independence. We also hope to incorporate an explanation system to justify the decisions made by the program, which we feel is important for the same reasons MYCIN needed this capability. A new model builder will also be implemented to increase the speed and generality of 3-D model building.

The metabolism project development will parallel the SECS project, but has special requirements for ALCHEM and aromatic chemistry, as well as for a pattern recognition module. A major problem here is how to develop and maintain such a complicated data base on metabolism. We expect to benefit from the experience gained by others in the medical diagnosis programs.

We hope at UCSC to have some local data handling capability such as printing, plotting, and tape handling to facilitate our work. Of course interactive graphics will continue to be our method of man-machine communication and we plan to add a GT-44 graphics terminal in the near future to expand current capability. Another graphics terminal is planned for the more distant future. We would continue to depend on SUMEX for host computing and file storage. We would hope that higher speed communication lines might become possible in the future.

B. Justification for Continued use of SUMEX by Our Project:

The SECS project requires a large interactive timesharing capability with high level languages and support programs. UCSC is not likely in the future to be able to provide this kind of resource. Thus from a practical standpoint, the SECS project really needs access to SUMEX for survival. Scientifically, interaction with the SUMEX community has been extremely important to the SECS project. Many of our future goals involve incorporation of ideas from other AIM projects into the chemical synthesis project. We would like to believe some of the ideas from the SECS projects are also influencing other AIM projects.

Our metabolism project requires collaboration with the metabolism experts at the National Cancer Institute 3000 miles away. The networking aspects of SUMEX-AIM will be very valuable to this important project. Several collaborations for development of strategies in SECS are being also planned and would require networking.

C. Comments and Suggestions for Future Resource Goals,
Development Efforts, etc:

From our standpoint multiplexing to Stanford might give us higher speed communication for graphics and file transport. Development of MAINSAIL seems important, but until that materializes, support of FORTRAN and standard DEC compatibility is crucial to the SECS project. FORTRAN-10 and LINK-10 are becoming the DEC standard and provide overlay capabilities which are needed in moving programs from machines with virtual memory to ones with limited memory.

It would be useful if there were a good file transfer program--the standard DEC FAILSAFE should be implemented so we can send out files and have their names, versions, etc preserved. It would also be convenient to have a way to send files over TYMNET and TELENET to other machines. We could use this in updating programs at First Data Corporation.

The SUMEX-AIM resource should have an annual workshop for the individuals actually implementing and building systems on SUMEX--the students, postdocs, etc. The purpose of this would be to spread innovation and techniques as well as actual sharing of programs among users of SUMEX. It would also be an opportunity to plan collaborations, development software, and plans for SUMEX. Importantly, it would also develop personal contacts to compliment network contacts. This could be in conjunction with or in addition to the current annual AIM workshop. The current AIM workshop should alternate between coasts.

6.2.3 HIGHER MENTAL FUNCTIONS PROJECT

Modeling of Higher Mental Functions

Kenneth M. Colby, M.D.
Professor of Psychiatry and Biobehavioral Sciences
University of California at Los Angeles

I) Summary of Research Program

A. Technical Goals:

There are three technical goals of the Higher Mental Functions Project:

(1) To improve and "therapeutically" experiment with a computer simulation of paranoid processes in order to make treatment recommendations to clinicians based on experience with the model.

(2) To develop a new taxonomy of psychiatric patients based on the conceptual patterns appearing in accounts of their illnesses.

(3) To develop an intelligent speech prosthesis for patients suffering from communication disorders.

B. Medical Relevance and Collaboration:

The Higher Mental Functions Project is located in the Neuropsychiatric Institute at UCLA. The medical relevance of its research concerns the fields of psychiatry and neurology. The Project collaborates with clinicians and investigators in psychiatry, neurology, the neural sciences and neurolinguistics.

C. Progress Summary:

We have improved the paranoid model to the point where it can be utilized for therapy experiments. (The model has now passed a true Turing Test in which it cannot be distinguished from real patients.)

The taxonomy effort is just under way, using the language recognition program which serves as the front end of the paranoid model. This program will have to be added to and modified to serve the purpose of finding and classifying the conceptual patterns appearing in patients' accounts of their illnesses.

We have interfaced a micro-processor with a voice-synthesizer to provide a speech prosthesis for patients unable to speak. The next step is to write an "intelligent" algorithm which attempts to figure out what the patient is trying to say from his partial input information.

D. Funding Status:

(1) Current funding. This project is currently funded by research grant NIMH MH 27132-02 and by a General Research Support Grant from the UCLA Neuropsychiatric Institute.

(2) Pending applications and renewals. Four additional grant applications have been submitted and are pending at the NIH for support of the above-described research.

II. Interactions with the SUMEX-AIM Resource

A. Collaborations:

The project collaborated with Professor Jon Heiser, Department of Psychiatry, University of California, Irvine, and consulted with Professor Robert K. Lindsay, Department of Psychology, University of Michigan, in conducting a Turing Test of the paranoid model. Other users of SUMEX have received advice and suggestions regarding their problems as well as opportunities to contrast their simulations with ours. We have benefitted greatly from others' comments on the adequacy and inadequacy of our paranoid model.

B. Sharing, etc.:

Members of the project have participated in two workshops held at Rutgers, presenting several papers, chairing panels, and conducting discussion groups. Informal discussions with large numbers of workers in Artificial Intelligence in Medicine have led to a helpful sharing of ideas and techniques. SUMEX is valuable to us as a communication channel combining the advantages of a telephone and the U.S. mail without the disadvantages of either. For widely scattered researchers, it facilitates the intimate, low-level communication which is normally accomplished in hallways or around water coolers. The individual discussions are not very profound, but the cumulative effect subtly improves our research.

The existence of SUMEX as an independent project naturally relieves numerous researchers of the burden of separately financing and staffing a large computer facility.

