STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

A PLAN FOR A UNIFIED PROGRAM OF RESEARCH

IN ARTIFICIAL INTELLIGENCE AT SRI

October 1967

Artificial Intelligence Group
Applied Physics Laboratory

CONTENTS

I GENERAL DESCRIPTION OF PLAN

A. Background

Artificial Intelligence research at the Stanford Research Institute is concentrated in a group of some 20 scientists, engineers, and programmers in the Applied Physics Laboratory. A broad list of topics is being actively explored, ranging from visual pattern recognition to mathematical theorem proving to natural language processing. Up to now, each topic has been more or less independently pursued, and continuing financial support for each project has been the separate responsibility of the project leader.

As our research progresses, however, it has become increasingly difficult to draw hard and fast boundaries separating these projects. The SRI robot project is a prime example of a deliberate attempt to integrate several highly interdependent subsystems. Several other projects are beginning to merge or overlap. For example, we are coming to realize that effective visual perception demands a problem solving subsystem similar to that needed for a question-answering system. Some applications of question-answering systems demand natural language processing; indeed, effective and unambiguous natural language processing will require a large "general fund of knowledge" stored in and accessible through a question-answering system. Furthermore, the identification and retrieval of "relevant" items from a large data store require perceptual ability related to pattern recognition.

These examples point to the necessity and desirability of planning a unified program of Artificial Intelligence research at SRI. In this document we shall present such a unified plan and outline its components.

B. Ultimate Goals

The Artificial Intelligence research program described here has as its long term, unifying goal the task of building intelligent machines to perform useful tasks. Some, but not all, of the tasks that we want these machines to perform will require intelligent coordination of motor and locomotion abilities. Others will require problem-solving abilities. Still others will require question-answering or special sensory abilities. The most difficult will require the union of all these abilities and more. (When we speak of "robots" in the following pages, we mean highly intelligent and versatile machines.) Although achievement of our ultimate goal may require many years, a continuing stream of highly useful applications of intermediate results can be expected to spring from this program as it proceeds.

It is clear that the "software" to control such robots will necessarily be complex and broad. It is quite unlikely that any simple schemes will have the requisite power. At the moment, research is needed in several areas to increase the power of key components of an overall robot control program. These areas shall be named here and described in more detail in Section II.

C. Key Components of the Program

1. Visual (and other sensory) perception
2. Question answering and theorem proving
3. Natural language processing
4. Planning and reasoning by analogy
5. Programming languages
6. Robot systems
7. Foundations of artificial intelligence.

The minimum level of effort that we feel is appropriate in these areas totals 14 professionals per year.

D. Research Facilities

The efficient pursuit of this program will require a powerful time-shared computer system together with some special-purpose hardware. Until better medium-priced time-shared computers become actually available, we will continue using our SDS-940. It should be augmented, however, with extra core, a disc system, and better displays. A detailed listing of these immediate needs and their costs is given in Section III.

E. Related Programs

The Artificial Intelligence Group pursues some research in other areas that, while related to the above program, are sufficiently independent to justify their being kept separate. Two of these other projects are:

(1) The automatic recognition of hand-printed FORTRAN characters on coding sheets using the syntax of the FORTRAN language as an aid in improving recognition accuracy, and

(2) The automatic recognition of certain biological materials (such as white blood cell types).

Also, we envision that the Artificial Intelligence program described above will produce results that will have application in areas other than in the design of intelligent machines. Some of these applications may from time to time interest specific members of the Group, and they will generally be encouraged to pursue those applications that strengthen the overall research program.

F. Cooperation with Stanford University

The Group cooperates in many ways with the Artificial Intelligence projects at Stanford University. Joint seminars are often arranged, and members of our staff frequently teach courses in the Computer Science Department at Stanford (as well as at the University of California at Berkeley). Several Stanford graduate students work at SRI on a half-time basis during the year or are supported through SRI-donated assistantships. Many of these students work here on a full-time basis during the summer. (Last summer we had four Stanford students, one from Cornell, and one from M.I.T.)

II DETAILED DESCRIPTION OF COMPONENTS OF PROGRAM

A. Research on Visual Perception

1. Objective

To achieve mechanized visual perception of basically unconstrained, real-world visual scenes.

2. Background

To function effectively in a real-world environment, a robot must be able to perceive the external world. Vision is obviously one of the most important senses. The demands placed on an effective visual system are severe. Objects of interest must be recognized despite rotation and translation, shadows and reflections, and partial occlusion by other objects. Facts about an object must be determined, such as its location, peculiar characteristics, and relation to other objects. Moreover, all necessary computation must be done quickly and with a limited amount of memory.

The present automaton's eye[1,2*] is an important first step towards this goal. It extracts edge information from a single black-white, medium-resolution television picture, and uses this information to produce a line drawing of the scene. This kind of processing is most effective when discontinuities in brightness identify object boundaries, and works well on geometrically simple, evenly illuminated objects.

3. Research Plans

Most of the research on mechanized visual perception remains to be done. All of the following topics should be investigated:

(a) Texture. Uniform texture separates a figure from the background, texture type identifies physical material, and texture gradient gives clues to depth. In many cases, texture helps to determine when a brightness discontinuity signifies shadows, and when it signifies the boundary of an object.

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* References are given at the end of each section.

(b) Color. Like texture, color is an area property of a figure. It adds a new dimension for figure-ground discrimination.

(c) Stereoscopic vision and relative motion. Differences in two stereo views, and/or differences observed due to motion provide valuable depth clues. They help to identify irregular objects (such as trees) as connected objects.

(d) Scene-description programs. Few of the local features of a scene--edges, texture, color, etc.--can be determined with 100 percent confidence. The synthesis of a scene description from these features is a major problem. General models of objects and components of objects, a priori knowledge concerning the effects of shadows, reflections, and occlusions, and contextual relations between objects in a scene must all be exploited.

