treatment. This system should perform at about the level of a board-certified psychiatrist, i.e. better than an average resident but not as well as a human expert in depression. Eventually, we plan to enlarge the knowledge base so that the expert system can diagnose and prescribe for a wider range of psychiatric patients, particularly those with illnesses which are likely to respond to psychopharmacological agents. We will design the system so that it could be used by non-medical clinicians or by non-psychiatrist MD's as an adjunct to consultation with a human expert.

B. Justification and Requirements for continued SUMEX use

This project is entirely dependent on access to SUMEX. We are using the EMYCIN system on SUMEX. That software is not available to us anywhere else. We also make extensive use of SUMEX as a means of communication and file-sharing with our consultant, Jon Heiser, and with David Mulsant and Benoit Servan-Schreiber. The access to SUMEX resources is essentially our sole means of maintaining contact with the community of researchers working on applications of AI in medicine.

We anticipate that our requirements for computing time and file space will continue to grow as the system evolves.

C. Needs and Plans for Other Computing Resources

As our project evolves and we run into the limitations of EMYCIN and the time-shared SUMEX facility, we anticipate employing different expert systems software. At this time, we are not at a stage to say exactly what that will be, but our project is not sufficiently large that we will be able to mount such a software development project ourselves, so we will depend on development and support elsewhere. Ultimately, when our consultant is made available for field trials and clinical use, it will need to be transported to a personal computer that is large enough support the system yet inexpensive enough to be widely available. A LISP machine is an obvious candidate. While current prices of the necessary hardware are too high, computer prices are continuing to drop. Our design strategy is to avoid limiting ourselves and our aspirations to that which is affordable today; instead we will attempt to project the growth of our project and the price-performance curve of computing such that they meet at some reasonable point in the future.

D. Recommendations for Future Community and Resource Development

Valuable as the present SUMEX facilities are to us, they are in many ways limited and awkward to use. The need for more and more computer cycles and memory continues to grow, of course. However, the major limitation we feel is the difficulty and sometimes the impossibility of making contact with everyone who could be of value to us. We hope that greater emphasis will be put on internetwork gateways. It is important not only to establish more of these, but to develop consistent and convenient standards for electronic mail, electronic file transfers, graphic information transfer, national archives and data bases, and personal filing and retrieval (categorization) systems. The present state of the art is quite limiting, now that the basic concepts of computer networking have become available and have proved their potential.

II.B. Books, Papers, and Abstracts

Publications for the various collaborative projects are summarized in their respective progress reports. They also have been submitted separately on the Scientific Subproject Form IIB. They are not reproduced here to avoid redundancy.

II.C. Resource Summary Table

Detailed resource usage information is summarized starting on page 30. Tabulations of this information also have been submitted separately on the requested Scientific Subproject Form. These are not reproduced here to avoid redundancy.

Appendix A

AIM Management Committee Membership

Following are the current membership lists of the various SUMEX-AIM management committees:

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Appendix B

Community Growth and Project Abstracts

This appendix contains a graphical display of the development of the SUMEX-AIM community over the years and abstracts of currently active projects. Figure 15 below illustrates the substantial growth in the cumulative number of projects in the Stanford, National AIM, and Rutgers-AIM communities since the resource began operation in 1974 up until this past year. The recent decrease in the total number of projects is due to the closure of several long time SUMEX-AIM projects, namely Dendral, Puff/Vm, Act, and Protein. Activity in the community however remains high, as evidenced by the number of pilot projects (5 Stanford pilots, 2 Aim pilots, and 1 Rutgers pilot) currently active in the SUMEX-AIM community.