C. Critique of Resources:

The few complaints we had regarding difficulties of network access have been remedied. The computer system performance is admirable with the staff being most receptive to suggestions.

III. Follow-on Period

A. Long-range Project Goals:

We anticipate working on the above-described projects for at least 5 years or more. The problems are highly complex and will require years of sustained effort to solve.

B. Justification for Continued Use of SUMEX:

The paranoid model and the conceptual pattern recognizer require a large time-shared computer because of the large size (100K) of these programs written in a high-level programming language (MLISP-UCI LISP). The speech prosthesis effort does not require a large system in itself because it stands as an independent unit. However, for constructing and developing dictionaries for types of speech prostheses, it is most efficient to do this on a large and fast system such as SUMEX.

C. Comments and Suggestions for Future Research Goals:

It seems that the resource fulfills all of its stated goals of facilitating research in the field. The only drawback is that there isn't more of a good thing. Doubling the computing power and memory storage capabilities would not be unreasonable.

D. Up-to-date List of Publications:

Colby, K.M., Parkison, R.C. and Faught, B. Pattern-matching Rules for the Recognition of Natural Language Dialogue Expressions. Am. J. Computational Linguistics, Microfiche 5, Sept., 1974.

Colby, K.M. Clinical Implications of A Simulation Model of Paranoid Processes. Archives of General Psychiatry, 33, 854-857, 1976.

Faught, W., Colby, K.M. and Parkison, R.C. Inferences, Affects and Intentions in A Model of Paranoia. Cognitive Psychology, 9, 153-187, 1977.

Colby, K.M. An Appraisal of Four Psychological Theories of Paranoid Phenomena. J. of Abnormal Psychology, 86, 54-59, 1977.

Parkison, R.C., Colby, K.M. and Faught, W.S. Conversational Language Comprehension Using Integrated Pattern Matching and Parsing. Artificial Intelligence (In Press) 1977.

Colby, K.M., Christinaz, D. and Graham, S. A Computer-driven, Personal, Portable and Intelligent Speech Prosthesis for Aphasic Disorders. Brain and Language (In Press) 1977.

Colby, K.M. On the Way People and Models Do It. Perspectives in Biology and Medicine (In Press) 1977.

Heiser, J., Colby, K.M., Faught, W. and Parkison, R.C. Testing Turing Test (Forthcoming).

Faught, W.S. Conversational Action Patterns in Dialogs. Proceedings of the Workshop on Pattern-directed Inference Systems, May, 1977.

6.2.4 INTERNIST PROJECT

INTERNIST - Diagnostic Logic Project

J. Myers, M.D. and H. Pople, Ph.D.
University of Pittsburgh

I. SUMMARY OF RESEARCH PROGRAM

A. Objectives

The principal objective of this research project has been and continues to be the development, evaluation, and implementation of a computer-based diagnostic consultation system for internal medicine. This work, which was initiated at the University of Pittsburgh approximately six years ago, has been supported for the past three years by a grant from the Bureau of Health Resources Development. A heuristic diagnostic program called INTERNIST has been developed, along with an extensive medical database now comprising more than four hundred disease categories and two thousand manifestations of disease. The system has been tested with a wide variety of difficult clinical problems: cases published in the medical journals, CPC's, and other interesting and unusual problems arising in the local teaching hospitals. In the great majority of these test cases, the heuristic INTERNIST program has proved to be effective in sorting out the pieces of the puzzle and coming to a correct diagnosis. In some cases, as many as six distinct disease entities have been identified correctly.

We believe that by the time of the expiration of the BHRD grant in June, 1977, our original objective, which was to develop a system providing expert diagnostic capability with regard to the major diseases of internal medicine, will have been accomplished to the extent possible in the current laboratory framework.

At that time, we propose to initiate a broader collaboration, which will invite the participation of remote users in

(a) further evaluation of the INTERNIST programs and data-base.

(b) development of specialized data-bases and procedures for various medical subspecialties.

(c) refinement of the user interface.

(d) investigation of alternate uses of the INTERNIST data-base.

We believe that the expansion of the experience base of INTERNIST users, which will result from this type of collaboration, will significantly enhance the further course of INTERNIST development.

B. Progress Summary

Expansion of the medical data-base to encompass new areas of disease is an on-going activity of the project. Much of this work is carried out by medical students who elect to take part in the project as part of their fourth year clinical rotation, with the period of participation varying from 6 to 18 weeks.

Each student is assigned a group of diseases, usually in a specific clinical area, for study. The literature on a disease is studied exhaustively for all quantitative data available. Frequently clinical experts on the faculty are consulted, particularly about controversial data. The student compiles a complex list of the manifestations of the disease under study and assigns tentative measures of strength of association.

The clinical principal investigator together with any other clinicians working on the project then review the data exhaustively in order to assure the appropriateness and completeness of the disease profile.

The profile is then entered into the computer and tested for completeness and reliability against a typical or "textbook" example of clinical cases. If available, other cases of the disease from the floors of our university hospital and from published cases such as the clinical-pathological conferences from the New England Journal of Medicine and the American Journal of Medicine are also used. Further refinement occurs in the course of the continued use of the data-base.

In addition to this data-base development, work on a refined diagnostic program has also been an on-going activity during this period.

The present INTERNIST process employs a 'problem - formation' heuristic, which identifies one of perhaps several problems in a clinical case as its initial focus of problem-solving attention. Although only one problem is considered at a time, the process recycles after each problem is solved, thereby uncovering the entire complex of diseases present. In the great majority of clinical cases tested, this strategy of iterative problem formation and solution has proved to be effective in sorting out the complexities of a case and rendering a correct diagnosis. In many respects, however, it seems clear that performance could be significantly enhanced if the program were to attend to the various component problems and their inter-relationships simultaneously. Use of a more global problem - formation strategy could be expected to yield more rapid convergence on the correct diagnosis in many cases, and in at least some cases to prevent missed diagnoses.