Mechanizing visual perception is closely related to other components of the SRI Artificial Intelligence research program. The visual system can use information in the robot's model of the world, and must in turn supply the robot with information relevant to its tasks. The most efficient use of relevant stored information can probably best be achieved by a question-answering system.

4. Level of Effort

Personnel	2 man years/year
Computer	10 units*

5. Key Individuals

Richard O. Duda
George E. Forsen

6. References

(1) G. E. Forsen, "A Preprocessor for an Automaton's Eye," WINCON '67 Conference Record, pp. IIIE-12 thru IIIE-34 (Los Angeles, February 7-9, 1967).

(2) G. E. Forsen, "Processing Visual Data with an Automaton Eye," a paper presented at the Pattern Recognition Society Symposium on Automatic Photointerpretation, Washington, D.C. (May 1967).

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* Computer effort is given in normalized units. The total Artificial Intelligence program described here is assumed to require 75 percent usage of the SDS-940 facility or 75 units. See Section III for a discussion of the total cost of the facility.

B. Research on Question Answering and Theorem Proving

1. Objective

The objective of this program is to develop techniques of computer memory organization, fact retrieval, and logical deduction, with an effective automatic question-answering system as the ultimate goal. These objectives require subsidiary efforts toward improving formal theorem-proving techniques, and developing on-line communication languages.

2. Background

A question-answering system is a computer program that has the following three interrelated characteristics:

(a) The ability to accept statements of fact, expressed in some suitable language, and store them in computer memory

(b) The ability to search stored information efficiently and to recognize items that are relevant to a particular query

(c) The ability to respond appropriately to a question by identifying and presenting the answer if it is present in memory, and most important, by deducing a logical response from relevant knowledge if the complete answer is not explicitly available.

The general area of question answering is a central problem of artificial intelligence. Whether the principal problem of interest is, for example, automatic problem solving, visual scene analysis, or mechanical translation of natural language, an effective computer program for its solution should be able to access and, in some sense, "understand" background information about the problem domain. Question answering research is aimed directly at these problems of access and "understanding."

Several research groups have been active in this area during the past few years. Before joining SRI, Raphael[1,2] developed a simple question-answering program based upon a list structured representation of relational data. More recently, a system has been developed within our Group[3] that makes use of sophisticated theorem-proving techniques in the first order predicate calculus. Although these efforts are at the forefront of current research, they have barely scratched the surface of the important problems involved.

3. Research Plans

Our future research will include efforts in the following areas:

(a) Memory organization. As the data base for our experiments grows, efficient filing and indexing schemes will become more important, and the ability to extract a reasonable set of facts "relevant" to a particular query will become increasingly difficult

(b) Deductive ability. The proof procedure for first-order predicate calculus which forms the basis of our present deductive program permits a large amount of wasted computational effort. Improvements to this program would permit more complex deductions and therefore more powerful question answering

(c) Question types and problem domains. Our present system is only capable of answering two types of questions: "True or false," and "Find an object with the specified characteristics." We are presently investigating how to do more complex problem solving involving time-sequence constraints within the question-answering framework

(d) Communications language. Inputs to the question answerer must presently be expressed in a formal logical notation. This restriction will be relaxed in conjunction with the related research program in natural language processing.

4. Level of Effort

Personnel	2 man years/year
Computer	10 units

5. Key Individuals

C. Cordell Green
Bertram Raphael

6. References

(1) B. Raphael, "A Computer Program Which 'Understands'," AFIPS Proc. FJCC, (October 1964).

(2) B. Raphael, "SIR: A Computer Program for Semantic Information Retrieval." To appear in Semantic Information Processing, M. Minsky (ed.) (MIT Press, 1968).

(3) C. C. Green and B. Raphael, "Research on Intelligent Question-Answering Systems," Scientific Report No. 1, Contract AFCRL-67-0370, SRI Project 6001, Stanford Research Institute, Menlo Park, Calif. (May 1967).

C. Research in Natural Language Processing

1. Objective

The ultimate goals of the research proposed are (1) to achieve fluent natural language communication with a computer, and (2) to explore the role of linguistic models in problem solving.

2. Background

A basic importance of natural language communication with computers lies in the possibility of making computers immediately accessible to professional persons not conversant with a formal computer language. A still more significant potential for natural language processing, however, lies in the possibility of using linguistic models to enhance the representational power of inferential, question-answering systems. It is this latter goal which the proposed research will attempt to explore.

Some progress in this direction has been reported[1] which attempts to formulate an integrated theory of syntactic and semantic descriptions for natural language suitable for computer implementation. Basic problems still remain to be investigated. One such fundamental problem is the question of lexical and syntactic ambiguity. Another is the discovery of antecedents for pronomial expressions in connected discourse. Still other problems relate to self-extending grammars, natural language generation, and voice pattern recognition.

3. Research Plans

a. A restricted natural language input will be provided for the SRI Intelligent Question-Answering System, currently operating on the SDS-940.

b. An English-like command language will be developed for the robot system.

The basic parsing algorithm written in Formula Algol is currently being reprogrammed in LISP.

4. Relation of this Project to Other Areas

a. Question-answering. This research could provide the basis for English inputs for information retrieval and computer-aided instruction systems.

b. Robot systems. This research will provide an English-like command language suitable for driving a problem-solving executive system for the robot.

c. Reasoning by analogy. We will be able to formulate tasks in English which are logically isomorphic to classical analogy problems, such as the monkey and bananas problem, suitable for solution by the robot.

d. Foundations of artificial intelligence. The automaton provides the computer with a real "time/space" window on reality which in turn uniquely permits the formulation of empirical exploration in the semantic modeling of language. Philosophical language problems can also be investigated for the first time, such as the problem of self-awareness.

