STANFORD RESEARCH INSTITUTE

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Proposal for Research
SRI No. ESU 68-45

RESEARCH ON INTELLIGENT AUTOMATA

Prepared for:

Advanced Research Projects Agency
Washington, D. C.

Prepared by:

N. Nilsson & B. Raphael
Artificial Intelligence Group
Applied Physics Laboratory

Approved by:

Charles A. Rosen, Manager
Applied Physics Laboratory

Torben Meisling, Executive Director
Information Science & Engineering

Copy No. 20

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RESEARCH ON INTELLIGENCE AUTOMATA

I BACKGROUND

Stanford Research Institute is now engaged in a project[*] to investigate techniques in artificial intelligence applied to the control of a mobile automaton as it carries out tasks in a realistic environment. These tasks could be ones whose performance would ordinarily require human intelligence; thus, our investigation is aimed ultimately at relieving the necessity of using humans for certain types of tasks.

Many military missions require abilities typically found in humans but for which it is undesirable to use humans, for example, reconnaissance in dangerous areas. Planetary exploration is an example of a nonmilitary task that could probably be accomplished by an automaton. (Concurrent with our past research, we have also engaged in preliminary systems studies to determine the most feasible automaton application areas. We are proposing to study one of these applications in detail under sponsorship of the ARPA Advanced Sensors Group.)

Several reports and papers[1-6†] describe the research conducted so far. In summary, that research has led to the development of a computer-controlled wheeled vehicle, carrying a television camera and other sensors. The primary emphasis of the research has been on the design of a hierarchy of computer programs that accept visual and other sensory information from the vehicle and direct its actions toward the completion of missions requiring the abilities to plan ahead and to learn from previous experience.

In addition, Stanford Research Institute is now completing a project[‡] devoted to the investigation of computer memory organization, fact retrieval, and logical deduction techniques for automatic question-answering systems. This latter program has resulted in the implementation of a preliminary theorem-proving question-answering program that is reported in several papers.[7-9]

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[*] Contract AF 30(602)-4147 with the Rome Air Development Center, Griffiss Air Force Base, New York and the Advanced Sensors Group of the Advanced Research Projects Agency.

[†] References are given at the end of this proposal.

[‡] Contract AF 19(628)-5919 with Air Force Cambridge Research Laboratories, Electronic Systems Division, Air Force Systems Command, Laurence G. Hanscom Field, Bedford, Massachusetts.

The present automaton research project began in March 1966 and is presently funded until 5 October 1968. The question-answering research project began in April 1966 and terminates in April 1968. Stanford Research Institute proposes herewith a new project to continue and draw together the research that was begun under the two projects mentioned above.

II DESCRIPTION OF THE PROPOSED PROJECT

We have divided the proposed research on intelligent automata into six major problem areas. These are:

Automaton Sensors and Sensory Processing--Sensory data (primarily visual) is obtained from the external world, and that information needed for task performance is extracted.

Automaton Memory Organization and Memory Processing--Significant information about the world (obtained either through the senses or provided by the experimenter) is stored in a memory structure. Processing routines use this structure to provide answers needed by other parts of the automaton system.

Planning and Problem Solving--High-level routines analyze the mission given to an automaton in order to decide the strategy and subgoals to be used in carrying out the mission.

Man/Automaton Communication--Special programs provide for communication with the automaton in either an English-like language, a lower-level control language, or through a display and a light-pen interface.

System Coordination--An executive level of programs provides for the coordination of all automaton subsystems.

Question Answering and Theorem Proving--Techniques are developed for accepting and storing a wide variety of information in computer memory, retrieving items relevant to a particular query, and logically deducing appropriate responses when answers are not explicitly available.

Research in the first five of the above problem areas will lead directly to components of a programmed automaton system. The relationship of these five areas is diagrammed in Fig. 1. The sixth area, Question Answering, will be pursued as an independent research study whose results are expected to have broad applicability throughout the automaton system.

Stanford Research Institute proposes specifically to carry on an intensive program of research on these six topics related to the development of an intelligent automaton. During the past two years we have identified and begun the solution of many key problems in this framework.