Alternative problem formation strategies that exploit the type of pseudoparallel processing facilitated by the INTERLISP 'spaghetti stack' are presently being investigated. We believe that this research will also set the stage for subsequent development of a therapeutic management component of the INTERNIST consultation facility; however at the present time it is not possible to project a precise timetable for the development of these additional capabilities.

C. Publications

1. Pople, H.E., Myers, J.D., & Miller, R.A., "The DIALOG Model of Diagnostic Logic and its use in Internal Medicine". Proceedings of the Fourth International Joint Conference on Artificial Intelligence, Tbilisi, USSR, September 1975.

2. Pople, H.E., "Artificial-Intelligence Approaches to Computer-based Medical Consultation, Proceeding IEEE Intercon, New York, 1975.

3. Pople, H.E., "The Syntheses of Composite Hypotheses in Diagnostic Problem Solving: An Exercise in Hypothetical Reasoning". Proceedings of the Fifth International Joint Conference on Artificial Intelligence, August 1977 (forthcoming).

D. Funding Status

1. Current Funding:
   Granting agency - BHRD; Number: 1 R01 MB 00144-03
   Total period of the award - 3 years (6-30-74 to 6-29-77)
   Current year of the award - 1977
   Current annual funding - 148,636

2. Pending Applications:
   1. Granting agency - NIH; Title: Clinical Decision Systems Research Resource
      First year request - 1,023,883

   2. Granting Agency - BHRD; Title: DIALOG: A Computer Model of Diagnostic Logic
      Fourth year request - 190,176

II. INTERACTION WITH SUMEX-AIM RESOURCE

A. Medical Use of Programs and Collaborations

Because of the research and development nature of our work on the INTERNIST system over the past several years, we have been somewhat limited in our ability to establish wide-spread collaborations. However, members of the medical house staff in the local hospitals having some prior experience with the project have continued to work with INTERNIST while pursuing their medical training. In addition, project staff often have occasion for interaction with individuals and groups who have interest in the characteristics of the diagnostic system from both medical and computer science perspectives. Future plans for more extensive collaboration are discussed in section III.

B. AIM Interactions

We have benefitted considerably from interactions with other members of the SUMEX-AIM community. In June '76 we participated in the AIM workshop at Rutgers, which provided an excellent perspective as to what else is going on in the field. During the past several months we have had useful exchanges with Randy Davis, Victor Yu, and John Foy, three individuals participating in the MYCIN project. In addition, we rather routinely interact with SUMEX staff regarding fine points and problems relating to our use of system facilities.

The opportunity to keep abreast of developments in a fast changing field is one of the principal benefits to be derived from the collegial environment fostered by SUMEX-AIM.

C. Critique Of Services

We have found the SUMEX-AIM resource to be a superb facility for the conduct of research and development activities related to the INTERNIST project. The general high level of user services, documentation, staff support and reliable operation, which characterizes this unique resource, has contributed significantly to the rate of progress our project has achieved.

III. <u>FOLLOW-ON SUMEX GRANT PERIOD (8/78 - 7/83)</u>

A. Long-Range User Project Goals And Plans

Continued research and development of the medical data base and diagnostic programs characteristic of our past and current work at SUMEX in anticipated.

We estimate that two to three years will be required to complete the medical data-base presently envisioned for INTERNIST. However, by the end of this grant period (June 30, 1977) we expect that the knowledge base should have reached "a critical mass" sufficient to allow initial clinical trial on a routine basis.

Sometime in mid-1977, we intend to begin limited field trials of the INTERNIST system by installing terminals in selected wards of Presbyterian University Hospital in Pittsburgh. A number of the members of the house staff have indicated their desire to participate in the evaluation studies, and several have expressed willingness for all cases entering their service to be run and rerun as necessary, in order to enhance our understanding of the strengths and weaknesses of the INTERNIST system.

As we move from the R&D stage to this more production-oriented phase of activity, it seems inevitable that the requirements for support of INTERNIST activities will become increasingly incongruous with the general purpose nature of the facility provided by SUMEX.

Our expectation is that on the services initially supported at Presbyterian University Hospital, there will be as many as 20 INTERNIST case analyses run each day. Based on our experience operating INTERNIST at SUMEX, we would anticipate that each of these studies would require 3 to 5 minutes of CPU time and entail an elapsed time on the order of 30 to 50 minutes during lightly loaded periods on the system. We have also found, however, that the only feasible time to perform such studies is in the early morning hours, and that by 11:00 or 12:00 Eastern time the response provided by SUMEX is unacceptable for such activities.

While marginally capable of supporting the heavy case load anticipated in the local evaluation studies, SUMEX-AIM will clearly not serve the more extensive collaboration - involving up to 6 remote user sites - which is presently contemplated for the second stage of field evaluation which we hope to have underway before January 1978.

We believe it to be critically important during these field trials, that highest priority be given to providing a responsive system, scheduled for the convenience of those clinical personnel asked to participate in the project. This suggests that dedicated hardware facilities, which can be optimized to support this central user service, be made available for the exclusive use of INTERNIST staff and collaborators.

For this purpose, we have proposed to NIH the establishment of a Clinical Decision Systems Research Resource, which would be a node in the AIM network having DECSYSTEM-20 hardware and software, a TYMNET interface, and the specialized mission described above.

Our hope is that this new facility can be in operation by January 1, 1978.

B. Justification For Continued USe of SUMEX By The INTERNIST Project

SUMEX will be used in the initial field trials of INTERNIST, which we hope can be accomplished without overload and interference with the work of other users. With establishment of a dedicated INTERNIST resource, this production case load will be removed from SUMEX, but at present it is not possible to define precisely when this changeover will take place. In any case, a continuing research effort requiring SUMEX facilities can be expected to require approximately the same level of resource utilization as in the past.

