STANFORD RESEARCH INSTITUTE
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Proposal for Research
SRI No. ESU 69-125

13 November 1969

DEVELOPMENT AND APPLICATION OF QUESTION-ANSWERING TECHNIQUES FOR A REMOTE-ACCESS MEDICAL-INFORMATION RETRIEVAL SYSTEM

Prepared for:

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Copy 16

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I INTRODUCTION

Since July 1968, NLM (by subcontract issued through EDUCOM and by NLM Contract No. NLM 69-13) has sponsored research at Stanford Research Institute that has had as its objective a medical-information retrieval system that would be a part of the Biomedical Communications Network (BCN) and be used by medical personnel and institutions all over the United States. This effort has been concerned with two major topics:

(1) Development of an information-retrieval system that will allow users to question the system in relatively natural language and to obtain answers containing both explicit and implicit information based upon facts stored in the system (referred to as a "Question-Answering System").

(2) Retrieval, presentation, and manipulation of information stored in documents (paper, microfiche) for viewers not located at the storage location (referred to as a "Remote Viewing System").

Two reports issued during the EDUCOM subcontract period ("Summary of Technical Status and Plans on SRI Project 7382," 15 November 1968, and "Medical Applications of Remote Electronic Browsing," Final Report, December 1968), presented to NLM some of SRI's preliminary conclusions regarding these two major topics. Of the two topics, remote viewing was the better defined and more amenable to solution by currently known techniques. Those reports discussed the technical problems of remote viewing and suggested a possible test demonstration system involving many of the elements of a practical operational system. The current capabilities and state of development of Question-Answering (Q-A) techniques was also presented.

During the period covered by Contract No. NLM 69-13, two reports were issued ("Design of A Remote Access Medical Information Retrieval System," Status Report Mid-term, 11 August 1969, and "Design of a Remote Access Medical Information Retrieval System," Final Report, 6 November 1969) describing the results of the continuing research. During that period, the design of the remote viewing system was carried to the point where cost and development information was prepared for NLM budget estimation purposes. During the work it became apparent that budgeting for such a demonstration system would be delayed by at least one year.

During the same period, the Q-A techniques were applied to the problem of drug interactions. In conjunction with two Clinical Pharmacists in the University of California Drug Information Center a small data base was established. The system allowed the pharmacists to query this data base on the SRI SDS 940 from a remote terminal located at their own facility. The results of that usage were very encouraging and it appears that a good foundation has been laid for further expansion, usage, and evaluation of Q-A techniques through practical use of the system by clinical medical personnel.

As a result of our work to date and knowing the importance of such advances to the medical information retrieval problem, SRI is submitting this proposal to NLM for continued development and application of the Q-A systems and their associated data bases.

II OBJECTIVES

The objective of the proposed research program is to further develop the application of Q-A theory and techniques to practical medical information-retrieval systems. The proposed effort will carry forward the development of the techniques involved, including language processing theorem proving, and memory organization. The work proposed herein will be a logical addition to work already performed for NLM by SRI and will be augmented and benefited by other Q-A system work currently being performed for other clients by SRI.

The results of this research will provide further basic information regarding the timeliness and applicability of Q-A techniques to a broader spectrum of medical information-retrieval problems than has previously been possible.

III METHOD OF APPROACH

1. General

Discussions have been undertaken with clinical pharmacists at the U.C. Drug Information Center, and a representative of the Dept. of Pharmacology, Stanford School of Medicine to learn how best to advance the Q-A system, through practical applications in medical information retrieval, to the full potential of which we believe it capable. We propose that this can best be done in a three-step process by augmenting the currently implemented Q-A system with the requisite data to allow it to be of assistance to physician and pharmacist in several well-recognized clinical situations. Not only do these applications and their data bases build from the present capability, but they are evolutionarily compatible, in a medical and in an information-processing sense, with the more advanced applications to be discussed below.

2. Step 1: Q-A Applied to Drug-Drug-Interaction Information and Patient-Specific Data

The situation in which a physician is treating a patient in an out-patient clinic who has been or is being seen by other physicians is frequently encountered. Before prescribing treatment or drug therapy, the physician wants to check that there will be no adverse interactions, at least of which he is unaware, between the therapy he is considering and those being administered by other doctors. If the presently mechanized Q-A system,with its drug-drug interaction data base, were used to help the physician in the above case, it would be necessary for the doctor or the pharmacist of our pilot operation first to examine the list of drugs already being taken by the patient. He would then formulate and put to the system a separate question concerning possible interactions between the new drug he wishes to prescribe and each of those already being taken by the patient.