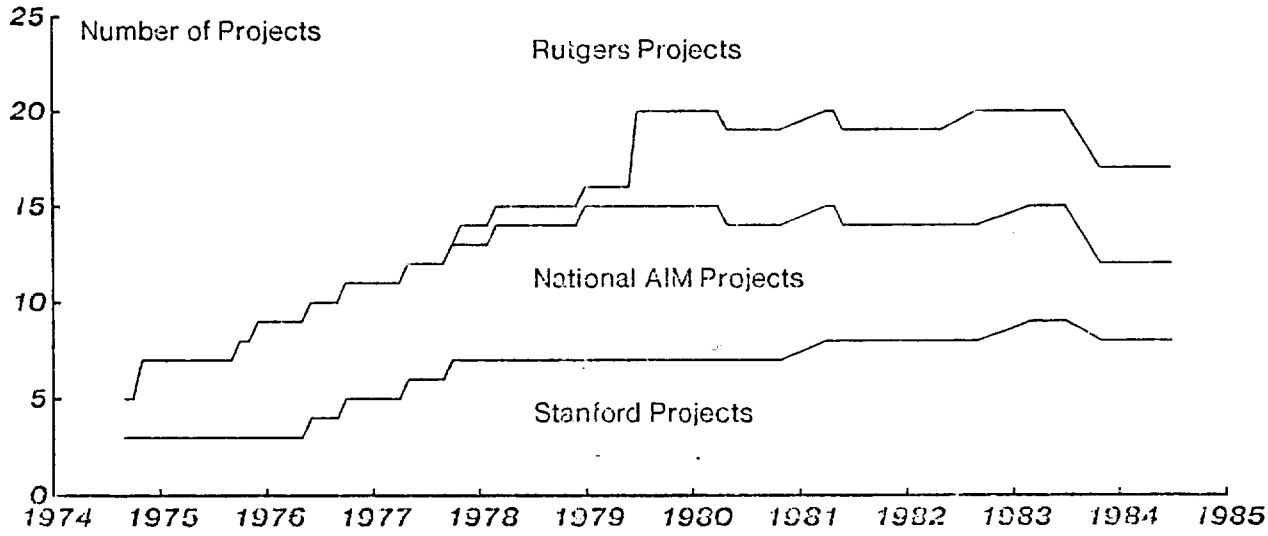

Figure 15: SUMEX-AIM Growth by Community

National AIM Project: CADUCEUS (formerly INTERNIST)

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The major goal of the CADUCEUS Project is to produce a reliable and adequately complete diagnostic consultative program in the field of internal medicine. Although this program is intended primarily to aid skilled internists in complicated medical problems, the program may have spin-off as a diagnostic and triage aid to physicians' assistants, rural health clinics, military medicine and space travel. In the design of CADUCEUS and its predecessor INTERNIST I, we have attempted to model the creative, problem-formulation aspect of the clinical reasoning process. The program employs a novel heuristic procedure that composes differential diagnoses, dynamically, on the basis of clinical evidence. During the course of a CADUCEUS or INTERNIST I consultation, it is not uncommon for a number of such conjectured problem foci to be proposed and investigated, with occasional major shifts taking place in the program's conceptualization of the task at hand.

SOFTWARE AVAILABLE ON SUMEX

Versions of INTERNIST are available for experimental use, but the project continues to be oriented primarily towards research and development; hence, a stable production version of the system is not yet available for general use.

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Pople, H.E.: *The formation of composite hypotheses in diagnostic problem solving: An exercise in synthetic reasoning.* Proc. Fifth IJCAI, Boston, August, 1977.

National AIM Project: SECS -- SIMULATION AND EVALUATION OF CHEMICAL SYNTHESIS

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The SECS Project aims at developing practical computer programs to assist investigators in designing syntheses of complex organic molecules of biological interest. Key features of this research include the use of computer graphics to allow chemist and computer to work efficiently as a team, the development of knowledge bases of chemical reactions, and the formation of plans to reduce the search for solutions. SECS is being used by the pharmaceutical industry for designing syntheses of drugs.

A spin-off project, XENO, is aimed at predicting the plausible metabolites of foreign compounds for carcinogenicity studies. First, the metabolism is simulated; then the metabolites are evaluated for possible carcinogenicity.

SOFTWARE AVAILABLE ON SUMEX

SECS-- An organic synthesis design program available with a reaction library of over 500 reactions. The program is accessible to users via a teletype or DEC GT40 type graphics terminal.