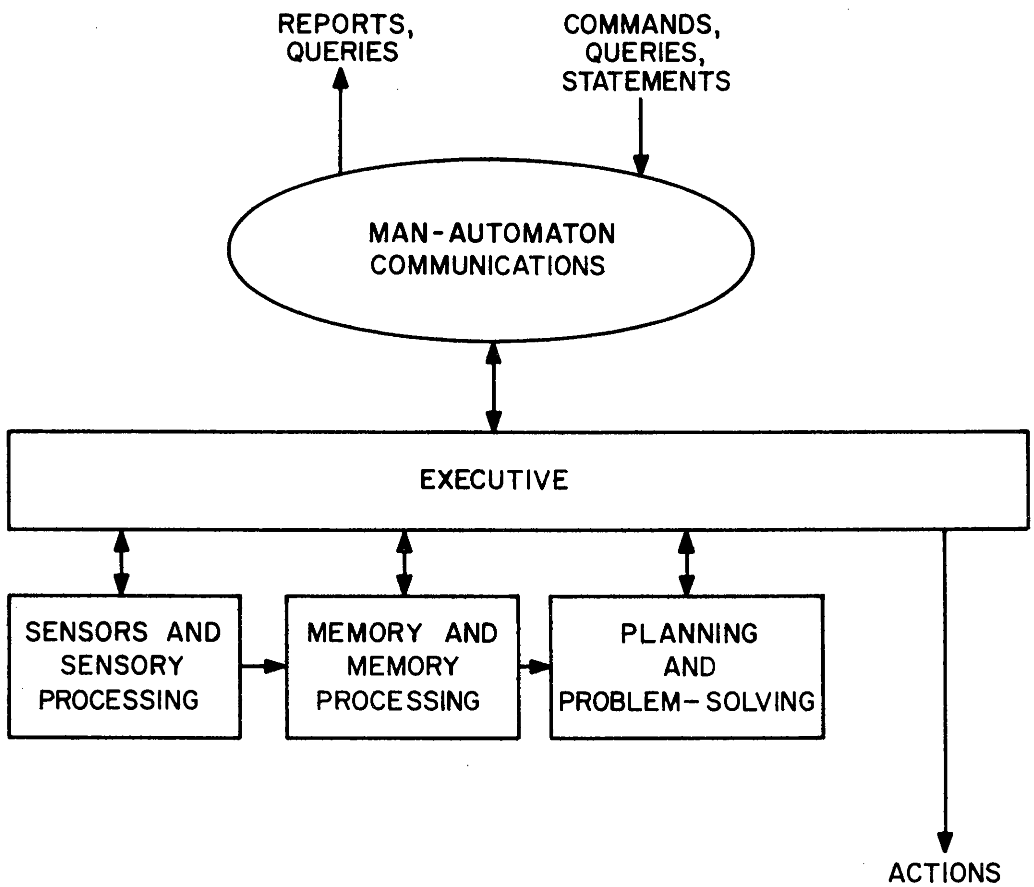

Fig. 1 Major Areas of Automaton Research

The remainder of this proposal discusses specifically those problems that we will attack in the proposed project and our method of approach toward their solution.

III RESEARCH AREAS AND METHODS OF APPROACH

A. Sensors and Sensory Processing

To function effectively in a real-world environment, an automaton 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.

Our present automaton's visual system is an important first step toward this goal. It extracts edge information from a single black-and-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.

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

Texture--Textural differences separate 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 as opposed to when it signifies the boundary of an object.

Color--Like texture, color is an area property of a figure. It adds a new clue for figure/ground discrimination.

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.

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 automaton research program. The visual system can use encyclopedic information in the robot's memory structures and must in turn supply the robot with information relevant to its tasks.

B. Memory Organization and Memory Processing

An automaton must have access to a large store of information. This information consists both of specific facts about the robot's immediate environment, e.g., that a cube-shaped object is at location (x,y), and general facts about the world around it, e.g., that waste baskets are movable but pillars are not.

In the current automaton project we are storing specific facts about the robot's environment in a set of three complementary "models:" a hierarchical grid "map," a line-drawing plan view, and a list-structured description. Extensions of these models will be investigated in the proposed new project.

A store of general facts is encyclopedic in nature and can require vast amounts of memory. The organization of such information depends upon the nature of the retrieval and deductive procedures that will make use of it. One of the principal goals of research in the question-answering area (discussed below) will be to determine an effective way for an automaton to store and utilize a large number of general facts.

C. Planning and Problem Solving

In analyzing a complex mission, the automaton must ultimately decide on a sequence of basic actions whose execution will accomplish the mission. Recent results indicate that certain problem-solving techniques are theoretically capable of eventually achieving appropriate action sequences for simple missions. Our question-answering work has suggested an approach, which we propose to pursue, that uses a formal theorem-proving program at the heart of the problem solver.

