REFERENCES

1. Shortliffe, E.H., Scott, A.C., Bischoff, M.B., Campbell, A.B., van Melle, W. and Jacobs, C.D.: *ONCOCIN: An expert system for oncology protocol management.* Proc. Seventh IJCAI, pp. 876-881, Vancouver, B.C., August, 1981.

2. Duda, R.O. and Shortliffe, E.H.: *Expert systems research.* Science 220:261-268, 1983.

3. Langlotz, C.P. and Shortliffe, E.H.: *Adapting a consultation system to critique user plans.* Int. J. Man-Machine Studies 19:479-496, 1983.

4. Bischoff, M.B., Shortliffe, E.H., Scott, A.C., Carlson, R.W. and Jacobs, C.D.: *Integration of a computer-based consultant into the clinical setting.* Proceedings 7th Annual Symposium on Computer Applications in Medical Care, pp. 149-152, Baltimore, Maryland, October 1983.

5. Hickam, D.H., Shortliffe, E.H., Bischoff, M.B., Scott, A.C., Jacobs, C.D.: A study of the treatment advice of a computer-based cancer chemotherapy protocol advisor (Memo KSL-85-21). *Annals of Internal Medicine* 103(6 pt 1):928-936 (1985).

6. Kent, D.L., Shortliffe, E.H., Carlson, R.W., Bischoff, M.B., Jacobs, C.D.: Improvements in data collection through physician use of a computer-based chemotherapy treatment consultant (Memo KSL-85-22). *Journal of Clinical Oncology* 3:1409-1417, 1985.

7. Tsuji, S. and Shortliffe, E.H.: Graphical access to a medical expert system: I. Design of a knowledge engineer's interface (Memo KSL-85-11). Meth. Inf. Med., 25:62-70, 1986.

8. Lane, C.D., Differding, J.C., Shortliffe, E.H.: Graphical access to a medical expert system: II. Design of an interface for physicians (Memo KSL-85-15). Meth. Inf. Med., 25:143-150, 1986.

9. Shortliffe, E.H. Medical expert systems: Knowledge tools for physicians. Memo KSL-86-52. Special issue on Medical Informatics, West. J. Med. 145:830-839, 1986.

Stanford Project: PROTEAN Project

Principal Investigators: Oleg Jardetzky
(JARDETZKY@SUMEX-AIM.STANFORD.EDU)
Nuclear Magnetic Resonance Lab, School of Medicine
Stanford University Medical Center
Stanford, California 94305

Bruce G. Buchanan, Ph.D.
(BUCHANAN@SUMEX-AIM.STANFORD.EDU)
Computer Science Department
Stanford University
Stanford, California 94305

Contact Person: Bruce G. Buchanan

The goals of this project are related both to biochemistry and artificial intelligence: (a) use existing AI methods to aid in the determination of the 3-dimensional structure of proteins in solution (not from x-ray crystallography proteins), and (b) use protein structure determination as a test problem for experiments with the AI problem-solving structure known as the Blackboard Model. Empirical data from nuclear magnetic resonance (NMR) and other sources may provide enough constraints on structural descriptions to allow protein chemists to bypass the laborious methods of crystallizing a protein and using X-ray crystallography to determine its structure. This problem exhibits considerable complexity, yet there is reason to believe that AI programs can be written that reason much as experts do to resolve these difficulties. A prototype knowledge-based system assembles major secondary structures of a protein into families of structures compatible with a given set of distance constraints under the control of an explicit assembly strategy. Structures can also be refined at the atomic level of detail using constraints within secondary structures and between amino acid side chains to further restrict the 3-dimensional structure found. By generalizing this approach to the assembly of arrangements of objects subject to constraints, we have developed a language for specifying actions and control for problem solving in similar problem domains.

REFERENCES

1. Altman, R. and Jardetzky, O.: *New strategies for the determination of macromolecular structures in solution.* Journal of Biochemistry (Tokyo), Vol. 100, No. 6, p. 1403-1423, 1986.