C. Comments and Suggestions

1) The members of the INTERNIST project agree that the plans to augment the SUMEX resource by the addition of more core memory and disk storage and retrieval facilities can be expected to provide quite tangible improvement in system performance.

2) In the experience of developing program access to the large INTERNIST data base, project members have perceived the potential value of a general system designed to facilitate the interface of user programs and structured data-bases. We would be interested in collaborating with the SUMEX staff in such a development, which might prove beneficial for the user community at large.

3) Another potentially valuable research area would be the investigation of methods to provide support for a project's efforts to improve real-time performance of its programs. While the design of program specific algorithms must be the concern of project staff, it is in the interest of the SUMEX community that user's be provided with information and tools to enable efficient use of SUMEX' languages and operating system. This is one of few areas in which we have found documentation of system features and facilities to be less than adequate. Perhaps special performance workshops, involving systems personnel from the various AIM sites, could be convened to address these issues.

6.2.5 MEDICAL INFORMATION SYSTEMS LABORATORY

MISL - Medical Information Systems Laboratory

M. Goldberg, M.D. and B. McCormick, Ph.D.
University of Illinois at Chicago Circle

I) SUMMARY OF RESEARCH PROGRAM

A.) TECHNICAL GOALS

The Medical Information Systems Laboratory (MISL) was established under grant HM-0114 in Chicago to pursue three activities: i) Construction of a database in ophthalmology, ii) Clinical knowledge system support, and iii) Network-compatible database design. Priorities in year 04 of MISL's operation are the same as in previous years: investigations into how to construct a database in ophthalmology, and into distributed database design, are ancillary to the exploration of a clinical knowledge system to support clinical decision making. We are developing ways to get reliable clinical information into the ophthalmic database primarily because we are interested in getting out significant clinical decision support.

B) APPROACH AND MEDICAL RELEVANCE

B.1) Construction of the database in Ophthalmology

A specific aim of this project is to construct a workable database in ophthalmology, using the outpatient population of the Illinois Eye and Ear Infirmary. We view this database as a testbed for developing clinical decision support systems. The Ophthalmology Department of the Illinois Eye and Ear Infirmary provides an excellent environment for evaluating new techniques for capturing and using clinical information.

B.2) Clinical knowledge support system

The goals for clinical knowledge system development are to provide a flexible user interface for a prototype relational database system, to devise means of accessing alphanumeric and pictorial information stored in the database system, and to provide efficient means for logically restructuring a database so that it can be adapted to different operating environments in a network-compatible distributed medical information network.

No clinical database, however, has intrinsic significance beyond its ability to support the diagnosis and management of disease. Additional goals for the clinical knowledge system are therefore to devise computer-based consultation systems for glaucoma and selected retinal/choroidal diseases, and to provide formal models which permit the relational development and evaluation of rule-based consultation systems containing 2,000 - 10,000 rules. In recognition that a continuum exists between physician-guided decision support and computer-based consultation, we choose to describe these services as a Clinical Knowledge System: a consortium of a clinical database and rules for its interpretation.

C) PROGRESS SUMMARY (INCLUDING ITEMS OF INTEREST TO SUMEX-AIM COMMUNITY ONLY)

C.1) The database in ophthalmology

Physician terminals and interfaces to ophthalmic instruments have been positioned in the general eye clinic and several key ophthalmic subspecialty clinics. Systematic, modular hardware and software for clinical source data acquisition have been established. The clinical support system computer will shortly be transfered to the newly dedicated Goldberg Research Center, adjacent to the Illinois Eye and Ear Infirmary. We look forward to stabilizing the hardware configuration, telecommunication linkages and software support.

C.2) Clinical knowledge system support

C.2.a) Development of the relational database includes the following:

- A user interface through which unsophisticated users communicate with the database.

- An intelligent coupler that serves as an intermediary between the end user and the distributed database system. The coupler listens to the user's retrieval requests; helps the user formulate his requests correctly; efficiently translates user's retrieval requests into a network-compatible retrieval command language; and obtains authorization from the system for data retrieval and/or update.

- Tools for picture data management. Graphical indexing techniques are provided so that the clinical researcher and physician can easily retrieve pictorial/graphical information from the medical database.

- Means for logical database synthesis. This involves conversion of the user's view of the database into a logically coherent physical organization.

C.2.b) Development of a computer-based consultation system for diagnosis and management of glaucoma.

This involves on-going collaboration between Dr. Jacob Wilensky at MISL, and, through SUMEX-AIM, other investigators around the United States. Included are the original investigators in glaucoma consultation: Dr. Casimir Kulikowski (Rutgers), Dr. Shalom Weiss (Mt. Sinai Hospital, NY), and Dr. Aaron Safir (Mt. Sinai Hospital).

C.2.c) Development of a consultation system for diagnosis and management of retinal/choroidal diseases.

A design has been proposed (in Walser and McCormick, see below) for MEDICO, a consultation system that advises non-expert physicians in the management of chorioretinal diseases. In addition, a major subsystem of MEDICO, responsible for mediating the acquisition and organization of rules, has been implemented.

C.2.d) Formal models for consultation systems.

Petri nets have been studied, primarily by Murata (see below), as a formal representation for interacting parallel processes. Petri nets are similar to causal networks, as described by Kulikowski and Weiss at Rutgers, except that, with Petri nets, cyclic activity is easily represented. The similarity between Petri nets and inference nets has also been noted (Walser and McCormick). The utility of the Petri net framework for modelling physical processes was explored by Walser, with the construction of a simulated coffee maker. Further studies are planned.

D.) LIST OF MISL PUBLICATIONS

Chang S. K., Donato N., McCormick B. H., Reuss J., and Rocchetti R. (1977) A relational database system for pictures. Proc. IEEE Workshop on Picture Data Description and Management, April 20-22, 1977, Chicago, Illinois.