5. Level of Effort

Personnel	$1\frac{1}{2}$ man years/year
Computer	5 units

6. Key Individuals

L. Stephen Coles
C. Cordell Green
Robert E. Kling

7. References

(1) L. S. Coles, "Syntax Directed Interpretation of Natural Language," Ph.D. Thesis, Carnegie Mellon University (June 1967).

D. Research on Planning and Reasoning by Analogy

1. Objective

To develop high level planning methods especially those which use analogies between the problem to be solved and those successfully solved previously.

2. Background

Artificial intelligence has been plagued by a paucity of proposals, not withstanding programs, to exploit the previous experience of a machine to accelerate problem solving and generate interesting conjectures about a new situation. The majority of proposals exploit accumulated experience to provide new facts or to improve some evaluation function. However, little interest has been shown in exploiting the structure (or strategy) of previous problem solving attempts. When one reasons by analogy, he is able to abstract the solution of a past problem and apply it to some similar new problem. Hypotheses about the nature of the problem solution and appropriate anticipations should be captured in the analogy.

3. Research Plans

A complete program of research on analogical reasoning should include the following:

(a) Theory of analogy. Little is known about the logic of analogical processes. There is no appropriate vocabulary for creating significant distinctions, nor are there good criteria for deciding to what extent an analogy will extrapolate into a solution to a new problem.

(b) Methods for generating analogies. A program must know the analogy before it can apply it. Until 1966 there were no general methods for generating analogies. Recently, efforts by a member of our Group[1] resulted in a rich, but general representation which allows analogies to be easily generated in a variety of areas including algebra, geometry, and elementary problem situations.

(c) Strategies. Interesting analogies often extrapolate into a new strategy, rather than into a step-by-step solution to the problem. A full-blown schema for extracting the invariants, as well as methods for strengthening and weakening plans is critical for effective implementation of programs that can problem solve by analogy.

(d) Information retrieval. Typically a system is presented with a problem to solve and it must decide which of its past experiences are relevant to the new problem. Methods of "retrieval by similarity" for focussing upon likely candidates need to be explored before real systems can function efficiently.

(e) Hypothesis formation. A deeper understanding of the role of analogy in hypothesis formation is critical. Clearly, analogies play a developmental role in concept formation, although the details of this process are yet unclear.

4. Level of Effort

Personnel	$1\frac{1}{2}$ man years/year
Computer	5 units

5. Key Individual

Robert E. Kling

6. References

(1) R. E. Kling, "Research on Reasoning by Analogy, Synopsis and Proposals: Project ZORBA," Technical Memo, Stanford Research Institute (August 1967).

E. Programming Language Research

1. Objective

The general objective of this effort is to develop new software tools that will reduce substantially the computer programming efforts needed for artificial intelligence research. This work has two specific current goals: the creation of a flexible user-expandable language oriented to a scientific research environment, and the more immediate integration and extension of presently available software into more powerful combined systems.

2. Background

The groundwork for the creation of a flexible new language has already been laid.[1,2] The central innovation of this development is the concept of a minimal, expandable computer language, i.e., a kernal language composed of the smallest set of linguistic constructs adequate to describe almost all programming languages. Such a set has already been selected, and the anticipated advantages of this approach to programming languages documented.[2,3]

This language would be valuable in artificial intelligence work because of the ability to tailor it for the needs of each of the diverse components of a complex system. For example, such a language could be used in the programming of a robot system for the control of external hardware and for modeling and problem solving, as well as for communication between the robot and the outside world.

Until such a truly general (or expandable) language is available, existing software facilities must be used. Much of our work makes use of the LISP programming language. Although symbol manipulation capabilities are clearly necessary for much artificial intelligence work,[4,5] a pure symbol manipulation language such as LISP is not adequate for all aspects of, say, a robot system. SRI is presently developing a software interface, under the SDS-940 time-sharing system, that will permit LISP and FORTRAN programs to interact. The design of extensions of this kind of facility would be included in our programming language research effort.

3. Level of Effort

Personnel	1 man year/year
Computer	5 units

4. Key Individuals

James Bell
Leonard Chaitin
Bertram Raphael

5. References

(1) J. R. Bell, "The Use of Boolean Matrices to Determine Syntactic Precedence Relations," (to be published).

(2) J. Garwick, J. Bell, and L. Krider, The GPL Language, Programming Technical Report TER-05, Control Data Corp.

(3) J. R. Bell, "Preliminary Results in the Design of a Minimal Expandable Computer Language," (unpublished SRI technical report).

(4) B. Raphael, "Aspects and Applications of Symbol Manipulation," Proc. ACM Nat'l. Conf. (1966).

(5) B. Raphael, et al., "A Brief Survey of Computer Languages for Symbolic and Algebraic Manipulation," in Proc. 1966 IFIPS Working Conf. on Symbol Manipulation Languages, No. Holland Publishing Company.

F. Research on Robot Systems

1. Objectives

Each of the areas described above should be pursued in depth as necessary components of a robot system. At the same time a robot system should be worked on as a separate component task to serve as a test-bed for the results developed. Furthermore, the task of putting a robot system together will have a great influence on the course of further research of each of the component areas. In fact, it is to be expected that needs for additional component areas will be thus exposed.

Even more important, though, is the fact that the robot system research task has its own special research topic. This topic is the important one of system integration. Important problems in the "flow of control" and information transfer among the subsystems need solution.

2. Background

Presently, SRI is developing an initial robot system,[1,2,3] capable of using simple visual perception and of solving the problems of getting around from place to place in its environment. We plan to augment and extend this program into a system with more sophisticated vision and capable of performing more complex problem-solving tasks.