In the case being discussed, the patient-specific data can easily be added to the drug data base already available to the Q-A system. Given such a system, the inquiring physician would ask directly whether or not the drug he was considering for his patient, whom he would identify, would result in any interactions with any drugs his patient was already taking.

The input translator program would transform the question into a slightly more complex theorem to be proved than it does for questions asked of the Q-A system in the present system. Only slight modifications would be needed to the current Q-A system to allow it to handle questions of this sort.

After such modification and additions, a physician at a remote teletype terminal would be able to ask for a check of drug-drug interactions for a specific patient for whom he was proposing a new regimen of drug therapy. No physician would want to accept an answer generated from data stored in a computer without knowing something about the certainty of the data in general, how the information applied to his patient specifically, and the source and reliability of the data. The addition, to each axiom in the data bank of drug-drug interactions, of information about the first and last of these points can be accomplished quite easily. Included would be a capsule description of the experiment, considered to represent the latest and most authoritative word on the interaction in question, perhaps in a form similar to that in which it appears in the de Haen cards for "drugs in use." Selected references to the pertinent literature would also be carried with each drug data axiom.

We can briefly look at the implication of a practical system. An initial rough calculation shows that the total number of these references is probably of the order of 1500 for the drug-drug interaction data base. If each such article had an average of three pages, a microfiche store of 5000 pages would accommodate the pertinent literature. Approximately 50 microfiche, each containing 98 pages, could be stored near

the physician's input/output console for reading through a proximate portable viewer. The Q-A system would supply the reference information in terms of the microfiche I.D. number and the coordinates of the first page of the article. By having rapid access to a readable image of the actual article, the physician could satisfy himself, first-hand, about the applicability of the data to his patient. Furthermore, the time when he has his mind on a specific problem concerning a particular patient is the ideal moment, tutorially to present him with new information on the subject: his interest, understanding, and retention will be greatly enhanced by the situation in which he finds himself.

3. Step 2: Q-A and Drug-Test Interference

A wide variety of tests are given to patients to aid in the diagnosis of their diseases and to monitor the progress of treatment being administered to them. Unfortunately, the drugs that a patient is taking, to say nothing of the food he ingests, may cast doubt on the validity of the results of some of these tests and may even vitiate others. Consequently, it is important for a physician to rule out these possibilities in selecting tests for his patient.

The major interactions between tests and drugs have already been tabulated. The volume of data involved is approximately equal to that in our current drug-drug interaction Q-A data base. It has come to our attention that a very complete tabulation of drug-test interactions has been put on magnetic computer tape for computer use. This has been accomplished by investigators at the University of Pittsburg. We expect to receive a copy of this tape shortly. This information could be put into axiomatic form and added to the Q-A data base. These data also give information about the direction in which a drug affects the test results that are interfered with. Where the process is known, the interference mechanism is stated and references to the sources of the information in the journal literature are given.

With all this information as part of the Q-A data base a physician could learn about the possible invalidation, due to drugs, of the results of a test he wants to give to his patient. He would formulate a question seeking this information, in which he would name the test proposed and the patient. The input translation routine would transform the question into a theorem to be proved and the reply would identify the interfering drugs.

4. Step 3: Q-A Applied to Patient-Specific Data and Drug Side-Effect Information

It is felt that the practical second step in the evolutionary process would come from the addition to the system described in the first step, above, of data about the side effects, contraindications, and normal dosage limits of the 1000 most frequently prescribed drugs. This information would be added to the data base available to the Q-A system through the same mechanism that was suggested in the previous step for use with

the patient specific data. However, in the case of the side-effect data, medically skilled effort would be needed to reduce the information, including dosage limits, in such pertinent publications as: The Hospital Formulary of the American Society of Hospital Pharmacists; and Side Effects of Drugs, Vol. VI, by Meyler and Herxheimer, to the form needed for its statement as axioms.