Chang S. K. and Cheng W. H. (1976) A database skeleton and its application to logical database synthesis. MISL report M.D.C. 1.1.17.

Chang S. K. and McCormick B. H. (1975) An intelligent coupler for distributed database systems. MISL report M.D.C. 1.1.7.

Malone, J. E. (1976) Interval generalization of structure representation. MISL report M.D.C. 1.1.22.

Malone J. E. (1975) User's guide to uniclass cover synthesis. MISL report M.D.C. 4.4.1.

Malone J. E. (1975) Addendum to AQVAL/1 (AQ7), part 1: User's guide and program description. MISL report M.D.C. 4.4.1.

Manacher G. K. (1977) The case for strong loops and selection structures in ordinary computer languages. MISL report M.D.C. 1.1.21.

Manacher G. K. (1975) On the feasibility of implementing a large relational data base with optimal performance on a minicomputer. Proc. International Conference on Very Large Data Bases, Framingham, Mass.

McCormick B. H. and Nordmann B. J. Jr. (1977) Modular asynchronous control design. Forthcoming in IEEE Transactions on Computers. Also MISL report M.D.C. 1.1.25.

McCormick B. H. and Amendola R. C. (1977) Cytospectrometers for subcellular particles and macromolecules: design considerations. Presented at Workshop on Theory, Design and Biomedical Applications of Solid State Chemical Sensors, Case Western Reserve University, March 28-30, 1977. Also MISL report M.D.C. 1.1.24.

McCormick B. H. and Wilensky J. (1975) Clinical knowledge acquisition: design of a relational data base in ophthalmology. Proc. Second Annual Medical Information Systems Conference, Urbana, Ill.

McCormick B. H., Goldberg M. F., and Read J. S. (1974) Clinical decision-making: design of a data base in ophthalmology. Proc. First Annual Medical Information Systems Conference, Urbana, Ill.

Michalski R. S. and Chang S. K. (1976) A self-model for a relational database. MISL report M.D.C. 1.1.16.

Michalski R. S. (1975) On the selection of representative samples from large relational tables for inductive inference. MISL report M.D.C. 1.1.9.

Murata T. (1976) On liveness and other properties of E-Nets. MISL report M.D.C. 1.1.15.

Murata T. (1976) Bibliography on Petri nets and related topics. MISL report M.D.C. 1.1.20.

Murata T. (1976) A method for synthesizing marked graphs from given markings. Presented at 17th Annual Symposium on Foundations of Computer Science, October 25-27, Houston, Texas.

Murata T. (1976) On deadlock and the liveness of E-nets. Presented at the 17th Annual Symposium on Foundations of Computer Science, October 25-27, Houston, Texas.

Murata T. (1975) State equation, controlability, and maximal matchings of Petri nets. MISL report M.D.C. 1.1.10.

Murata T. and Church R. W. (1975) Analysis of marked graphs and Petri nets by matrix equations. MISL report M.D.C. 1.1.8.

Vere S. A. (1975) Induction of concepts in the predicate calculus. Proc. Fourth IJCAI.

Vere S. A. (1975) Relational production systems. Forthcoming in Artificial Intelligence. Also MISL report M.D.C. 1.1.5.

Walser R. L. and McCormick B. H. (1976) Organization of clinical knowledge in MEDICO. Proc. Third Illinois Conference on Medical Information Systems, Urbana, Ill.

Walser R. L. and McCormick B. H. (1977) A system for priming a clinical knowledge base. Forthcoming in Proc. 1977 National Computer Conference, June 13-16, Dallas, Texas.

E.) FUNDING STATUS

Year 03 -- 6/30/76 - 6/30/77: $228,000.
Year 04 (projected, pending renewal) -- 7/1/77 - 6/30/78: $278,109.

II) INTERACTION WITH SUMEX-AIM RESOURCE

A.) COLLABORATION

Major collaboration at present is through the ONET, involving the ophthalmology departments of five medical schools. Dr. Jacob Wilensky is actively engaged in evaluating and modifying the Glaucoma Consultation Program, written originally by Shalom Weiss.

B.) CRITIQUE OF RESOURCE SERVICES

Users at MISL are pleased with SUMEX-AIM services. The availability of up-to-date on-line documentation makes it easy to learn how to use the system and stay abreast of new developments. The on-line bulletin board is especially commendable. Since documentation is so readily available, consultation with SUMEX staff has rarely been necessary.

III) FOLLOW-ON SUMEX GRANT PERIOD

A.) LONG RANGE USER PROJECTS AND GOALS

In the future, we expect to become more involved in the development of software for decision support. We also anticipate more extensive collaboration, especially sharing of databases, with investigators at other sites.

B.) SPECIFIC PROJECTS AND JUSTIFICATION FOR CONTINUED USE OF SUMEX

While much of our development to date has been conducted in a minicomputer environment, we have now reached a stage at which we can benefit greatly from software available from SUMEX. Access by our staff to SUMEX facilities and opportunity for inter-institutional collaboration will be enhanced by a SUMEX (PDP-10) - MISL (PDP-11) phone connection, which we plan to implement shortly. This connection will be valuable to our decision support group, since it will be possible to develop and test programs in INTERLISP at SUMEX, then to translate them into the lower level HARVARD LISP, which is available on our UNIX (PDP-11) operating system. It will also be possible to edit programs on our machine (which is an advantage for us since we can operate at 9600 baud), then execute the programs on the SUMEX PDP-10.

Also, using SUMEX, we have recently implemented the planning system described by Earl Sacerdoti in his thesis "A structure for plans and behavior" (Stanford, 1975). We are impressed by the potential power of the system and are considering it as a basis for our consultation system for managing chorioretinal diseases. Since our version has only been tested in a blocks world, further development is necessary, and we would, of course, require continued access to SUMEX and INTERLISP.