A graded list of tasks of increasing difficulty has been developed to provide definite milestones for a continuing project in robot system research. These tasks will require increasingly sophisticated component systems and better means for integrating them. It is of utmost importance that continuity in funding be available here because of the unifying nature of this project.

3. Level of Effort

Personnel	5 man years/year
Computer	35 units

4. Key Individuals

L. Stephen Coles	Bertram Raphael
George E. Forsen	Charles A. Rosen
Milton W. Green	Elmer B. Shapiro
John H. Munson	Sven E. Whalstrom
Nils J. Nilsson	John H. Wensley

5. References

(1) N. Nilsson and B. Raphael, "Preliminary Design of an Intelligent Robot," in Computers and Information Sciences-II, pp. 235-259, J. Tou (ed.) (Academic Press, New York, N.Y., 1967).

(2) C. Rosen and N. Nilsson, "An Intelligent Automaton," 1967 IEEE International Convention Record, Part 9, pp. 50-55.

(3) C. Rosen and N. Nilsson (eds.), "Applications of Intelligent Automata to Reconnaissance," Interim Reports No. 1 (November 1966) and No. 2 (March 1967), Contract AF 30(602)-4147, SRI Project 5953, Stanford Research Institute, Menlo Park, Calif.

G. Research on the Foundations of Artificial Intelligence

1. Objective

To develop a conceptual and theoretical framework which sets forth the unifying principles underlying as wide a variety as possible of Artificial Intelligence programs.

2. Background

Artificial Intelligence is still more an art than a science. It is noted for its lack of firm theoretical underpinnings. As research results accumulate it will be important to attempt to build a conceptual framework that can provide the basis for more efficient future exploratory research.

It has been suggested that a theoretical foundation for automatic problem solving (a key aspect of artificial intelligence) would most likely be provided by a formalism such as the predicate calculus. Special problem domains would then have to be axiomatized such that problems in each domain could be handled by formal proof procedures. The SRI question-answering system represents a large step forward in the application of formal methods to problem solving, and further progress in this area could well have profound implications for a solid theoretical base for artificial intelligence.

Many of the formal problem-solving methods can be related to the general problem of finding a path through a graph. In a recent paper,[1] there has been established the first formal basis for drawing together the mathematical and the heuristic approaches toward finding paths through graphs. This paper defines precisely the nature of the information from a problem domain that may be utilized by an algorithm for searching a graph derived from that domain. It then proves that a particular algorithm is optimal in the way it uses such information, under certain mild assumptions. It is thought that these results might well provide a basis for the development of a theory of heuristic search.

It will also be important to be able to incorporate theoretical explanations for planning strategies, such as reasoning by analogy into our framework. The use of natural language and semantic nets in planning should also be objects of attempts at formalization.

3. Research Plans

a. The theoretical results on graph searching should be pursued further. There are several remaining topics here including:

(1) Variations of the algorithm to satisfy alternative optimality conditions, e.g., minimization of total computational effort, and

(2) Analogous algorithms for data forms other than directed graphs, e.g., game trees.

b. As research progresses on question answering, natural language processing, and planning it should be a common goal of all of the researchers concerned to attempt a synthesis of basic principles into a unifying framework.

c. The robot system project should serve as a common meeting ground where breadth (rather than specialization) is a necessity, thus providing the most potent catalyst for unifying ideas.

4. Level of Effort

Personnel	1 man year/year
Computer	5 units

5. Key Individuals

L. Stephen Coles
Peter E. Hart
Robert E. Kling
Nils J. Nilsson
Bertram Raphael

6. References

(1) P. Hart, N. Nilsson, and B. Raphael, "A Formal Basis for the Heuristic Determination of Minimum Cost Paths," submitted for publication (June 1967).

III FACILITY NEEDS AND TOTAL COSTS

A. Computer

Currently, the Artificial Intelligence Group is using an SDS-940 time-shared computer system. The present complex includes:

(1) CPU with 32K core

(2) Two magnetic tape drives (800 bits per inch)

(3) Paper tape reader and punch

(4) Four-million character Random Access Data (RAD) storage

(5) Sixteen TTY channels

(6) Three Direct Access Communication Channels (DACC's)

(7) One SDS display

(8) One RAND Graphic Input Tablet.

The RAND tablet is government furnished equipment, and the rest of the complex is leased from SDS at a price of $17,000/month.

In addition to the above equipment, it is necessary to upgrade the system to include:

(1) 32K additional core at $2,000/month

(2) A 96 million character Bryant disc and memory interface connector (MIC) at $4,000/month.

The 32K extra core has been ordered and will arrive in December 1967. The total cost of the expanded facility, including $5,000/month for system support, communications, and supplies, would be $28,000/month.

Assuming that the Artificial Intelligence program described here would require about a 75 percent usage of the machine, the program would require a computing budget of approximately $250,000/year. The other 25 percent usage would be absorbed by other projects within the Group and occasional users outside of the Group.

B. Other Special-Purpose Hardware

In all probability the present SDS display will not prove adequate for all of our work. It is contemplated eventually to duplicate the display system developed in the Augmented Human Intellect program at SRI. Such a display system would require the construction of a controller (so that the display and the disc can share a MIC), and would cost approximately $75,000. Extra displays would cost about $4,000 each.

At least two of the research areas named would have occasional needs for the construction of special-purpose hardware. These are: visual system research and robot system research. While it is difficult to estimate precise annual figures, costs during the first year or two of the program could amount to about $75,000/year.

