that the organization of the memory structure should be subordinate to, and designed for the convenience of, the formal logical component of the system. This work is continuing, and no final conclusions have yet been reached.

B. Theorem Proving[1,2]

An effective deductive mechanism is an essential part of any question-answering system. For this project we chose to implement a complete theorem-proving procedure for the first-order predicate calculus, to use as the deductive component of the question answerer. The resulting program, which uses the Robinson "resolution principle," is one of the most powerful general programs in existence for proving theorems in the predicate calculus. Copies of this program can be made available by the author upon request. A revised version that incorporates new results from the theorem-proving literature to improve the efficiency of the program is currently being completed.

C. Applications[2,3]

One of our principal interests during this project was the application of the theorem prover to problem domains outside of formal mathematics. A theorem-proving program used in the most obvious way can only

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[†]Superscripts refer to the publications abstracted in the next section of this report.

answer "true or false" queries. We have shown how, for general information retrieval applications, certain simple extensions can enable the program to make reasonable replies to questions that request the identification of objects satisfying certain descriptive specifications. More recent work has shown how the same program can be used to construct solutions to problems requiring sequential actions.

D. Natural Language[4]

The work described above was conducted under the assumption that all inputs to the system would be expressed in a formal language based on the predicate calculus. Recent work has shown how natural English statements about a well-defined problem domain frequently may be translated automatically into predicate calculus. A program that performs this translation now enables users to converse with the question-answerer in a subset of English.

III ABSTRACTS OF REPORTS

The following reports were all at least partially supported under this project. Among them, they contain the technical details of the supported research.

1. C. Cordell Green and Bertram Raphael, Research on Intelligent Question-Answering Systems, Scientific Report 1, Project AF 19(628)-5919, Report AFCRL-67-0370, Air Force Cambridge Research Laboratories, May 1967.

This report describes progress toward an "intelligent question-answering system"--a system that can accept facts, retrieve items from memory, and perform logical deductions necessary to answer questions. Two versions of such a system have been implemented, and the authors expect these to be the first in an evolving series of question answerers.

The first system, QA1, is based upon relational information organized in a list-structured memory. The data consist of general facts about relations as well as specific facts about objects. QA1 has limited deductive ability.

QA2 is based upon formal theorem-proving techniques. Facts are represented by statements in the predicate calculus. Although the memory organization is simpler than that of QA1, the sophisticated logical abilities of QA2 result in greater question-answering power.

The report gives examples of the performance of QA1 and QA2 on typical problems that have been done by previous question-answerers, and describes plans for extending the capabilities of QA2.

2. C. Cordell Green and Bertram Raphael, "The Use of Theorem-Proving Techniques in Question-Answering Systems," to be published in the Proceedings of the 1968 ACM Conference, August 1968.

This paper describes results of a recent research project aimed at the development of more effective automatic question-answering systems. The authors identify two key problems that must be solved before practical question-answering systems can be developed: the problem of identifying items in a data base that are relevant to a particular query, and the problem of logically deducing new specific facts. Examples from two experimental computer programs developed by the authors illustrate two approaches to solving these problems. The first program, called QA1, is based on an elaborate list-structured memory and uses ad hoc rules for logical inferences. QA2, the latest research effort, is based upon formal theorem-proving techniques; the nature of the theorem prover largely determines the structure of the rest of the system. This approach increases the generality of the resulting question answerer.

3. C. Cordell Green, "Axiomatization of Pure LISP and List Structures" (in preparation).

This paper presents a formalization, in first-order logic, of the syntax and semantics of a subset of the LISP 1.5 programming language. An example is given, showing how a resolution-type theorem prover can use this axiomatization to construct a list-sorting function and to prove the correctness of the function constructed.

4. L. Stephen Coles, "An On-Line Question-Answering System with Natural Language and Pictorial Input," to be published in the Proceedings of the 1968 ACM Conference, August 1968.

This paper describes a conversational, question-answering system that permits input in the form of simple English sentences and elementary line drawings. English sentences are acceptable if they lie within a subset of natural language defined by a small phrase structure grammar. Pictures are input to the computer directly by means of a graphic

display console. Using a method called syntax-directed interpretation, expressions in the predicate calculus are constructed to correspond to each input sentence. These logical expressions are then evaluated with respect to the picture currently displayed to determine whether they are true or false. Frequently an input sentence will contain syntactic ambiguity. Under certain conditions the semantic information in the picture may provide a context within which such syntactic ambiguity can be resolved.

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