XENO-- A program for prediction of metabolites of xenobiotic compounds. Although the project is still in the early development stages, this program is available for preliminary exploration and testing.

PRXBLD-- A facility for building approximate 3-dimensional molecular models from their 2-dimensional representations. The program employs an energy minimization approach and is available both stand-alone and as part of SECS.

QED-- A domain-independent inference engine which represents knowledge in first order predicate calculus.

FSECS-- A forward-working synthesis prototype program for finding starting material oriented syntheses.

SST-- A program for searching through a library of possible starting materials to suggest potential starting materials for a given target molecule.

REFERENCES

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Synthesis. SST: Starting Material Selection Strategies. An Application of Superstructure Search. J. Chem. Inf. Comput. Sci., 24:0000, 1984.

Wipke, W.T., Ouchi, G.I. and Chou, J.T.: *Computer-assisted prediction of metabolism.* IN L. Goldberg (Ed.), STRUCTURE-ACTIVITY CORRELATIONS AS A PREDICTIVE TOOL IN TOXICOLOGY. Hemisphere Publishing Corp., New York, 1983, pp 151-169.

Wipke, W.T., Ouchi, G. and Krishnan, S.: *Simulation and evaluation of chemical synthesis--SECS. An application of artificial intelligence techniques.* Artificial Intelligence 10:999, 1978.

National AIM Project: CLIPR -- HIERARCHICAL MODELS OF HUMAN COGNITION

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The CLIPR Project is concerned with the modeling of complex psychological processes. It is comprised of two research groups. The prose comprehension group has completed a project that carries out the microstructure text analysis described by Miller and Kintsch (1980), yielding predictions of the recall and readability of that text by human subjects. More recently, this group has been interacting with the Heuristic Programming Project at Stanford, using the AGE and UNITS packages to build a more complex model of the knowledge-based processes characteristic of prose comprehension. The planning group is working toward a model of the planning processes used by expert computer software designers. The initial processes involved in learning to use computers and other complex devices.

SOFTWARE AVAILABLE ON SUMEX

A set of programs has been developed to perform the microstructure text analysis described in Kintsch and van Dijk (Psychological Review, 1978) and Miller and Kintsch (1980). The program accepts a propositionalized text as input, and produces indices that can be used to estimate the text's recall and readability. A more complex model based in AGE and UNITS, which emphasizes the knowledge-based aspects of comprehension, is currently under development.

REFERENCES

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Rutgers AIM Project: RUTGERS RESEARCH RESOURCE-
COMPUTERS IN BIOMEDICINE

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The Rutgers Research Resource provides the research support with artificial intelligence systems, and the computing support with its DEC2060 facility to a large number of biomedical scientists and researchers. There are currently 86 investigators associated with the Resource. Research activities are concentrated in three major areas: expert medical systems, models for planning and knowledge acquisition, and general AI systems development.

One of the most significant achievements in bringing the work of the Resource to bear on clinical research and practice lies in the transfer of technology from our large DEC20 machine to microprocessor compatible representations. The initial breakthrough came with the automatic translation of a serum protein electrophoresis interpretation model so that a version could be incorporated in an instrument - the scanning densitometer (CliniScan) produced by Helena Laboratories. After testing, it was disseminated commercially, marking the first successful transfer of technology from the Resource to general availability in the clinical community. It is now being used in over one hundred clinical locations.

During the current period, we have started a new project with long term implications for the impact of AIM technology: the development of a hand-held microcomputer version of an expert consultation system for front-line health workers. In collaboration with Dr. Chandler Dawson (UCSF), Director of the World Health Organization's Collaborative Centre for the Prevention of Blindness and Trachoma, we have developed a prototype model for consultation on primary eye care. This has been oriented at problems of injury, infection, malnutrition and cataract in situations where an ophthamologist is unavailable. In most developing nations, the incidence of blindness is 10% to 40% higher than in the USA because of these kinds of problems. With the help of a grant from the USAID, we are developing the systems needed for management of eye disease by front-line health workers in developing nations, and outlying parts of the USA.