It has also been proposed that the planning system be used to construct sequences of database retrieval statements in RAIN, a relational algebraic interpreter developed by Dr. S. K. Chang at MISL. This could benefit our user interface, since physician's requests could be phrased at a high level, and then translated into appropriate RAIN commands. The planning system provides a convenient, procedural representation for the database semantics necessary to make the translation from a high level language.

INTERLISP is also being used by Dr. Brian Phillips and his students to code a model of knowledge developed over a period of years at the State University of New York at Buffalo, and later in the Department of Information Engineering and MISL in Chicago. While the model of knowledge is well-developed, and has been implemented at another site in SNOBOL, the INTERLISP version requires further work. It is anticipated that the implementation, when complete, will be useful to the decision support group.

C.) SUGGESTIONS FOR FUTURE RESOURCE DEVELOPMENT EFFORTS

As mentioned above, we are very interested in coupling our PDP-11 based UNIX operating system with the SUMEX-AIM network. and would like to encourage similar connections at other sites. There are several advantages. Maintaining voluminous patient-related data on minicomputer systems would provide for local security, and help to keep SUMEX secondary storage free for service and development programs and documentation. The enhanced opportunity for inter-site collaboration and database sharing is obvious, and would be beneficial to the SUMEX-AIM community as a whole.

6.2.6 RUTGERS COMPUTERS IN BIOMEDICINE

Rutgers Research Resource - Computers in Biomedicine

Principal Investigator: Saul Amarel
Rutgers University, New Brunswick, New Jersey

I) SUMMARY OF RESEARCH PROGRAM

A) Goals and Approach

The fundamental objective of the Rutgers Resource is to develop a computer based framework for significant research in the biomedical sciences and for the application of research results to the solution of important problems in health care. The focal concept is to introduce advanced methods of computer science - particularly in artificial intelligence - into specific areas of biomedical inquiry. The computer is used as an integral part of the inquiry process, both for the development and organization of knowledge in a domain and for its utilization in problem solving and in processes of experimentation and theory formation.

The Resource community includes 48 researchers - 30 members, 8 associates and 10 collaborators. Members are mainly located at Rutgers. Collaborators are located in several distant sites and they interact, via SUMEX-AIM, with Resource members on a variety of projects, ranging from system design/improvement to clinical data gathering and system testing. At present, collaborators are located at the Mt.Sinai School of Medicine, N.Y.; Washington University School of Medicine, St. Louis, Mo.; Johns Hopkins Medical Center, Baltimore, Md.; Illinois Eye and Ear Infirmary, Chicago, Ill.; and the University of Miami.

Research in the Rutgers Resource is oriented to "discipline-oriented" projects in medicine and psychology, and to "core" projects in computer science, that are closely coupled with the "discipline-oriented" studies. Work in the Resource is organized in three AREAS OF STUDY; in each area there are several projects. The areas of study and the senior investigators in each of them are:

(1) Medical Modeling and Decision Making (C. Kulikowski, A. Safir).

(2) Modeling Belief Systems and Common-sense Reasoning (C.F. Schmidt, N.S. Sridharan).

(3) Artificial Intelligence: Representations, Reasoning and System Development (S. Amarel)

In addition, the Rutgers Resource is sponsoring an Annual National AIM Workshop, whose main objective is to strengthen interactions between AIM activities, to disseminate research methodologies and results, and to stimulate collaborations and imaginative resource sharing within the framework of AIM. The second AIM Workshop was held near the New Brunswick Rutgers Campus on June 1-4, 1976. The third Workshop is scheduled for July 6-8, 1977.

B) Medical Relevance; Collaborations

A major part of our research is focusing on the development of computer based medical consultation systems. We are using artificial intelligence approaches in problems of: knowledge acquisition from experts in a medical specialty and from their clinical experience; the representation and management of these complex and changing data bases of medical knowledge within the computer; and the development of a sufficiently rich repertoire of reasoning strategies for diagnosis, prognosis, therapy selection, explanation and teaching. By linking such a system to a data base of prospectively chosen cases, we are in the position to provide a powerful tool for clinical research with built-in interpretative capabilities.

Our approach emphasizes the development and application of clinically useful models that describe the pathophysiology and dysfunction of diseases in a variety of tasks:

a) Consultation embodying expert knowledge, which is expressed in terms acceptable to the clinician;

b) Clinical research aid, assisting the investigator to;

  i) Summarize and incorporate his knowledge, experience, and opinions into a computer system;

  ii) Analyze his data, check it against that of other investigators, pooling it when appropriate to draw stronger conclusions based on the large sample of cases;

  iii) Test, evaluate and modify the data base of models and decision strategies to produce an up-to-date summary of experience in his specialty.

c) Screening and diagnosis, to aid nursing or paramedical personnel in performing routine decision procedures within restricted medical environments;

d) Instruction to provide practitioners and support personnel with appropriate explanation and guidance in clinical decision-making.

A unique and novel aspect of our work is the creation of a <u>network of clinical investigators</u> to collaborate on the testing and continued development of the computer programs needed to accomplish the above tasks. During 1976, the ophthalmological network (ONET) of glaucoma investigators has grown and established itself, with several significant collaborative research projects currently underway. <u>The consultation program for glaucoma</u> using the causal associational network (CASNET) model developed within the Rutgers Resource, was jointly presented by the ONET members at the 1976 meeting of the Association for Research in Vision and Ophthalmology. An important new emphasis has been the incorporation into the consultation program of alternative expert opinions on subjects currently under debate. Dr. Douglas Anderson of the Bascom-Palmer Eye Institute at the University of Miami has joined ONET to provide such alternatives and strengthen the glaucoma model in certain important areas. The SUMEX-AIM shared computer resource has been essential to the activities of ONET.