2. Altman, R. and Buchanan, B.G.: *Partial Compilation of Control Knowledge.* To appear in: Proceedings of the AAAI 1987.

3. Brinkley, J., Cornelius, C., Altman, R., Hayes-Roth, B. Lichtarge, O., Duncan, B., Buchanan, B.G., Jardetzky, O.: *Application of Constraint Satisfaction Techniques to the Determination of Protein Tertiary Structure.* Report KSL-86-28, Department of Computer Science, 1986.

4. Brinkley, James F., Buchanan, Bruce G., Altman, Russ B., Duncan, Bruce S., Cornelius, Craig W.: *A Heuristic Refinement Method for Spatial Constraint Satisfaction Problems.* Report KSL 87-05, Department of Computer Science.

5. Buchanan, B.G., Hayes-Roth, B., Lichtarge, O., Altman, A., Brinkley, J., Hewett, M., Cornelius, C., Duncan, B., Jardetzky, O.:*The Heuristic Refinement Method for Deriving Solution Structures of Proteins*. Report KSL-85-41. October 1985.

6. Garvey, Alan, Cornelius, Craig, and Hayes-Roth, Barbara: *Computational Costs versus Benefits of Control Reasoning*. Report KSL 87-11, Department of Computer Science.

7. Hayes-Roth, B.: *The Blackboard Architecture: A General Framework for Problem Solving?* Report HPP-83-30, Department of Computer Science, Stanford University, 1983.

8. Hayes-Roth, B.: *BB1: An Environment for Building Blackboard Systems that Control, Explain, and Learn about their own Behavior*. Report HPP-84-16, Department of Computer Science, Stanford University, 1984.

9. Hayes-Roth, B.: *A Blackboard Architecture for Control*. Artificial Intelligence 26:251-321, 1985.

10. Hayes-Roth, B. and Hewett, M.: *Learning Control Heuristics in BB1*. Report HPP-85-2, Department of Computer Science, 1985.

11. Hayes-Roth, B., Buchanan, B.G., Lichtarge, O., Hewett, M., Altman, R., Brinkley, J., Cornelius, C., Duncan, B., and Jardetzky, O.: *PROTEAN: Deriving protein structure from constraints*. Proceedings of the AAAI, 1986, p. 904-909.

12. Jardetzky, O.: *A Method for the Definition of the Solution Structure of Proteins from NMR and Other Physical Measurements: The LAC-Repressor Headpiece*. Proceedings of the International Conference on the Frontiers of Biochemistry and Molecular Biology, Alma Alta, June 17-24, 1984, October, 1984.

13. Lichtarge, Olivier: *Structure determination of proteins in solution by NMR*. Ph.D. Thesis, Stanford University, November, 1986.

14. Lichtarge, Olivier, Cornelius, Craig W., Buchanan, Bruce G., Jardetzky, Oleg: *Validation of the First Step of the Heuristic Refinement Method for the Derivation of Solution Structures of Proteins from NMR Data.*, April 1987. Submitted to Proteins: Structure, Function, and Genetics.

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

Principal Investigators: Robert L. Blum, M.D.
Departments of Medicine
and Computer Science
Stanford University
Stanford, California 94305
(415) 497-9421 (BLUM@SUMEX-AIM)

Gio C.M. Wiederhold, Ph.D.
Department of Computer Science
Stanford University
Stanford, California 94305
(415) 497-0685 (WIEDERHOLD@SUMEX-AIM)

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 first 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.

The second goal of the project is to develop a program and set of techniques for automated summarization of patient records. The summarization program is designed to automatically create patient summaries of arbitrary and appropriate complexity as an aid for tasks such as clinical decision making, real-time patient monitoring, surveillance of quality of care, and eventually automated discovery. Two prototype summarization modules have been implemented in KEE on the Xerox 1108 workstation.