Another significant technology transfer experiment involves a very large consultation model. The rheumatology knowledge base developed by our collaborators Drs. Lindberg and Sharp at the University of Missouri has been transferred by us to the MC68000 microprocessor based system, and in the past year testing has begun at their site. This represents a major step in bringing the results of artificial intelligence research to the point where clinical researchers who do not have access to large research machines will be able to make use of the results. We are designing a specialized ***rheumatology machine*** which can carry out the same sophisticated reasoning that now needs the Resource DEC20 , but will cost little over **$10,000.** Because the transfer has been accomplished we can continue to develop large scale models using the full facilities of the Resource DEC20 , but with the confidence that they can then move out into clinical research environments when completed.

REFERENCES

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Kulikowski, C.A. contributor to the Knowledge Acquisition chapter edited by B. Buchanan in the book ***Building Expert Systems*** (F. Hayes-Roth, et al., eds) Addison-Wesley, 1983 (in press).

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Kulikowski, C.A. *Knowledge Acquisition and Learning in EXPERT*, Proc. 1983 Workshop on Machine Learning, Univ. of Illinois,Champaign-Urbana 1983.

Indicate by an asterisk (*) that the resource was given credit.

National AIM Project: SOLVER -- PROBLEM SOLVING EXPERTISE

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The Minnesota SOLVER project focuses upon the development of strategies for discovering and representing the knowledge and skill of expert problem solvers. Although in the last 15 years considerable progress has been made in synthesizing the expertise required for solving complex problems, most expert systems embody only the limited amount of expertise that individuals are able to report in a particular constrained language (e.g., production rules). What is still lacking is a theoretical framework capable of reducing dependence upon the expert's intuition or on the near exhaustive testing of possible organizations. Our methodology consists of: (1) extensive use of verbal thinking aloud protocols as a source of information from which to make inferences about underlying cognitive structures and processes; (2) development of computer models as a means of testing the adequacy of inferences derived from protocol studies; (3) testing and refinement of the cognitive models based upon the study of human and model performance in experimental settings. Currently, we are investigating problem-solving expertise in domains of medicine, physics, engineering, management, and law.

SOFTWARE AVAILABLE ON SUMEX

A redesigned version of the Diagnoser simulation model, named Galen, has been implemented on SUMEX.

REFERENCES

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Johnson, P.E., Duran, A., Hassebrock, F., Moller, J., Prietula, M., Feltovich, P. and Swanson, D.: *Expertise and error in diagnostic reasoning*. Cognitive Science 5:235-283, 1981.

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National AIM Project: Computer-Aided Diagnosis of Malignant Lymph Node Diseases (PATHFINDER)

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We are building a computer program, called PATHFINDER, to assist in the diagnosis of lymph node pathology. The project is based at the City of Hope National medical center in collaboration with the Stanford University Medical Computer Science Group. A pilot version of the program provides diagnostic advice on 45 common benign and malignant diseases of the lymph node based on 77 histologic features. Our research plans are to develop a full-scale version of the computer program by substantially increasing the quantity and quality of knowledge and to develop techniques for knowledge representation and manipulation appropriate to this application area. The design of the program has been strongly influenced by the INTERNIST/CADUCEUS program developed on the SUMEX resource.

SOFTWARE AVAILABLE ON SUMEX

PATHFINDER-- A version of the PATHFINDER program is available for experimentation on the DEC 2060 computer. This version is a pilot version of the program, and therefore has not been completely tested.

Stanford Project: EXPEX -- EXPERT EXPLANATION

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EXPEX is a recent Stanford research project that is involved with the development of new representation schemes to facilitate knowledge acquisition and explanation. This includes not only the study of fundamental representational formalisms but also the encoding of various types of knowledge, such as causal information and user models. The research effort deals with medical domains and is being undertaken on SUMEX or on professional workstations linked to the central resource.