For the system both in Step 1 and in this step, a dictionary will be needed in the computer memory to permit translation between trade and generic names of drugs. Such a dictionary must have approximately 5000 entries.

With the above described capabilities and data bases inhering in the Step-2 system, a physician who is about to prescribe a new drug-therapy regimen for a patient could frame a question to learn from the system all the possible side effects and contraindications for the proposed drug-dose combination for his particular patient.

In order for the system to be able to handle these questions, which are slightly more complex than the ones encountered in the Step-1 system, some small additions will have to be made to the Step-1 Q-A programs. As experience is gained with the use of the expanded system, it will be found that a few axioms must be added to the data base to allow the system to handle all of the questions put to it. Our experience with the current system in test operations with clinical-pharmacist users has demonstrated the need to add axioms that fill in gaps in the systems's knowledge about the world of drug therapy. For instance, it was discovered that although the data base indicated an interaction between coumarin (as a class) and barbiturates through the mechanism of enzyme induction, wrong answers could be obtained to questions seeking this interaction. The cure for the difficulty was the addition of an axiom the effect of which was to cause the system to ask the user whether or not the barbiturate regimen was begun before the coumarin therapy and, if it were, by how many days.

The important thing to note is that, when such deficiencies are discovered, only the addition of an axiom to the data base is needed to rectify the trouble; no programming is needed, as with most information-retrieval systems. In the application of Q-A techniques to medical information retrieval that has been outlined, the experimental operational use of the Step-2 system will undoubtedly help its evaluation as a practical tool for physicians. Such experimental and pilot operations will probably highlight the technical changes needed in the system to make it more efficient and useful. However, the most important insights to be gained in such tests are those into the best ways to represent medical knowledge in a Q-A system. These should include a perspective on the role of medical terminology; on the ways to axiomatize the knowledge; and on ways of representing the broad medical background, outside the area of clinical pharmacology, that an experienced practitioner brings to the drug therapy problem.

5. Summary of Remarks on Stepwise Evolution of the Q-A System

The three-step evolutionary development of the Q-A system just outlined is practical in two senses as a way of working toward the more challenging applications not yet been discussed. In the first sense, it addresses three related problems frequently encountered by many physicians in their clinical work: interference between tests and drugs; side effects, contraindications, and allowable maximum dosage levels (toxicity) for a drug to be prescribed to a patient; and probably interactions between the proposed drug and others the patient is taking. A Q-A system equipped with the requisite data bases can be an aid to any physician, especially those in a clinic environment. Furthermore, this system could have considerable self-tutorial value to medical students, interns, and residents. Patient data for a hypothetical set of diagnoses and clinical indications could be put into the data base. The learning physicians could then use the system to check their solution to the problem.

In the second sense, the three-step system development sketched in this section is possible and practical. The development can be achieved with reasonable effort starting with our present Q-A system and its data base of drug-drug interaction information.

Extremely important is the fact that the development of these techniques is required to provide the necessary information-retrieval capabilities to any remote-access medical information-retrieval system. Without such techniques the retrieval system will be limited to standard inquiry formats, stylized in nature and limited in value.

IV STATEMENT OF WORK

As reflected in our discussion in Section III above, SRI will direct its efforts toward the performance of:

(1) Adding patient-specific data to our current Q-A system drug interaction files and expand the Q-A system to accommodate the enlarged data-base potential.

(2) Adding drug-test data to the enlarged files of Item 1 above and further expand the Q-A system to accommodate this additional information.

(3) Adding drug side-effect information to the enlarged files of Item 2 above and further expand the Q-A system to accommodate this additional information. The complexity of the work under this item is more difficult to describe or estimate; therefore this work would procede in four steps, with the degree of completion depending upon each preceeding step. These steps include adding the information concerning:

(1) Clinical indications
(2) Contraindications
(3) Dose limits
(4) Side effects and their probabilities.

A technical report covering the work completed will be submitted within 30 days after completion of the project.

V GOVERNMENT FURNISHED EQUIPMENT

This proposal assumes that the SDS 940 computer will be replaced by a government-furnished PDP-10 facility by the end of 1969 on a rent free basis. The large core memory, more powerful instruction set, and better LISP implementation on the PDP-10 should result in large improvements in the efficiency of the experimental programming work described in this proposal. Since the new computer will be a dedicated facility purchased by the U.S. Government for the Automaton project we request that permission be obtained and granted to use the PDP-10 facility on this program on a non-interference basis.