Such general problem-solving approaches will be practical in achieving interesting automaton behavior only if they can be made more efficient than they presently are. One way to achieve this efficiency is to divide each complex mission into a set of easier submissions.

The process of selecting subgoals, sometimes called "planning," is not yet very well developed although several approaches to the problem have been suggested. One of the most promising suggestions uses a method of "reasoning by analogy." We propose to investigate various of these planning methods, especially the analogy method, in some detail.

D. Man/Automaton Communication

At the present time, human control of the automaton is largely through direct low-level calls to system subroutines. Two specific ways of enhancing man/automaton communication will be developed. One is through the use of an English-like problem specification language, and the other is to improve the various monitoring systems that now exist making major use of a display and light pen.

With regard to natural language processing, it is proposed to use a method suggested by Coles,[10] who has formulated an integrated theory of syntactic and semantic descriptions suitable for computer implementation. Coles has already developed routines to allow a restricted natural language input for the "QA2" system developed under the current question-answering project. This work will be extended to the point where a person could conveniently communicate with the system. This involves a large increase in the number of phrase structure rules in the underlying grammar and ultimately the incorporation of a transformational component into the grammar.

E. System Coordination

In the area of system coordination research we lump together a variety of functions necessary for the robot system. First, there must be executive routines that supervise the sensory, memory processing, planning, and communication activities. The executive system must decide which missions can be solved by simple memory processing techniques and which will require complex analysis and planning. It must decide when vision should be used to gather more information. Problems of hierarchical organization and flow of control for the whole system are part of this area. Any special modifications to the SDS 940 system software plus utility routines such as the "valet" program (which permits easy interchange between programming systems such as FORTRAN and LISP) also come under this heading.

Probably one of the most important of these system coordination problems is "learning." By an ability for learning we mean any provision, built into the executive routines, for making changes in the data or programs of the automaton system as a result of its experience. Thus, the present automaton system has a rudimentary learning ability in that its "model of the world" can be changed as a result of sensory experience.

Future systems should have more sophisticated learning abilities influencing the problem solving and visual functions as well. Clustering and parameter adjustment techniques can probably be applied at several points in the automaton system, and these will be investigated in detail.

F. Question Answering and Theorem Proving

The general area of question answering concerns a central problem of artificial intelligence that arises in several areas of an intelligent automaton system. Whether the principal problem of interest is, for example, visual scene analysis, automatic problem solving, or resolution of ambiguity in a communication 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."

Under the current question-answering project we have implemented a simple but promising question-answering system based upon formal theorem-proving techniques. In order to make use of future versions of this system within the automaton program, we propose to direct our question-answering research towards the following three tasks: generalizing program organization, axiomatizing new subject areas, and improving theorem-proving efficiency.

1. Program Organization

We propose to give the question answerer the ability to execute special-purpose subroutines such as robot sensor and control routines. The resulting system would thus combine the generality and power of the formal theorem prover with the efficiency of subroutines that have special effects or "knowledge" in a particular problem domain.

Our work on program organization will include the development of flexible techniques for modifying and testing the problem-solving capabilities of the question answerer. This may make it possible to transform the question answerer itself into the executive component of an automaton system.

2. Axiomatization of New Subject Areas

The question answerer can be applied to particular problem domains if those domains can be appropriately characterized by sets of axioms. We propose to axiomatize sequential tasks such as robot navigation, thereby potentially enabling the question answerer to serve as the problem-solving component of an automaton system. We also will attempt to axiomatize the behavior of the theorem prover, thereby permitting the system to solve problems about its own internal workings. Such "bootstrapping" could lead to new kinds of high-level learning.

3. Improved Theorem Proving

An efficient theorem prover is a prerequisite for all applications of this kind of question answerer. We propose to study ways to improve the efficiency of the theorem prover, such as implementing special bookkeeping and other schemes for reducing redundancy in proofs, and adding routines for special high-speed treatment of equality and other important predicates.

IV EXPERIMENTAL FACILITIES

A. Computer

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

(1) Central Processor Unit with 64K 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 teletype channels
(6) One SDS display
(7) One RAND Graphic Input Tablet.

The RAND tablet is government-furnished equipment, and the rest of the complex, which is shared by other SRI projects, is leased from SDS.