C. Total Costs

The following is a tabulation of the total level of effort thought to be appropriate for this program:

Professional personnel	14 man years/year
Computer facility changes	$250,000/year
Upgraded display costs (one display)	$75,000 (one time)
Other hardware costs	$75,000/year

IV Biographies of Key Individuals

Chaitin, Leonard J. - Systems Programmer, Applied Physics Laboratory

Mr. Chaitin received a B.S. degree in Chemical Engineering from the Pennsylvania State University in 1959.

From 1959 to 1962 Mr. Chaitin was employed by C-E-I-R, Inc. as an EDPM Programmer. From 1962 to 1966 he was employed as a Programmer for Stanford Research Institute. From March 1966 to October 1966 he was employed by Programming Services, Inc. Mr. Chaitin returned to the Institute in October 1966 as a Systems Programmer in the Applied Physics Laboratory.

Mr. Chaitin has done utility, systems, and specific programs. Among these were the first pass and modifier of an "SOS" type compiler (CEIRCODER), a FORTRAN preprocessor for such a compiler, a system for estimating the thermodynamic properties of gaseous substances at unusual temperature ranges, tracking and orbit control of satellites, data-reduction programs, a statistical survey for the Federal Aviation Agency, a gasoline-blending program, and various chemical design and unit processes and operations programs.

At the Institute Mr. Chaitin has implemented an input-output package and monitor for a large-scale war-game simulation program, developed a program to change digitized analog data into reducible form and added a package to facilitate its reduction, worked on an information-retrieval program as part of a "man-machine" system, and written a number of statistical programs concerned with power spectral density and hypothesis testing. As a Systems Programmer, he has worked on software modifications to the B-5500, the dissemination of programming information, and writing utility routines. Other projects include a test and diagnostic system for General Electric Company, text editor for a Government agency, and a feasibility and damage-assessment program for the Navy. Mr. Chaitin is currently responsible for software implementation on the SRI Automata project.

Mr. Chaitin has programmed for the IBM 650, IBM 704, IBM 709, IBM 7090, IBM 1620, Burroughs 220, CDC 1604, RCA 501, IBM AN/FSQ-32, GE 435, GE 625, GE DATANET 30, and SDS 940.

Coles, L. Stephen - Research Mathematician
Applied Physics Laboratory

Dr. Coles received his B.S. degree in Electrical Engineering from Rensselaer Polytechnic Institute in 1962, his M.S. degree in Mathematics from Carnegie Institute of Technology in 1964, and his Ph.D degree in Systems and Communication Sciences from Carnegie Mellon University in 1967.

Dr. Coles held a New York State Regents Engineering Scholarship and a Rensselaer Scholarship at R.P.I. from 1958 to 1962. At Carnegie Tech he held an ARPA Research Assistantship and was elected to the Society of Sigma Xi in 1966.

Dr. Coles has been involved in the field of computing (both analog and digital) in one form or another since the summer of 1960, when he began programming at Republic Aviation Corporation in Farmingdale, New York. While employed by the System Development Corporation in 1962-63, he aided in the design of the Strategic Air Command Control System. During the summer of 1965, he acted as assistant to the Director of Information Processing at the Advanced Research Projects Agency of the Department of Defense. During the summer of 1966, he was awarded a National Science Foundation International Travel Grant to attend the NATO sponsored Summer School in Man-Machine Interaction at the University of Edinburgh. In addition to his current research at SRI, Dr. Coles is also serving as a Lecturer with the Department of Electrical Engineering and Computer Science at the University of California at Berkeley and with the Computer Science Department at Stanford University.

Dr. Coles is a member of the Association for Computing Machinery, the Institute for Electronic and Electrical Engineers, the Association for Machine Translation and Computational Linguistics, and the Society of Sigma Xi.

Duda, Richard O. - Research Engineer, Applied Physics Laboratory

Dr. Duda received a B.S. degree in 1958 and an M.S. degree in 1959, both in Electrical Engineering, from the University of California at Los Angeles. In 1962 he received a Ph.D. degree from the Massachusetts Institute of Technology, where he specialized in network theory and communication theory.

Between 1955 and 1958 he was engaged in electronic component and equipment testing and design at Lockheed and ITT Laboratories. From 1959 to 1961 he concentrated on control system analysis and analog simulation, including adaptive control studies for Titan II and Saturn C-1 boosters, at Space Technology Laboratories.

In September 1962, Dr. Duda joined the staff of Stanford Research Institute, where he has been working on pattern recognition and related topics in artificial intelligence. He has taught a course on learning machines for the University of California Extension and has been the author or coauthor of several papers in this field.

Dr. Duda is a member of Phi Beta Kappa, Tau Beta Pi, Sigma Xi, the Institute of Electrical and Electronics Engineers, and the Association for Computing Machinery.

Forsen, George E. - Research Engineer, Applied Physics Laboratory

Mr. Forsen received both the S.B. and the S.M. degrees in Electrical Engineering from the Massachusetts Institute of Technology in 1957, and the degree of Electrical Engineer from MIT in 1959.

He was employed part time from 1954 to 1956 by the General Electric Company, on the Cooperative Plan with MIT. While with GE he worked on non-destructive testing methods, and measurement techniques for heat flow in power transistors.

From 1958 to 1959 he was a Research Assistant and staff member of the Communications Biophysics Group, Research Laboratory of Electronics at MIT. There he designed electronic instrumentation for the study of neurophysiological phenomena. From 1957 to 1959 he was also employed by the Electrical Engineering Department of MIT as a Teaching Assistant.

In October 1959 Mr. Forsen joined the staff of Stanford Research Institute where he has been engaged in the study of neuron-like devices and adaptive, cognitive systems. He is currently working on mechanizing vision of three-dimensional environments. He has authored several patents and papers in these fields.

Mr. Forsen is a member of Sigma Xi, the Institute of Electrical and Electronics Engineers, and the IEEE Professional Group on Electronic Computers.