It will then be necessary to transfer the present Q-A files and software from the current SDS 940 computer to the PDP-10 facility for the Automaton project. Any software transfer costs associated directly with the Automaton project will not be charged to the effort described herein.

VI PROJECT ORGANIZATION

A project of interdisciplinary nature such as this one will draw upon resources from several areas of SRI. The bulk of the effort will come from the Information Science and Engineering Division with a supporting role played by Life Sciences Division.

SRI plans to continue its relationship with the University of California Drug Information Center and the Stanford University School of Medicine, Department of Pharmacology, in the execution of this project. Dr. Oliver Whitby of the Applied Systems Group will serve as Project Leader for this work. He will be assisted by Drs. Stephen Coles and Charles Rosen of the Artificial Intelligence Group. Dr. Whitby will also draw upon the assistance of Life Sciences personnel when required.

Biographies of the above personnel and other potential contributors are included in Section X of this proposal.

VII ESTIMATED TIME AND CHARGES

The research described in this proposal will be completed in eight calendar months from execution of a contract. The cost for this research is estimated at $53,547. A breakdown of the costs is contained in the cost summary attached to this proposal.

VIII CONTRACT FORM

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

IX ACCEPTANCE PERIOD

This proposal will remain in effect untill January 1960. Should NLM require further time for consideration, SRI would be pleased to entertain such a request.

X QUALIFICATIONS OF STANFORD RESEARCH INSTITUTE

1. General

Stanford Research Institute is a nonprofit corporation engaged in a broad spectrum of basic and applied research and development prolems. The bulk of the effort for the work discussed in this proposal will come from the Information Science and Engineering (ISE) Division and the Life Sciences Division. Within ISE the work will be performed by two groups: the Applied Systems, and the Artificial Intelligence groups. Life Sciences will support the work as required from the Biomedical Research Department and the Chemical Documentation Section.

The capabilities of these various groups are summarized below.

2. Applied Systems Group

The Applied Systems Group is concerned primarily with the analysis, design, and evaluation of information-processing sytems. The work of the group includes both applied and basic study efforts relating to the design and implementation of such systems.

Members of the group have participated in the design of such systems as a nation-wide airlines space-reservation system, a nation-wide system for automatically processing and disbursing bank checks, the ground-based system for processing and distributing vidicon and infrared cloud pictures collected by the Nimbus weather satellite, a system for handling with greater accuracy the information in doctors' orders for the hospital patient, and an automated text-handling and printing system for a large publisher.

Examples of the group's analytic studies include development of improved methods for generating requirements and selecting criteria for the evaluation of the performance of information storage and retrieval systems; development of new design techniques for determining the conductivity, channel capacities, and network-control doctrines of both store-and-forward and real-time networks; and the development of approximate methods for analysis of queuing problems arising in the design of information systems.

In the experimental area, a broad program of research is being pursued in real-time man/machine systems aimed at developing concepts and techniques for improving the problem-solving ability of humans. Work is currently underway to develop methods applicable to such tasks as computer programming, information entry and retrieval, and data management.

3. The Artificial Intelligence Group

The Artificial Intelligence Group is concerned primarily with the exploration and practical implementation of systems to perform tasks normally thought to require human intelligence or supervision.

For over eight years, this group has been engaged in studies of pattern recognition, which is an essential part of artificial intelligence. Methods of classification, including "adaptive" or "learning machine" techniques, have been explored in depth, and several special-purpose machines have been built; in addition, many computer simulation studies have been performed. Applications have been made to character recognition, recognition of hand-printed graphical data, signal signatures, and weather prediction. A program is being pursued in depth for the sensing and classification of three-dimensional real-world objects.

A current project involves the development of a mobile automaton fitted with multiple sensors under the control of a large time-shared computer. Software includes routines for problem solving, pattern recognition of objects in the environment, and assembly--in computer memory--of models or representations of the environment as important aids for planning and problem solving.

A key underlying capability in the development of an automaton is the quality to analyze and answer questions, since what is a command from the supervisor's point of view appears as a question to be analyzed from the robot's point of view. This has led the Artificial Intelligence Group to develop an increasing depth of capabilities in certain key technologies of question answering. Particular emphasis has been put on language processing and theorem proving as a means of fact deduction.