The knowledge base and the strategies of our CASNET glaucoma consultation system are being strengthened and refined continuously in the ONET environment. The system is now at a point where it is considered by leading ophthalmologists as "highly competent to expert" in several subspecialties of glaucoma. The ONET group was confident enough about the system to demonstrate it at the October 1976 meeting of the American Academy of Ophthalmology and Otolaryngology. The reactions to the system were most favorable. The response of an independent sample of ophthalmologists taken at this meeting strongly emphasized the importance of the system for glaucoma research.

In addition to the main glaucoma research activities, the Resource has collaborated with the Mt. Sinai-Rutgers Health Care Computer Laboratory in the development of models for refraction and visual fields. These will be used by clinical prototype programs for guiding paramedical personnel in data acquisition and decision-making. These programs run on the PDP-11 computers of the clinical ophthalmological system at Mt. Sinai, which are to be linked to the PDP-10 at Rutgers for accessing the more complex models of disease when they are needed. The activities in conjunction with the Health Care Computer Laboratory reflect the more applied aspects of our work in the medical area.

The collaboration with Dr. R. Nordyke of the Straub Clinic on thyroid disease consultation systems has continued at a low level of activity during 1976.

In the area of Belief Systems, collaboration has continued with Professor Andrea Sedlak and her group at the University of North Carolina. This collaboration is focusing on developmental aspects of action perception.

In the AI Area we had extensive interactions with researchers in several institutions on problems of representation, problem solving systems, natural language processing, automatic programming, data base systems, and interactive systems. Contacts continued with the natural language group at BBN (Woods, Bruce) on the design of natural language processors for medical systems. Also, we had contacts with the Stanford-Xerox group (Winograd, Bobrow) which is involved in the development of KRL (Knowledge Representation Language).

Following the Rand Workshop on Biomedical Modeling (February 18-20, 1976), in which S. Amarel participated, preliminary contacts started with Dr. D. Garfinkel from the University of Pennsylvania in connection with possible applications of AI methods to the modeling of metabolic processes.

Our close contacts with the Stanford projects on Heuristic Programming (Drs. Buchanan, Feigenbaum, Lederberg) are continuing. The orientation and approach of these Stanford projects are very similar to ours. We continue to share with the investigators in DENDRAL and METADENDRAL a strong interest in computer-based methods of scientific inference and in AI ideas and techniques for representation of knowledge in computers, diagnostic problem solving and theory formation.

One of the significant collaborative developments this period was the joint work of Ed Feigenbaum and his students at Stanford, and Saul Amarel and his students at Rutgers, on the development of an AI Handbook. This handbook is being prepared on the SUMEX-AIM and RUTGERS-10 computers, and it is intended to provide a network-accessible encyclopedic coverage of the AI field for the AIM community and AIM guests.

C) Progress Summary

1. Areas of Study and Projects

a) Medical Modeling and Decision-Making

The consolidation of the opthalmological network (ONET) of collaborating glaucoma investigators using the SUMEX-AIM shared resource facility, the testing and improvement of the CASNET consultation system with the help of the collaborators, the design and implementation of a time-oriented database system and a set of analysis programs for aiding joint clinical research activities within ONET, and the development of a new knowledge-based consultation system (IRIS), represent the main achievements in the last year.

The network of investigators in glaucoma is designed to foster development of consultation systems that embody sufficient depth for knowledge and expert opinion in a variety of subareas to be useful as research and teaching tools. The collaborative activities, coordinated by Dr. A. Safir at Mt. Sinai, bring together selected scientist-users with complementary interests and strengths in different aspects of glaucoma, and Resource investigators who are concentrating on the development of new computer science methodologies in modeling and problem solving. During this period, there has been more extensive testing of the CASNET glaucoma consultation program. The collaborators had several meetings to discuss the structure of the glaucoma model and suggested many improvements and additions. A significant new capability of the program is the inclusion of alternative interpretations that capture differences of opinions among the experts on aspects of the model that are currently under debate.

A new development during this period has been the implementation of a time-sequenced data base for glaucoma, which has the dual purpose of aiding the clinical research of ONET collaborators and of providing a systematic means for evaluating and improving the performance of the consultation programs.

In the area of general methods and systems we have developed a multilevel-semantic network representation for characterizing disease processes, their anatomical descriptions and their taxonomic identification. This is used by a set of normative rules for diagnostic, prognostic and therapeutic reasoning, which results in a very general and flexible system for clinical consultation. A prototype model called IRIS is being developed using the glaucoma knowledge-base. We have also continued our investigations of other representation paradigms: a frame-based approach and the relationship to mathematical models of optics and refraction. Another subproject is concerned with developing methods of inference over network structures that will permit us to incorporate the results of clinical experience with different groupings of case-types into the models of consultation, aiding at the same time in the evaluation of the programs.

b) Modeling of Belief Systems and Common-Sense Reasoning

During this period a major achievement was the development and implementation of the AIMDS system. This is an MDS-based system that is specialized and augmented for use in modeling reasoning about actions. A noteworthy aspect of the system is the use of the MDS concepts of Consistency Conditions and Residues to guide frame instantiations and the drawing of further inferences from such frame instantiations.

The BELIEVER theory is a psychological model of the processes involved in the interpretation and common-sense reasoning about observed human actions. The AIMDS system is being constructed to provide a framework for formulating, studying and testing the BELIEVER theory. The computer system and the psychological theory are growing together, and they are strongly influencing each other's development. The domain of common-sense reasoning about actions represents a prototypical example of knowledge based reasoning. The richness of the psychological data that this theory must explain, namely, persons' linguistic descriptions and summarizations of everyday behavior, has forced us to think very carefully about how knowledge is to be represented and used. Out of this has emerged a general scheme that not only seems psychologically plausible but also appears to provide a useful framework for viewing a wide variety of problems of interpretation including medical diagnosis and theory-based interpretive problems involved in organic chemistry.