In addition to the above equipment, we expect delivery of a 96-million character Bryant disc and memory interface connector in June 1968.

B. Special Equipment

The research to be conducted under the proposed project will make use of the automaton vehicle, visual preprocessor and interface equipment developed under the present project. It is not anticipated that major additions to the hardware will be needed during the term of the proposed work. Some additions to the visual system may require hardware purchases such as a stereo adaptor and color filters.

V REPORTS

A final report will be written giving the results of the work outlined above.

VI ESTIMATED TIME AND CHARGES

The time required to complete this work and report its results is 18 months. We could begin work on the question-answering research immediately upon receipt of a contract. Automaton research could begin on 1 October 1968. A detailed cost estimate for the proposed work is attached.

VII CONTRACT FORM

It is requested that any contract resulting from this proposal be written on a cost-plus-fixed-fee basis.

VIII ACCEPTANCE PERIOD

This proposal will remain in effect until 1 June 1968. If consideration of this proposal requires a longer period, the Institute will be glad to consider a request for extension of time.

IX PERSONNEL

The following key personnel are expected to participate in this proposal.

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 Electrical and Electronics 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 semiconductor 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 with research on devices for computer logic and memory systems, and with computer logic and organization. He was project leader on a research program for achieving high-speed logic with magnetic thin films, and 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 subgroup of the Automata program) seeks to define the basic tasks to be carried out by a mobile automaton and to device strategies and programming tactics 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.

Harris, Joyce C. - Computer Programmer, Applied Physics Laboratory

Mrs. Harris graduated from Stanford University in 1965 with a B.S. cum laude in mathematics.

From 1965 to 1967 she was employed by the Stanford Electronics Laboratories at Stanford University, where she worked on pattern-recognition problems, simulations of adaptive systems, and special-purpose computers. The computers primarily used for this work were the IBM 7090, the Burroughs B5500, and the IBM 1620. Since February

1967 she has been with Stanford Research Institute working on the SDS 940 computer.

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. In 1966 Dr. Hart joined the staff at Stanford Research Institute, where he has been working on problems in the areas of pattern recognition and artificial intelligence.

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

Nilsson, Nils J. - Senior Research Engineer
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 1965, a monograph by Dr. Nilsson describing recent theoretical work in pattern recognition. He has written several papers on pattern recognition and artificial intelligence topics.

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 - Senior 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. He is presently serving as editor of the newsletter of the ACM Special Interest Committee on Artificial Intelligence, and has been appointed an ACM National Lecturer for 1967-68.

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.

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 stages 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).

Yates, Robert A. - Systems Programmer, Applied Physics Laboratory

As a part-time employee at Stanford Research Institute, Mr. Yates is working on a deductive question-answering system. Mr. Yates received his B.A. degree in Mathematics from Johns Hopkins University in 1965 and is working towards his Doctorate in Mathematics at Stanford University.

Mr. Yates worked in the computing centers of the University of Mexico and Politecnico in 1964, designing a LISP programming system for the IBM 709 computer. In 1965 he worked on bubble-chamber analysis programs at the Johns Hopkins Physics Department. Later, as an employee of Bell Telephone Laboratories, he worked on a storage-management program for the SNOBOL4 language.

Mr. Yates is a member of Phi Beta Kappa.

REFERENCES

1. N. J. Nilsson and B. Raphael, "Preliminary Design of an Intelligent Robot," in Computer and Information Sciences-II (Academic Press Inc., New York, N.Y., 1967).

2. C. A. Rosen and N. J. Nilsson, "An Intelligent Automaton," presented at the IEEE Int'l. Conv., New York, N.Y., March 20-23, 1967.

3. G. E. Forsen, "Processing Visual Data with an Automaton Eye," presented at the Pattern Recognition Society Symp. on Automatic Photo-interpretation, Washington, D.C., May 31-June 2, 1967.

4. C. A. Rosen and N. J. Nilsson (Eds.), "Application of Intelligent Automata to Reconnaissance," First Interim Report, Contract AF 30 (602)-4147, Stanford Research Institute Project 5953 (November 1966).

5. C. A. Rosen and N. J. Nilsson (Eds.), "Application of Intelligent Automata to Reconnaissance," Second Interim Report, Contract AF 30 (602)-4147, Stanford Research Institute Project 5953 (March 1967).

