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COMPUTER-AIDED INSTRUCTION USING AN INFERENTIAL QUESTION-ANSWERING SYSTEM WITH NATURAL LANGUAGE INPUT: A PLAN FOR RESEARCH

by

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Technical Note 11

I INTRODUCTION

The development of systems for computer-aided instruction (CAI) has been going forward for a number of years. It has proven very difficult, however, to achieve the level of performance hoped for in the early Sixties. Current systems still exhibit considerable weakness in the areas of:

(1) Communicating in English with the student

(2) Capacity for diagnosing failures on the part of the student to truly comprehend the required material

(3) Providing individualized guidance for deficient students

(4) Providing an efficient facility for teachers to construct CAI lessons on-line with the help of the computer.

It is suggested that these inadequacies can be partially remedied by the development of computer systems which are capable of "understanding" the content of the course material to be presented to the student, and thus be in a proper position to assess the level of understanding achieved by the student at any given point in time. Based on its assessment, the system can then guide the deficient student through personalized remedial material in natural language form.

By "understanding" in this context, we mean the ability of the student or the system to answer questions posed in English about the subject domain being taught. Consequently, an "understanding" CAI system must itself have been able to answer correctly the questions which it now poses to its students, assuming that all questions can be answered in terms of information acquired during the course. In addition, it must have a capability for constructing a "model" of the student's level of understanding in terms of the semantic content of the student's wrong answers, as well as his correct answers. It will also need a rich vocabulary and extensive repertoire of basic knowledge about the universe of discourse to interpret properly the significance of right and wrong answers.

A. Background

Stanford Research Institute has been conducting research in the areas of natural language processing and computer-aided instruction for several years. In the natural language area we have developed such systems as ENGROB[1*] and ENGDRG[2] for English language communication between a man and an intelligent automaton in the first case and a medical information retrieval system in the second. In the CAI area we have modified and extended the PILOT system[3] (originally developed at Berkeley) for instruction of grade school children and have been actively conducting experiments with classes from the San Francisco Bay Area.[4] These systems form the technological base from which we propose to design and build an experimental CAI system to demonstrate the usefulness of natural language understanding in overcoming the deficiencies of conventional CAI systems described above.

B. Objective and Scope

We propose to define the operational requirements, design, and implement an experimental, natural language, computer-aided instruction system using techniques of logical inference, information retrieval, question answering, and syntactic/semantic analysis previously developed in connection with other research projects within the Artificial Intelligence Group at Stanford Research Institute. For this initial system we will choose a sufficiently small domain, such as a chapter from a meteorology textbook, to permit a three-hour demonstration of the system.

We propose to accomplish the above objective during a period of one and one-half years. It is anticipated that this work would be followed by a future proposal for testing and experimentation with the system in a real-world student environment.

II STATEMENT OF THE PROBLEM

Consider the following scenario generated by a recent PILOT geology program instructing an elementary grade school child about rocks. The student's replies are always preceded by a period in the left-hand margin.

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*References are listed at the end of the report.

TO BEGIN INSTRUCTION PUSH THE SPACE BAR--

HI, WHAT'S YOUR NAME?

. MIKE

LET'S TALK ABOUT ROCKS, MIKE...
CAN YOU NAME SOME DIFFERENT TYPES OF ROCKS FOR ME?

. SANDSTONE, LIMESTONE, GRANITE

THAT'S FINE, MIKE...
THESE ARE ALL ORDINARY ROCKS. CAN YOU NAME ANY PRECIOUS STONES?

. DIAMONDS, RUBIES

RUBIES AND DIAMONDS ARE REALLY PRECIOUS, MIKE.
DID YOU KNOW THAT TURQUOISE AND GARNETS ARE CONSIDERED ONLY SEMI-PRECIOUS?

. NO

LET'S GO ON TO WHERE SOME OF THEM ARE FOUND. DO YOU KNOW SOME PLACES?

. MINES

OK, NOW CAN YOU GIVE ME SOME COLORS?

. I'M TIRED OF THIS STUFF

WHAT! YOU MUST HAVE ROCKS IN YOUR HEAD.
CAN YOU TELL ME WHAT ROCKS ARE MADE OF?

. GOOD BY

LET'S GO ON TO SOMETHING ELSE, MIKE. DO YOU KNOW ABOUT IGNEOUS ROCKS?