4. Biomedical Research Department, Life Sciences Division

The Biomedical Research Department was formally organized three years ago and brings together the following disciplines and research interest categories: Biochemistry, Biochemical Pharmacology, Biophysics, Microbiology, Virology, Biochemical Laboratory Analysis Services and Clinical Research activities.

The majority of activities is directed toward education of drug metabolism pathways, solution of problems associated herewith, and contribution of new knowledge contributing to the understanding of mechanisms of drug actions. Clinical Research activities have involved the Phase I and II studies of Investigational New Drugs in the U.S. and abroad.

5. The Chemical Documentation Section, Life Sciences Division

The Chemical Documentation Section has, over the past four years, been involved in the development and implementation of a chemical coding system (via the Wiswesser Line Notation) and the generation of computer programs for the manipulation and display of the information contained in the system. This material has been primarily used in association with biological data (biological activity, toxicology, molecular properties) for the investigation of structure-activity relationships. The Section is operated by two practicing pharmaceutical chemists.

XI BIOGRAPHIES OF PROJECT PERSONNEL

JACK J. BIALIK, MANAGER, APPLIED SYSTEMS GROUP
INFORMATION SCIENCE LABORATORY
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Computer systems requirements analysis
- Man/machine information-handling system design
- Computer hardware evaluation
- Display system design
- Information handling system management

Representative research assignments at SRI (joined 1955)

- Analysis of the ADP requirements of a missile defense system
- Project leader for design of an ADP assisted editorial system
- Technical Monitor for requirement analysis and functional design of a command and control system to support USCINCEUR
- Project leader for analysis and evaluation of the use of large displays in military command and control systems
- Requirements analysis and initial system design for the ground data network of the NIMBUS weather satellite system
- Project leader for electronic display design for a desk calculator
- Project leader for system design and implementation of a ground based data-handling system to support an airborne reconnaissance system.
- Analysis and evaluation of the use of integrated circuits in certain low-cost instrumentation problems
- System checkout and modification, ERMA banking system
- Managerial responsibility for the installation and operation of a Burroughs 220 computer and a CDC 3100 computer at SRI

Other professional experience

- Convair Division, General Dynamics, 1950-55; Project leader, Model 70-B CRT display system; design and development of test equipment to evaluate Charactron display tubes; communications equipment design for ATLAS ICBM; Convair, design, installation and testing of special ship-based communications test equipment for TERRIER program
- 1st Lt., Communications Officer, USAAF, 1942-46

Academic background

- B.S.E.E. in communications (1950), University of Michigan

Publications and patents

- "Another Look at Team Contracting," IRE Trans. EM (June 1960)
- Author and coauthor of numerous classified and client private reports
- One patent pending for display system

WILLIAM T. COLWELL, ORGANIC CHEMIST
DEPARTMENT OF PHARMACEUTICAL CHEMISTRY
LIFE SCIENCES DIVISION

Specialized professional competence

- Organic synthesis
- Drug design
- Coding, computer manipulation, and biological activity vs. structure correlations of organic chemicals
- Drug metabolism studies

Representative research assignments at SRI (joined 1962)

- Syntheses of:
  - Antimycobacterial acetylenes
  - Psychomimetic alkaloids
  - Mon-steroidal aldosterome antagonists
  - Insect chemosterilants
  - Anti-parasitic drugs
- Metabolism of diaminodiphenyl sulfone in animals and humans
- Coding various chemical files into Wiswesser line notation, development of computer programs to handle this information, structure-activity studies based on this work.
- Development of data base for medical remote-browsing system

Other professional experience

- Research staff of Richfield Oil Co. during vacations
- Research and teaching assistant at the University of California, Los Angeles

Academic background

- B.S. (1956) Occidental College
- Ph.D. (1962), University of California, Los Angeles

Publications

- Coauthor, "5,5-Diarylpenta-2,4-Dienoic Acid Amides II, J. Med. Chem., 12, 946 (1969)
- Coauthor, "Structure/Activity Relationships of Sulfones," 4th Annual Leprosy Research Conference, 1969
- Coauthor, "Blood and Urinary Metabolism of Diaminodiphenyl Sulfone," Submitted for publication
- Author and coauthor of several other Publications issued in various journals