6. C. A. Rosen and N. J. Nilsson (Eds.), "Application of Intelligent Automata to Reconnaissance," Third Interim Report, Contract AF 30 (602)-4147, Stanford Research Institute Project 5953 (December 1967).

7. C. C. Green and B. Raphael, "Research on Intelligent Question-Answering System," Scientific Report 1, Contract AF 19(628)-5919, Stanford Research Institute Project 6001 (May 1967).

8. C. C. Green and B. Raphael, "The Use of Theorem-Proving Techniques in Question-Answering Systems," submitted for presentation at the 1968 ACM Conference, Las Vegas, Nevada, August 27-29, 1968.

9. L. S. Coles, "An On-Line Question-Answering System with Natural Language and Pictorial Input," submitted for presentation at the 1968 ACM Conference, Las Vegas, Nevada, August 27-29, 1968.

10. L. S. Coles, Syntax Directed Interpretation of Natural Language, Ph.D. Thesis, Carnegie-Mellon University, Pittsburgh, Pa. (June 1967).

Proposal for Research
SRI No. ESU 68-45

29 March 1968

COST ESTIMATE

Personnel Costs

Project Supervision,	5 man-months @ [redacted]/mo.	$[redacted]	
Senior Professional,	7 man-months @ [redacted]/mo.	[redacted]	
Professional,	60 man-months @ [redacted]/mo.	[redacted]	
Editor,	1 man-month @ [redacted]/mo.	[redacted]	
Technical,	7 man-months @ $[redacted]/mo.	[redacted]	
Clerical,	3 man-months @ $[redacted]/mo.	[redacted]	
Total Direct Labor		[redacted]	
Payroll Burden at 19%*		[redacted]	
Total Salaries and Wages		[redacted]	
Overhead at 96% of Salaries and Wages*		[redacted]	
Total Personnel Costs			[redacted]

Direct Costs

Travel:		
Three (3) trips to Washington, D.C. @ [redacted]/trip	$ [redacted]	
Six (6) days subsistence @ [redacted]/day	[redacted]	
Materials & Services	[redacted]	
Computer Time: SDS 940	[redacted]	
Reports	[redacted]	
Total Direct Costs	[redacted]	
Total Estimated Cost		[redacted]
Fixed Fee		[redacted]
TOTAL ESTIMATED COST PLUS FIXED FEE		[redacted]

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*The rates quoted represent our current experience. It is requested that contracts provide for reimbursement at billing rates acceptable to the Contracting Officer subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. Included in payroll burden are such costs as vacation and sick leave pay, social security taxes, and contributions to employee benefit plans.

SCHEDULE A - DIRECT LABOR

Direct labor charges are based on the actual salaries for the staff members contemplated for the project work plus a judgmental factor applied to base salary for merit increases during the contract period of performance. Frequency of salary reviews and level of merit increases are in accordance with the Institute's Salary and Wage Payment Policy as published in Topic No. 505 of the SRI ADMINISTRATION MANUAL and as approved by the Defense Contract Administration Services Region. (For explanation of "Support" charges see Schedule D - REPORT COSTS.)

SCHEDULE B - OVERHEAD AND PAYROLL BURDEN RATES

The rates quoted represent our current experience for General Overhead and for Payroll Burden, which includes such costs as vacation and sick leave pay, social security taxes, and contributions to employee benefit plans. Cost data in support of these rates has been submitted to the Resident Representative of the Defense Contract Audit Agency.

It is requested that contracts provide for reimbursement at billing rates acceptable to the Contracting Officer subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data.

SCHEDULE C - MATERIALS & SERVICES

Description	Estimated Cost
To be specified during research work possibly including items such as:	
Stereo equipment Color equipment Interface equipment Arms for Automaton Video camera Miscellaneous parts and supplies	[redacted]
Computer (SDS 940):	
Regular Use Mode, 7,000 hrs. @ [redacted]/hr.	[redacted]
Display/Automata Mode, 1,000 hrs. @ [redacted]/hr.	[redacted]
Total Computer	[redacted]

Air fares are based on prices established in OFFICIAL AIRLINE GUIDE dated March 1, 1968.

Domestic subsistence rates and travel by private auto are established standards based on cost data submitted to and approved by DCAA.

SCHEDULE D - REPORTS COSTS

Report costs are segregated into two broad categories--preprinting and printing costs. Preprinting, or "Support," includes editing, illustrating, typing, proofreading, and supervisory time. Printing, or "Report Production" considers the cost of press and binding.