Green, Claude Cordell - Research Engineer, Applied Physics Laboratory

Mr. Green received a B.A. degree in 1963 and a B.S. degree in 1964 in Electrical Engineering from Rice University. He received an M.S. degree in Electrical Engineering in 1965 from Stanford University and is presently working toward the completion of his doctorate at Stanford University in the field of artificial intelligence. As a part-time employee at SRI he is working on an intelligent question-answering system, and on the application of intelligent automata to reconnaissance.

Mr. Green held a Western Electric Scholarship and a Nussbaum Scholarship while at Rice University. He received National Science Foundation Graduate Fellowships while at Stanford.

Mr. Green worked for Texas Instruments in Houston in the summers of 1963 and 1964 designing electronic circuits. In the summer of 1965 he worked in the field of pattern recognition for Dr. Louis Fein of Synnoetic Systems, Palo Alto, and coauthored a paper with Dr. Fein on Bionic Systems.

Mr. Green is a member of Tau Beta Pi, Sigma Tau, the Association for Computing Machinery, and the Institute of Electrical and Electronics Engineers.

Green, Milton W. - Senior Research Engineer
Computer Techniques Laboratory

Mr. Green received a B.S. degree in Electrical Engineering from Purdue University in 1947. From 1947 to 1959 he was a member of the technical staff of RCA Laboratories Division, Princeton, New Jersey. At RCA Mr. Green was at first engaged in the design and fabrication of special-purpose vacuum tubes having application to nuclear radiation measurement and infrared detection. The first of the velocity selector infrared image tubes was designed and built by him at this time.

During the years 1950-1957 Mr. Green was engaged in semiconductor work, where he was responsible for the design of power-semiconductor devices and their associated enclosures. His hermetic enclosure for RCA developmental power transistors was standard for some time and is still in wide usage. Further semiconductor experience was gained in investigations of ferroelectric and electroluminescent materials in computer applications.

Subsequently Mr. Green became interested in the application of cryogenic devices, particularly those involving superconductivity, to computer memory systems and logic networks. During this period, he designed a novel, all-superconductive, content-addressed memory system and demonstrated the feasibility of the component logic devices.

Fifteen patent assignments have been made in the electron tube and semi-conductor fields. Approximately ten more patents are pending in the areas of superconductivity, semiconductor, and ferroelectric devices and systems.

In June 1959 Mr. Green joined the staff of Stanford Research Institute, where he has been concerned primarily with research on devices for computer logic and memory systems. He was project leader on a research program for achieving high-speed logic with magnetic thin films, and more recently was project leader for the neuristor research program. In 1965 he became a member of the Computer Sciences Group where he presently leads two projects. One of these (a sub-group of the Automata program) seeks to define the basic tasks to be carried out by a mobile automaton and to devise strategies and programming tatics for their execution. The other project (internally sponsored by SRI) investigates new heuristic programming techniques with a view toward greater utilization of human intuition in the man-computer problem solving process.

Hart, Peter E. - Research Engineer, Applied Physics Laboratory

Dr. Hart received a B.E.E. degree in 1962 from the Rensselaer Polytechnic Institute, Troy, New York. He received the M.S. and Ph.D. degrees in Electrical Engineering from Stanford University in 1963 and 1966, respectively.

His doctoral work was on the application of nonparametric statistics to the pattern-recognition problem. During the course of his graduate studies he was a Hughes Master Fellow, a participant in the Philco Honors Co-op program, and a Research Assistant at Stanford University.

Dr. Hart is a member of Eta Kappa Nu, Tau Beta Pi, Sigma Xi, and the Institute of Electrical and Electronics Engineers.

Kling, Robert E. - Research Engineer, Applied Physics Laboratory

Mr. Kling received a B.S. degree in 1966 in Electrical Engineering from Columbia University and an M.S. from Stanford University in the same field in 1967. He is presently completing his doctoral studies at Stanford, focusing upon artificial intelligence.

Since the winter of 1966 he has been developing a program for reasoning by analogy with applications to geometry and algebra.

Mr. Kling worked for Watkins Johnson during the summers of 1964 and 1965, first researching the beam properties of ultralow-noise traveling-wave tubes. Later he developed a design for an ultrahigh-speed microwave "scanning receiver."

Since June 1966 he has been working on advanced techniques of concept learning and problem solving for the SRI automaton in addition to his thesis effort.

Munson, John H. - Research Physicist, Applied Physics Laboratory

Since joining Stanford Research Institute in 1963, Dr. Munson has been engaged in computer and learning machine research and applications. He was primarily responsible for joining the MINOS II learning machine to a digital computer to provide a powerful learning-machine facility, used in theoretical studies and diverse pattern-recognition applications.

Dr. Munson received a B.Sc. degree (with honors) from the California Institute of Technology in 1960. He received an M.A. degree in 1962 and a Ph.D. degree in 1964, both in Physics, from the University of California at Berkeley. He held a National Merit Scholarship award as an undergraduate, and a National Science Foundation fellowship as a graduate student.

In his doctoral research in nuclear physics, Dr. Munson participated in the design and use of a computer-connected system (the Scanning and Measuring Projector, SMP) for measurements on bubble-chamber film.

He was primarily engaged in mixed-language computer programming, real-time man-machine operation, and optical pattern recognition. In 1964 he created a time-sharing "executive" computer program for the SMP system, with the unique feature of allowing multiple on-line consoles to operate simultaneously within a single, user-written, processing computer program. Dr. Munson is the principal author or co-author of several papers related to both the SMP and the MINOS II facility.

In 1965, Dr. Munson led a project to investigate the state of computing facilities at SRI and to make recommendations for SRI computing in the next five years.

Dr. Munson is a member of Tau Beta Pi and the Association for Computing Machinery.