. (no answer)

As can be discerned from the above dialogue, the PILOT system has an extremely limited capacity for assessing the correctness of a student's answer. What PILOT is doing internally amounts to scanning the student's reply for certain combinations of key words contained in a prestored list of anticipated student responses and then branching to the next pre-programmed continuation. PILOT cannot handle questions or assertions from the student about his progress. This constraint creates a very rigid dialogue with a fragile man-machine interface.

Instead of a system where the correctness of a student's reply is based solely on syntactic criteria, what is needed is a system which translates the student's answer in conjunction with a set of transformations and semantic rules into an underlying conceptual structure which can then be compared by means of various inferential rules to a "deep structure" corresponding to a correct answer. To properly diagnose the reason for the student's failure to respond correctly, the system must refer to its past experience with incorrect replies on this question and attempt to find the underlying difficulty before blindly offering a rigid, prestored remedial sequence.

III METHOD OF APPROACH

The CAI system envisioned will consist of seven components:

(1) A syntax analyzer for simple English declarative and interrogative sentences generated by the student

(2) A semantic interpreter, which will map the output of the syntactic component--i.e., phrase markers for legal English sentences--into an appropriate deep-structure representation

(3) An inferential component using advanced theorem-proving techniques

(4) A subject model containing invarient knowledge (axioms) about the universe of discourse

(5) A student model containing specific student information, such as statistical measures of progress

(6) An output sentence generator for English sentences

(7) A lesson plan which guides the direction of the dialogue and contains the text of the course content together with the standard questions deemed by the teacher to establish competence in the subject being taught.

The basic paradigm will be to:

(1) Present the course material in the lesson plan, together with a set of related questions one at a time

(2) Translate each student reply, whether question or statement, into a formal language based on the first-order predicate calculus

(3) Perform any necessary inferences based on the axioms in the subject and student models

(4) Establish the validity of the reply, if a statement, and present the next question in the sequence if correct; otherwise initiate appropriate remedial material and dialogue

(5) If the student response was a question, then generate the appropriate response.

The initial translation to the predicate calculus will be accomplished by means of productions in the syntactic and semantic components. Deductions will be carried out by means of a resolution-based automatic theorem prover. English output sentences will be produced by translating answer expressions in the predicate calculus into their English equivalents, again by means of a set of productions. The specific details of the methods by which the syntactic, semantic, inferential, and generative components will operate are contained in Refs. 1 and 5-9.

We expect to evaluate the system developed under this proposal by demonstrating its effectiveness on a three-hour course dealing with a specific topic, such as meteorology. It is expected that the course chosen will make nontrivial inferential demands on the student giving rise to at least a 30-50 percent error rate for the average student, so that the capacity of the system to respond to demands for remedial instruction can be demonstrated.

To appreciate more fully the inferential capabilities of the system proposed, consider the question "Why does it rain?" together with the following facts:

(1) If the humidity is less than 50 percent, then it is dry.

(2) If it is sunny and dry, then evaporation causes it to be damp.

(3) If it is damp, then cooling causes condensation.

(4) If there is condensation, then droplets forming causes rain.

(5) It is now sunny and the humidity is 10 percent.

A legitimate answer to the above question given the above facts would be, "It rains because droplets form whenever cooling occurs after evaporation occurs." As a simple exercise, the above example was encoded and run on the current version of the theorem-proving system, QA3. The results are shown in Appendix A.

IV PERSONNEL

Under present plans, it is expected that the principal contributors to the study and their areas of effort will be as follows:

Dean Brown	Computer-Aided Instruction
Stephen Coles	Project Coordination and Linguistics
Bertram Raphael	Inferential Question-Answering Techniques.

In addition to the above, several programmers will be employed for the system implementation. Appendix B gives biographies for the key individuals named above.

V COMPUTER FACILITIES

The Artificial Intelligence Group is currently negotiating the purchase of a new computer system, based on the DEC PDP-10 computer, to be funded by ARPA and dedicated for use by our group. We believe that the new system will clearly dominate other available computer systems suitable for our research purposes. We expect delivery of all major components by the end of 1969 and hope to have the system operational shortly thereafter. Software changeover from our current computer, the SDS 940, to the PDP-10 has already begun, and hopefully will be sufficiently advanced to permit operation with the new system when it has passed its acceptance tests. We are currently testing our conversions on a neighboring PDP-10. The proposed configuration in shown in Fig. 1. We expect that this system will be well suited for research in natural language, computer-aided instruction.