Our interest in explanation derives from the insights we gained in developing explanatory capabilities for the MYCIN system. In that system and its descendants, we were able to generate intelligible explanations by taking advantage of a rule-based representation scheme. The limitations of the justifications generated using MYCIN's explanation capabilities have become increasingly obvious, however, and have led to improved characterization of the kinds of explanation capabilities that must be developed if clinical consultation systems are to be accepted by physicians. EXPEX is devoted to the development of new practical and theoretical insights into this problem.

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Stanford Project: GUIDON/NEOMYCIN --
KNOWLEDGE ENGINEERING
FOR TEACHING MEDICAL DIAGNOSIS

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SOFTWARE AVAILABLE ON SUMEX

GUIDON--A system developed for intelligent computer-aided instruction. Although it was developed in the context of MYCIN's infectious disease knowledge base, the tutorial rules will operate upon any EMYCIN knowledge base.

NEOMYCIN--A consulation system derived from MYCIN, with the knowledge base greatly extended and reconfigured for use in teaching. In contrast with MYCIN, diagnostic procedures, common sense facts, and disease hierarchies are factored out of the basic finding/disease associations. The diagnostic procedures are abstract (not specific to any problem domain) and model human reasoning, unlike the exhaustive, top-down approach implicit in MYCIN's medical rules. This knowledge base will be used in the GUIDON2 family of instructional programs.

REFERENCES

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Stanford Project: MOLGEN -- AN EXPERIMENT PLANNING SYSTEM FOR MOLECULAR GENETICS

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The goal of the MOLGEN Project is to apply the techniques of artificial intelligence to the domain of molecular biology with the aim of providing assistance to the experimental scientist. Previous work has focused on the task of experiment design. Two major approaches to this problem have been explored, one which instantiates abstracted experimental strategies with specific laboratory tools, and one which creates plans in toto, heavily influenced by the role played by interactions between plan steps. As part of the effort to build an experiment design system, a knowledge representation and acquisition package--the UNITS System, has been constructed. A large knowledge base, containing information about nucleic acid structures, laboratory techniques, and experiment-design strategies, has been developed using this tool. Smaller systems, such as programs which analyze primary sequence data for homologies and symmetries, have been built when needed.

New work has begun on scientific theory formation, modification, and testing. This work will be done within the domain of regulatory genetics. We plan to explore fundamental issues in machine learning and discovery, as well as construct systems that will assist the laboratory scientist in accomplishing his intellectual goals.

SOFTWARE AVAILABLE ON SUMEX

SPEX system for experiment design.
UNITS system for knowledge representation and acquisition.
SEQ system for nucleotide sequence analysis.

REFERENCES

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Stanford Project: ONCOCIN -- KNOWLEDGE ENGINEERING FOR ONCOLOGY CHEMOTHERAPY CONSULTATION

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Project Directors: Dr. Lawrence M. Fagan and Ms. Miriam B. Bischoff

The ONCOCIN Project is overseen by a collaborative group of physicians and computer scientists who are developing an intelligent system that uses the techniques of knowledge engineering to advise oncologists in the management of patients receiving cancer chemotherapy. The general research foci of the group members include knowledge acquisition, inexact reasoning, explanation, and the representation of time and of expert thinking patterns. Much of the work developed from research in the 1970's on the MYCIN and EMYCIN programs, early efforts that helped define the group's research directions for the coming decade. MYCIN and EMYCIN are still available on SUMEX for demonstration purposes.

The prototype ONCOCIN system is in routine use by oncologists in the Stanford Oncology Clinic. Thus much of the emphasis of this research has been on human engineering so that the physicians will accept the program as a useful adjunct to their patient care activities. ONCOCIN has been well-accepted since its introduction, and plans are underway to transfer the program to professional workstations (rather than the central SUMEX computer) so that it can be implemented and evaluated at sites away from the University.