Professional associations

- American Chem. Soc.
- Sigma Xi
- Phi Lambda Upsilon

CHARLES A. ROSEN, MANAGER
INFORMATION SCIENCE LABORATORY
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Artificial intelligence
- Pattern recognition
- Solid-state devices (especially piezoelectric)
- Electron physics

Representative research assignments at SRI (joined 1957)

- Developed the Electron Physics Group and the Artificial Intelligence Group, as group manager
- Development of mobile automaton system
- Pattern-recognition and learning-machine studies and applications
- Development of microelectronic devices and systems

Other professional experience

- Assistant Head, Transistor Circuit Group; Head, Dielectric Devices Group; Consulting Engineer, Dielectrics and Magnetics, General Electric Company
- Manager of Radio Department and Spot Weld Department, Fairchild Aircraft, Canada
- Technical investigations for radio and instruments, British Air Commission
- Co-owner, Electrolabs Reg'd., Montreal, Canada, Alarm Intercom Systems
- Lecturer, Stanford University, piezoelectric and ferroelectric devices

Academic background

- B.E.E. (1940), Cooper Union Institute of Technology
- M.Eng. in communications (1950), McGill University
- Ph.D. in electrical engineering (minor in solid-state physics) (1956), Syracuse University

Publications and patents

- Coauthor of Principles of Transistor Circuits, R. F. Shea, editor (John Wiley and Sons, Inc., 1953)
- Coauthor of Solid State Dielectric and Magnetic Devices, H. Katz, editor (John Wiley and Sons, Inc., 1959)
- Author or coauthor of several papers in the fields of piezoelectric devices, learning machines, pattern recognition
- Six patents relating to solid-state devices

Professional associations

- Senior Member of the Institute of Electrical and Electronics Engineers
- Member of the American Physical Society
- Member of the Scientific Research Society of America

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

Specialized professional competence

- Computational linguistics
- Question-answering systems

Representative research assignments at SRI (joined 1967)

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

Other professional experience

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

Academic background

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

Publications

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

Professional associations

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

OLIVER W. WHITBY, STAFF SCIENTIST
INFORMATION SCIENCE LABORATORY
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Information storage and retrieval system design
- Command information system design
- Airline operational management information system design
- Wire communication system analysis

Representative research assignments at SRI (joined 1949)

- Preliminary design of a command information system for a top-level naval staff that could be adapted by the staff to new situations
- Analysis of the real-time operating system for an ABM computer
- Analysis and general design of a nation-wide remote-browsing system (remote viewing and automatic question answering) for U.S. physicians
- Feasibility study of the telephone network for national emergency warning
- Design and specification of the passenger reservation system for a transcontinental air carrier
- Writing specs. and evaluating manufacturers' bids for a large operational management information system for a transcontinental air carrier
- Research on new techniques for message flow control and network reconstitution in a military communication network
- Design study of performing all functions in a high-speed photographic printer by a built-in, small-scale computer

Other professional experience

- Research Associate, Radio Research Laboratory, Harvard University, 1945-46; research on airborne radio direction finding for a large radar countermeasure program involving overseas field work
- Research Associate, Harvard University, 1940-43; taught basic electronics in officer's preradar training course
- Receiver design engineer, Northern Electric Company, 1938-39

Academic background

- B.Eng. (1938), McGill University, Montreal, Canada
- S.M. (1940), Harvard University
- S.D. in communication engineering (1949), Harvard University

Publications

- Author, "Information for Production Planning and Control," delivered at the First Lustrum of the Genootschap Studiecentrum Voor Administratieve Automatiseering, Eindhoven, Holland, April 1965
- Coauthor of SRI reports on airline reservations systems, advanced communication network design and control techniques, command information systems, telephone warning networks, and remote browsing
- Coauthor, "Output Analysis and Alignment Techniques for Phase-Rotation Single Side-Band Transmitters," AIEE Trans. (1951)

Professional associations and honors

- Senior member-Institute of Electrical and Electronic Engineers
- IRE Representative to the 1955 Western Joint Computer Conference
- Conference Manager, 1954 Western Joint Computer Conference