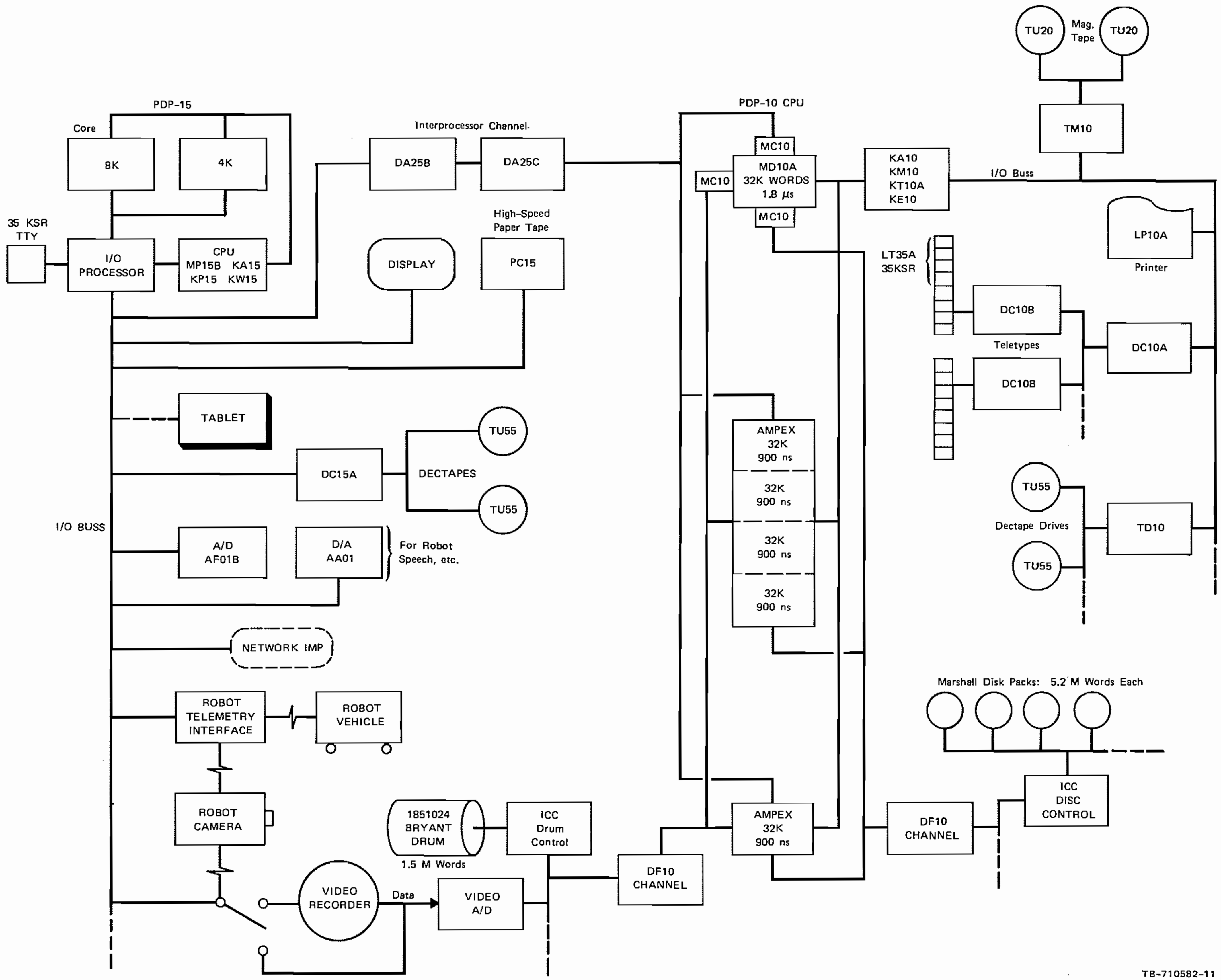

FIGURE 1 PDP-10 CONFIGURATION

Appendix A

PROOF OF WHY IT RAINS

Axioms:

1. $(\forall x,s)\{Humidity(x,s) \wedge Less(x,50) \Rightarrow Dry(s)\}$
2. $(\forall s)\{Sunny(s) \wedge Dry(s) \Rightarrow Damp(EVAPORATION(s))\}$
3. $(\forall s)\{Damp(s) \Rightarrow Condensation(COOLING(s))\}$
4. $(\forall s)\{Condensation(s) \Rightarrow Rain(DROPLETSFORM(s))\}$
5. $Sunny(now) \wedge Humidity(10,now)$

Question: $(\exists s)\{Rain(s)\}$

Answer: Yes, s = DROPLETSFORM(COOLING(EVAPORATION(now)))

Proof:

1.	Humidity(10,now)	Axiom 5
2.	Sunny(now)	Axiom 5
3.	$\sim$Rain(s)	Neg. of Thm.
4.	Rain(DROPLETSFORM(s)) $\vee$ $\sim$Condensation(s)	Axiom 4
5.	$\sim$Condensation(s)	From 3, 4
6.	Condensation(COOLING(s)) $\vee$ $\sim$Damp(s)	Axiom 3
7.	$\sim$Damp(s)	From 5, 6
8.	Damp(EVAPORATION(s)) $\vee$ $\sim$Sunny(s) $\vee$ $\sim$Dry(s)	Axiom 2
9.	$\sim$Sunny(s) $\vee$ $\sim$Dry(s)	From 7, 8
10.	$\sim$Dry(now)	From 2, 9
11.	Dry(s) $\vee$ $\sim$Humidity(x,s) $\vee$ $\sim$Less(x,50)	Axiom 1
12.	$\sim$Humidity(x,now) $\vee$ $\sim$Less(x,50)	From 10, 11
13.	Contradiction	From 1, 12

Statistics:

8 clauses left

6 clauses generated

8 clauses entered

6 resolutions out of 8 tries

Time was 28 seconds

Appendix B

BIOGRAPHIES OF KEY INDIVIDUALS

H. DEAN BROWN, HEAD
SYSTEMS DEVELOPMENT GROUP
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Computer-aided instruction
- Educational policy and planning
- Nuclear reactor physics

Representative research at SRI (joined 1967)

- Computer-aided instruction techniques for grade school children
- Man-machine studies
- Computer-based systems for management, banking, manufacturing, and communications

Other professional experience

- University Fellow, University of Kansas, 1950-52
- Nuclear Reactions Specialist, duPont Atomic Energy Division Savannah River Laboratory and Project Matterhorn at Princeton University, 1952-58
- Visiting Scientist, Norwegian Institute for Atomic Energy, Halden, 1958
- Senior Officer, Reactor Division, International Atomic Energy Agency, Switzerland and Yugoslavia, 1959-60
- Manager, Basic Physics and Applied Mathematics, duPont Savannah River Laboratory, 1961-63
- Scientific Director, Computer Usage Company, Washington, D.C., 1963-65
- Manager, Computer Usage Company, Palo Alto, 1965-67
- Vice President, Computer Usage Education, New York, 1967

Academic background

- B.S. in physics, mathematics, chemistry (1947), South Dakota State College
- M.A. in physics (1951), University of Kansas
- Ph.D. in physics (1952), University of Kansas

Publications

- Author or coauthor of numerous reports and technical papers
- Member of Board of Editors for Nuclear Science and Engineering

Professional associations

- Sigma Pi Sigma (physics), Sigma Xi, Sigma Tau (engineering), Pi Mu Epsilon (mathematics), American Mathematical Society, American Physical Society, American Nuclear Society, Association for Computing Machinery

L. STEPHEN COLES, RESEARCH MATHEMATICIAN
INFORMATION SCIENCE LABORATORY
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

. Computational linguistics
. Question-answering systems

Representative research assignments at SRI (joined 1967)

. Design and development of a natural-language communication system for an intelligent automaton
. Application of formal problem-solving techniques to a robot executive system
. Design of a restricted English query language for medical information retrieval and question-answering systems

Other professional experience

. Lecturer, Computer Science Department, Stanford University, and Electrical Engineering and Computer Science Department, University of California, Berkeley
. Assistant, Director of Information Processing Techniques, Advanced Research Projects Agency (ARPA), Washington, D.C., 1965
. Project Scientist, Computation Center, Carnegie Institute of Technology, Pittsburgh, Pennsylvania