SOFTWARE AVAILABLE ON SUMEX

MYCIN-- A consultation system designed to assist physicians with the selection of antimicrobial therapy for severe infections. It has achieved expert level performance in formal evaluations of its ability to select therapy for bacteremia and meningitis. Although MYCIN is no longer the subject of an active research program, the system continues to be available on SUMEX for demonstration purposes and as a testing environment for other research projects.

EMYCIN-- The "essential MYCIN" system is a generalization of the MYCIN knowledge representation and control structure. It is designed to facilitate the development of new expert consultation systems for both clinical and non-medical domains.

ONCOCIN-- This system is in routine use but is designed for special high speed terminals and therefore cannot be tested or demonstrated via network connections. Much of the knowledge in the domain of cancer chemotherapy is already well-specified in protocol documents, but expert judgments also need to be understood and modeled.

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Stanford Project: RADIX -- DERIVING KNOWLEDGE FROM TIME-ORIENTED CLINICAL DATABASES

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The objective of clinical database (DB) systems is to derive medical knowledge from the stored patient observations. However, the process of reliably deriving causal relationships has proven to be quite difficult because of the complexity of disease states and time relationships, strong sources of bias, and problems of missing and outlying data.

The goal of the RADIX Project is to explore the usefulness of knowledge-based computational techniques in solving this problem of accurate knowledge inference from non-randomized, non-protocol patient records. Central to RADIX is a knowledge base (KB) of medicine and statistics, organized as a taxonomic tree consisting of frames with attached data and procedures. The KB is used to retrieve time-intervals of interest from the DB and to assist with the statistical analysis. Derived knowledge is incorporated automatically into the KB. The American Rheumatism Association DB containing records of 1700 patients is used.

SOFTWARE AVAILABLE ON SUMEX

RADIX--(excluding the knowledge base and clinical database) consists of approximately 400 INTERLISP functions. The following groups of functions may be of interest apart from the RADIX environment:

SPSS Interface Package -- Functions which create SPSS source decks and read SPSS listings from within INTERLISP.

Statistical Tests in INTERLISP -- Translations of the Piezer-Pratt approximations for the T,F, and Chi-square tests into LISP.

Time-Oriented Data Base and Graphics Package -- Autonomous package for maintaining a time-oriented database and displaying labelled time-intervals.

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Stanford Pilot Project: THE COMPUTER-AIDED DECISION ANALYSIS (CAMDA) PROJECT

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The CAMDA project is a program of research in the area of medical decision making. The main focus of this effort is to combine decision analysis and artificial intelligence to develop systems that support medical decisions.

Nearly two decades of experience in the application of decision analysis to problems in industry and government have shown that the technique constitutes an extremely helpful tool for making difficult choices. The potential benefit of decision analysis is particularly great when choices must be made in the presence of uncertainty and when the stakes involved are high. This situation is common in medical decisions.

Partly as a result of the high cost of an individual decision analysis, and partly due to the inherent complexity of making choices which involve outcomes such as pain and death, medical decision analysis has remained essentially within the realm of the academic community. Therefore, the majority of patients and physicians have been deprived of the benefits of this powerful technique.

Expert system technology make it possible to bring decision analysis to the medical community in general. By providing a sophisticated modeling methodology, expert systems allow the process of decision analysis (within a specific medical context) to be formalized with sufficient accuracy to make much of the analysis amenable to computer automation. The resulting CAMDA systems could provide an attractive alternative to unaided decision making, and to the usually unaffordable option of analyzing medical decisions individually. Furthermore, these systems can help decision makers think more clearly about the difficult issues they face by providing them with a means to experiment with the logical consequences of their assumptions and preferences.

A major focus of our research effort is the development of RACHEL, an intelligent decision systems for infertile couples. The field of infertility was chosen for several reasons, including the prevalence of the condition, the complexity of the values that are usually attached to the possible outcomes in this field, the rapidly growing set of available tests and treatments, and the time-dependent nature of the human reproductive process.

As part of the development of RACHEL, a substantial portion of the current CAMDA effort is aimed at the development of a general computer-based aid for medical decision analysis, which could be used in other medical decision domains.

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