Nilsson, Nils J. - Head, Artificial Intelligence Group
Applied Physics Laboratory

Dr. Nilsson has been on the staff of Stanford Research Institute since August 1961 where he has participated in and led research in pattern recognition, learning machines, and artificial intelligence. He has taught courses on learning machines at Stanford University and at the University of California, Berkeley. McGraw-Hill published, in March 1965, a monograph by Dr. Nilsson describing recent theoretical work in learning machines.

Dr. Nilsson received an M.S. degree in Electrical Engineering in 1956 and a Ph.D. degree in 1958, both from Stanford University. While a graduate student at Stanford, he held a National Science Foundation Fellowship. His field of graduate study was the application of statistical techniques to radar and communication problems.

Before coming to SRI, Dr. Nilsson completed a three-year term of active duty in the U.S. Air Force. He was stationed at the Rome Air Development Center, Griffiss Air Force Base, New York. His duties entailed research in advanced radar techniques, signal analysis, and the application of statistical techniques to radar problems. He has written several papers on various aspects of radar signal processing. While stationed at the Rome Air Development Center, Dr. Nilsson held an appointment as Lecturer in the Electrical Engineering Department of Syracuse University.

Dr. Nilsson is a member of Sigma Xi, Tau Beta Pi, the Institute of Electrical and Electronics Engineers, and the Association for Computing Machinery.

Raphael, Bertram - Research Mathematician
Applied Physics Laboratory

Dr. Raphael received a B.S. degree in Physics from Rensselaer Polytechnic Institute in 1957, an M.S. degree in Applied Mathematics from Brown University in 1959, and a Ph.D. degree in Mathematics from MIT in 1964.

Dr. Raphael held several scholarships at RPI from 1953 to 1957, and the Universal Match Foundation fellowship at Brown University in 1958. He received an N.S.F. honorable mention and was elected to the Society of Sigma Xi in 1957.

Dr. Raphael's interest and experience in automatic computation includes work in that field for R.C.A., Moorestown, New Jersey; for Bolt, Beranek and Newman, Inc., Cambridge, Massachusetts; and as a Consultant for the RAND Corporation, Santa Monica, California. He taught at RAND summer institutes for Heuristic Programming (1962) and Simulation of Cognitive Processes (1963), and lectured at UCLA during the summers of 1963 and 1964. During his doctoral studies he worked as a Research Assistant in the Artificial Intelligence Group at the MIT Computation Center. From June 1964 to February 1965, he held joint appointments as Assistant Research Scientist and Acting Assistant Professor of Electrical Engineering at the University of California at Berkeley. Since joining the staff of SRI in February of 1965, he has served as a part-time Lecturer in Electrical Engineering at Berkeley and in Computer Science at Stanford University.

Dr. Raphael is a member of the Association for Computing Machinery, the Association for Machine Translation and Computational Linguistics, and the Society of Sigma Xi.

Rosen, Charles A. - Manager, Applied Physics Laboratory

Dr. Rosen received a B.E.E. degree from the Cooper Union Institute of Technology in 1940. He received an M.Eng. in Communications from McGill University in 1950, and a Ph.D. degree in Electrical Engineering (with a minor in Solid-State Physics) from Syracuse University in 1956.

Since December 1959, Dr. Rosen has been Manager of the SRI Applied Physics Laboratory, engaged in directing a program including major projects in microelectronics, learning machines, and artificial intelligence.

From 1940 to 1943 he served with the British Air Commission dealing with inspection and technical investigations of aircraft radio systems, components, and instrumentation. From 1943 to 1946, he was successively in charge of the Radio Department, Spot-Weld Engineering, and Aircraft

Electrical and Radio Design at Fairchild Aircraft, Ltd., Longueuil, Quebec, Canada. From 1946 to 1950 he was a partner in Electrolabs Reg'd., Montreal, engaged in the development of intercommunication and electronic control systems. From 1950 to 1957 he was employed at the Electronics Laboratory, General Electric Co., Syracuse, New York, and was successively Assistant Head of the Transistor Circuit Group, Head of the Dielectric Devices Group, and Consulting Engineer, Dielectric and Magnetic Devices Subsection. In August 1957 Dr. Rosen joined the staff of Stanford Research Institute, where he was shortly given responsibility for developing the Applied Physics Laboratory.

His fields of specialization include learning machines, dielectric and piezoelectric devices, electromechanical filters, and a general acquaintance with the solid-state device field.

He has contributed substantially as co-author to two books: Principles of Transistor Circuits, R. F. Shea, editor (John Wiley and Sons, Inc., 1953), and Solid State Dielectric and Magnetic Devices, H. Katz, editor (John Wiley and Sons, Inc., 1959).

Dr. Rosen is a Senior Member of the Institute of Electrical and Electronics Engineers, and a member of the American Physical Society and the Scientific Research Society of America.

Shapiro, Elmer B. - Senior Research Engineer
Systems Engineering Laboratory

Mr. Shapiro joined the staff of Stanford Research Institute in 1960. He headed a project concerned with the development of new and advanced techniques for designing and analyzing communication networks. This involved studies of various switching methods (such as circuit switching and store-and-forward switching,) network-congestion phenomena, and traffic routing and control doctrines. He also served on a DOD switching committee that studied and evaluated several major military developmental switching systems.

Mr. Shapiro's interests are in the synthesis and analysis of digital information-processing systems and switching systems for communication networks.

Recently, he participated in an SRI command-and-control study of the U.S. European Command, particularly concerned with the data-processing aspects of communication-network management and radio-frequency allocations.