Academic background

. B.S. in electrical engineering (1962), Rensselaer Polytechnic Institute
. M.S. in mathematics (1965), Carnegie Institute of Technology
. Ph.D. in systems and communication sciences (1967), Carnegie-Mellon University

Publications

. "Syntax Directed Interpretation of Natural Language," Ph.D. Thesis, Carnegie-Mellon University, Pittsburgh, Pennsylvania (1967)
. "An On-Line Question-Answering System with Natural Language and Pictorial Input," Proc. 23rd National ACM Conference, pp. 157-167 (Brandon Systems Press, 1968)
. "Talking with a Robot in English," Proc. First Int'l Artificial Intelligence Conference, Washington D.C. (May 1969)

Professional associations

. Association for Computing Machinery
. Member, Institute for Electrical and Electronics Engineers
. Association for Computational Linguistics
. American Society for Cybernetics
. American Association for the Advancement of Science
. Society of Sigma Xi

BERTRAM RAPHAEL, SENIOR RESEARCH MATHEMATICIAN
INFORMATION SCIENCE LABORATORY
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Question-answering systems
- Heuristic problem solving
- Symbol manipulation techniques
- Theorem-proving methods

Representative research assignments at SRI (joined 1965)

- Development of data structures and deductive techniques for on-line question-answering systems
- Studies of problem-solving activity in a simulated robot
- Direction of system design for an experimental "intelligent" automaton
- Survey of computer languages for symbolic and algebraic manipulation

Other professional experience

- Lecturer, Electrical Engineering and Computer Science, University of California at Berkeley; Lecturer, Computer Science, Stanford University; and Instructor, summer course at University of California at Los Angeles
- Consultant, Computer Science Department, RAND Corp., Santa Monica, California
- Assistant Research Scientist, University of California at Berkeley
- Part-time research staff, Bolt, Beranek and Newman, Inc., Cambridge, Massachusetts

Academic background

- B.S. in Physics (1957), Rensselaer Polytechnic Institute
- M.S. in Applied Mathematics (1959), Brown University
- Ph.D. in Mathematics (1964), Massachusetts Institute of Technology

Publications

- More than a dozen papers in technical journals and in the proceedings of national and international computer conferences

Professional associations

- Association for Computing Machinery (National Lecturer, 1967-68; founding editor, Newsletter of the group on artificial intelligence)
- Association for Computational Linguistics
- Sigma Xi

REFERENCES

1. L. S. Coles, "Talking with a Robot in English," Proc. First International Joint Conference on Artificial Intelligence, 7-9 May 1969, Washington, D.C., pp. 587-596 (1969).

2. J. H. Chadwick, O. W. Whitby, J. H. Jones, L. S. Coles, and B. Raphael, "Medical Applications of Remote Electronic Browsing," Final Report for the National Library of Medicine, Stanford Research Institute, Menlo Park, California (February 1969).

3. D. Ladd, T. Baumbach, and R. M. White, "Description of '940-PILOT'--A Language for Computer-Assisted Instruction and Inquiry," University of California, Berkeley (1968).

4. H. D. Brown and J. Lewis, "The Process of Conceptualization," EPRC-6747-9, Educational Policy Research Center, Stanford Research Institute, Menlo Park, California (1968).

5. L. S. Coles, "Syntax Directed Interpretation of Natural Languages," Ph.D. Thesis, Carnegie-Mellon University, Pittsburgh, Pennsylvania (1967).

6. L. S. Coles, "An On-Line Question-Answering System with Natural Language and Pictorial Input," Proc. 23rd National ACM Conference, pp. 157-167 (Brandon Systems Press, 1968).

7. C. C. Green and B. Raphael, "The Use of Theorem-Proving Techniques in Question-Answering Systems," Proc. 23rd National ACM Conference, pp. 169-181 (Brandon Systems Press, 1968).

8. C. C. Green, "Theorem Proving by Resolution as a Basis for Question-Answering Systems," Machine Intelligence 4, Michie and Meltzer, eds. (Edinburgh University Press, Edinburgh, Scotland, 1969).

9. C. C. Green, "Application of Theorem Proving to Problem Solving," Proc. First International Joint Conference on Artificial Intelligence, 7-9 May 1969, Washington, D.C., pp. 219-239 (1969).