Along with the implementation of the system, we have developed the representation of the central knowledge components of the BELIEVER theory. The central common-sense concepts of Person, Plan and Act have been represented as frames. These frames are highly articulated structures which express the core assumptions of the common-sense psychological theory. By expressing these concepts as frames we have been able to provide a representation of these assumptions that can be used to guide and control the overall processes of reasoning about particular persons, plans and actions. The procedural components of the theory have been defined and are closely linked to these frames. This interplay and association between processes and highly articulated structures promises to provide a basis for strongly decomposing the knowledge of the domain. Since the interdependencies of these concepts are represented structurally rather than procedurally, the active database of our MDS-based system provides the basis for communication and cooperation between the processes that monitor these person, plan and act frames.

The definition of these central structural components together with the general system components have also provided a competence theory within which detailed predictions of the BELIEVER theory were specified. These predictions about the structure of summary protocols were tested and borne out by the data. This provides one of the few examples of the verification of predictions derived from work on the development of psychological theory using AI concepts in the process of theory formation.

c) Artificial Intelligence; Representations, Reasoning and Systems Development

Our work in this area continues to be oriented to collaboration with investigators in other Resource projects and to study of basic AI problems that are related to Resource applications. The collaborations involve adaptation and augmentation of existing AI methods and techniques to handle specific key problems identified in the application projects.

The close collaboration with investigators in the Belief Systems area has resulted this year in the development of the AIMDS System for handling problems of action interpretation of the type encountered in the domain of the BELIEVER theory. This system has provided one of the first examples of a working frame-based AI system. In addition, it has led to several important AI results, such as elucidation of the "frame problem" and unification of previous approaches to planning in heuristic problem solving.

Our research in language processing has led this period to two important applications - in Medical Systems and in Belief Systems. In one project, the PEDAGLOT system is being adapted to provide a natural language interface for communicating patient case histories to our glaucoma system. In a second project, PEDAGLOT is providing the basis for implementing the experimental component of a competence theory within which the BELIEVER theory can be evaluated. Empirical work in this area requires the ability to process summaries and other natural language data.

In the basic component of our work on language processing, we continued to develop a language inference system based on a "developmental paradigm" for grammar acquisition. We made progress in the area of coalescing rules of hypothesized grammars, and we started to look into ways of using semantic information to guide the hypothesis formation process.

In another project, which is also focusing on hypothesis formation, we are studying processes of computer assisted acquisition of domain knowledge from empirical data, where knowledge is in the form of weighted production rules. This type of knowledge can be represented as a stochastic graph. This year we obtained several new results in this area. We explored the implications of these results with the help of an experimental program which constructs a stochastic graph from empirical data. Also, we wrote a program which makes use of a file of graph-structured knowledge to make decisions about a domain.

In our work on theory formation in programming, we developed a formation strategy which combines a global, model-guided, approach with a local analysis of special cases. In order to study experimentally this strategy, we are now developing a system for acquiring and handling information about programs in various stages of specification, as well as other knowledge which is relevant to the formation task.

During this period we made important progress in building a strong basis of AI languages for our work. The UCI-LISP and FUZZY programming languages were adapted to the RUTGERS-10 and they were further improved. The availability of these languages made possible the implementation of major parts of AIMDS over a relatively short period of time. Work has now started on exploring the use of

FUZZY (including its features for effective use of incomplete and/or uncertain knowledge) and AIMDS in certain problems of medical decision making.

2. AIM Workshop

The Second AIM Workshop took place June 1 to 4, 1976 near the Rutgers campus, and it was attended by about 150 participants. The program included reviews of recent AI developments in Medicine, Biochemistry and Psychology; lectures and panel discussions on knowledge representation and AI system design; papers summarizing recent AI work in other application areas (outside AIM); and presentations of current research on computer-based biomathematical models. The Workshop included panels on networking and shared resources; in addition, there were a number of informal meetings in which specific projects or issues were discussed in depth. Hands-on experimentation and demonstration of AI systems (which were accessed via TYMNET and ARPANET) were an important feature of the Workshop. All indications are that the Workshop was very effective in stimulating scientific interactions and in disseminating work being done in the area of AIM.

In support of the AIM Workshop series we devoted considerable effort this period to systems development, to related computer and networking enhancements, to preparation of proceedings for the first Workshop, and comprehensive supporting documentation for the second.

A panel on Applications of AI to Science and Medicine was organized for the week following the Second AIM Workshop at the National Computer Conference in New York. It was intended to further augment the dissemination activities of AIM by bringing to a wide audience of professionals in the computer field recent developments in the AIM community.

D) Up-to-Date List of Publications

Amarel, S. and Kulikowski, C. (1972) "Medical Decision Making and Computer Modeling, Proc. of 5th International Conference on Systems Science, Honolulu, January 1972.

Amarel, S. (1974) "Inference of Programs from Sample Computations", Proc. of NATO Advanced Study Institute on Computer Oriented Learning Processes, 1974, Bonas, France.

Amarel, S. (1974) "Computer-Based Modeling and Interpretation in Medicine and Psychology: The Rutgers Research Resource", Proc. on Conference on the Computer as a Research Tool in the Life Sciences", June 1974, Aspen, by FASEB; also appears as Computers in Biomedicine TR-29. June 1974, Rutgers University, also in Computers in Life Sciences. W. Siler and D. Lindberg (eds.), Faseb and Plenum, 1975.

Amarel S. (1976) Abstract of Panel on "AI Applications in Science and Medicine" in 1976 National Computer Conference Program, N.Y., June 7-10, 1976.

Bruce B. (1972) "A Model for Temporal Reference and its Application in a Question Answering Program", in "Artificial Intelligence", Vol. 3, Spring 1972.