Before joining the Institute, Mr. Shapiro was a member of the Technical Staff at the Bell Telephone Laboratories from 1953 to 1955 and from 1957 to 1960. He supervised a group responsible for the planning and development of data trunks, including signaling and supervision facilities. He was also responsible for the system planning of maintenance and error control for a developmental, solid-state data processor. During his early years at BTL, Mr. Shapiro participated in the logical design of the Tradic Computer (an airborne digital machine) and the design of high-output transistor pulse-regenerative amplifiers.

From 1955 to 1957, Mr. Shapiro was on active duty in the U.S. Army at the Computing Laboratory of the Ballistic Research Laboratories (BRL), Aberdeen Proving Grounds. There, he served as an electronic engineer on the engineering staff of the Ordvac computer, concerned with the operation and maintenance of the system. He was also responsible for the logical and circuit design (a mixture of solid-state and vacuum-tube design) of control equipment necessitated by the installation of an enlarged core memory. Also, during 1957, he served as a full-time licensed engineer of the commercial AM station, WAMD, in Aberdeen, Maryland.

Mr. Shapiro received a B.S. degree from the Illinois Institute of Technology in 1952 and an M.S. degree from Stanford University in 1953, both in Electrical Engineering. He completed the BTL Communications Development Training Program in 1958.

Mr. Shapiro is a member of the Association for Computing Machinery, the Institute of Electrical and Electronics Engineers, and the IEEE Groups on Computers and Communication Technology.

Wahlstrom, Sven E. - Senior Research Engineer
Computer Techniques Laboratory

Mr. Wahlstrom received an Electronics Engineer degree from Hogre Tekniska, Laroverket, Orebro, Sweden in 1947 and an M.S. degree from Chalmers Institute of Technology in Gothenburg in 1952. From June 1952 until January 1954, when he joined the staff of the Swedish Board for Computing Machinery, he worked on design of sounders and transistor circuits for hydroacoustic equipment.

In 1954 he developed paper tape equipment, similar to the Flexowriter, and a card-to-paper-tape converter. In 1955 he was responsible for advanced development work in the use of transistor circuits for core memories; he was also responsible for the BESK Computer Center.

In 1956 he joined the group that formed Facit Electronics, where his first task was to develop the Carousel Random Access Memory. After significant contributions to the design of other products, such as core memories and electromechanical devices, he was given the full responsibility for the design of the Facit EDB 3 computer system. This computer, which was completed in early 1962, has a unique system of combining large core memories with the central processor, carousel memories, punch card equipment, line printers, etc., permitting a very effective input and output of data. For example, up to 5 peripheral units could transfer data simultaneously.

Mr. Wahlstrom was Section Manager and later Head of the Development Department; as such he was responsible for the development of all commercial products of Facit Electronics. In February 1963 he joined Ampex Corporation, where he held positions as Manager, Tape Transports Development, and Manager of Systems. His work at Ampex was mainly devoted to digital equipment; he was also project leader for the development of a special-purpose digital computer.

In May 1965 he joined the staff of Stanford Research Institute, where he has reviewed the practical aspects of cellular logic and suggested the programmable cellular-logic approach. He has assisted in the design of digital equipment for evaluation of oblique ionospheric-sounder data, designed digital equipment for data communication, and designed a digitizer for video signals from TV cameras for use in pattern-recognition research.

Mr. Wahlstrom took part in a major economic research project where he was responsible for predicting the change in the structure of computers in the period 1966--1975 and the consequences this would have on the use of electronic components.

Mr. Wahlstrom is presently responsible for the design of an automaton consisting of a mobile vehicle and associated equipment for activation of commands, communication and preprocessing of sensor data, and interfacing to a computer.

Wensley, John H. - Senior Research Engineer
Systems Engineering Laboratory

Mr. Wensley joined the staff of Stanford Research Institute in July 1962 and worked until early 1964 on the Augmented Human Intellect program. In particular, he was project leader on the first snages of RECAP, a research project aimed at the augmentation of a programmer's effectiveness by on-line use of a computer.

He has been concerned with the problems of new computer system designs, and in particular with the problems of using such new computers. In this work he was the principal investigator on an SRI-sponsored project to investigate a prototype design for a highly parallel computer system.

In addition, he has worked on problems of the reduction of graphical data from the OGO series of satellites. Recently he has been carrying out research on intelligent automata, and particularly on the design of heuristics and their simulation on a computer.

In 1950 he joined the staff of the Research Laboratories of the General Electric Company (of Great Britain) in their Line Communications

Laboratory. His first work was concerned with research into new methods of designing networks and feedback systems. In 1954 he started the computing service of the company, being responsible for all phases of its activity including programming, operating, and scheduling. This service was centered around a digital computer.

In 1956 he became a founder member of a new company, jointly sponsored by the GEC and International Computers and Tabulators, Ltd. This company planned and designed computers and associated systems. He was responsible for the logical design and programming for the 1301 computer (a medium-size business data processor). He held the position of Head of the Methods Division and during 1961 was appointed as Manager of the Project Planning Department of International Computers and Tabulators.

He has been active in the field of automatic coding since 1956 and was a member of the European working committee which defined ALGOL 60. He led a team which implemented COBOL 60 and "ICT Rapidwrite" and was responsible for the definition of an early automatic coding language "CODEL" which was aimed at use by both scientific computers and business data processors.

Mr. Wensley received his B.A. honours degree in Mathematics at Cambridge University, England in 1950.

He has been author or coauthor of the following papers: "The Solution of Electrical Field Problems Using a Digital Computer" (coauthor), Electrical Energy, Vol. 1, pp. 12-16 (September 1956); "The 1301 Data Processing System" (coauthor), G.E.C. Journal, Vol. 27, No. 2, pp. 77-85 (Spring 1960); "A Class of Non-Analytical Iterative Processes," The Computer Journal, Vol. 1, No. 4, pp. 163-167 (January 1959).