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.

REFERENCES

Monograph

Blum, R.L.: *Discovery and representation of causal relationships from a large time-oriented clinical database: The RX project.* in D.A.B. Lindberg and P.L. Reichertz (Eds.), LECTURE NOTES IN MEDICAL INFORMATICS, Vol. 19, Springer-Verlag, New York, 1982.

Journal Articles

Blum, R.L.: *Computer-Assisted Design of Studies using Routine Clinical Data: Analyzing the Association of Prednisone and Cholesterol.* Annals of Internal Medicine 104(6):858-868, June, 1986.

Blum, R.L.: *Discovery, confirmation, and incorporation of causal relationships from a large time-oriented clinical database: The RX Project.* Computers and Biomedical Research 15(2):164-187, April, 1982.

Walker, M.G. *How Feasible is Automated Discovery?* IEEE Expert 2(1):70-82, Spring, 1987.

Conference Proceedings

DeZegher-Geets, I.M., Freeman, A.G., Walker, M.G., Blum, R.L., and Wiederhold, G.C.M. *Computer-aided Summarization of a Time-oriented Medical Data Base.* In Proceedings of the Third Annual Conference on Computerization of Medical Records. Institute for Medical Record Economics, 1987.

Downs, S., Walker, M.G., and Blum, R.L. *Automated Summarization of On-line Medical Records.* In Proceedings of the Fifth World Congress on Medical Informatics (Medinfo), pages 800-804. Elsevier Science Publishers, 1986.

Walker, M.G., and Blum, R.L. *Towards Automated Discovery from Clinical Databases: the RADIX Project.* In Proceedings of the Fifth World Congress on Medical Informatics (Medinfo), pages 32-36. Elsevier Science Publishers, 1986.

National AIM Project: CADUCEUS
(INTERNIST-I)

QMR
(Quick Medical Reference)

Principal Investigators:

CADUCEUS PROJECT:
Harry E. Pople, Ph.D. (POPLE@SUMEX-AIM)
Jack D. Myers, M.D. (MYERS@SUMEX-AIM)

QMR PROJECT:
Randolph A. Miller, M.D.(RMILLER@SUMEX-AIM)
Fred E. Masarie, Jr. M.D. (MASARIE@SUMEX-AIM)
Jack D. Myers, M.D. (MYERS@SUMEX-AIM)
University of Pittsburgh
Pittsburgh, Pennsylvania 15261

Dr. Pople: (412) 624-3490
Dr. Myers: (412) 648-9933
Dr. Miller: (412) 648-3190
Dr. Masarie: (412) 648-3190

The major goal of both the CADUCEUS and INTERNIST-I/QMR Projects 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-offs as a diagnostic and triage aid to physicians' assistants, rural health clinics, military medicine and space travel. In the design of INTERNIST-I and QMR, 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 INTERNIST-1 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. QMR is broader in scope than INTERNIST-I or CADUCEUS, in that it provides quick and efficient access to the INTERNIST-I/QMR knowledge base to provide low and intermediate level informational support for physicians' decision-making, in addition to providing consultative advice.

SOFTWARE AVAILABLE ON SUMEX

Versions of INTERNIST-I 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. QMR has been shared on a restricted basis with a limited number of academic colleagues, who have agreed to give the QMR development team feedback on the program's strengths and weaknesses.

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

Principal Investigators: Walter Kintsch, Ph.D. (KINTSCH@SUMEX-AIM)
Peter G. Polson, Ph.D. (POLSON@SUMEX-AIM)
Computer Laboratory for Instruction
in Psychological Research (CLIPR)
Campus Box 345
Department of Psychology
University of Colorado
Boulder, Colorado 80309
(303) 492-6991
Contact: Dr. Peter G. Polson (Polson@SUMEX-AIM)

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 text analysis described by van Dijk & Kintsch (1983), yielding predictions of the recall and readability of that text by human subjects. The human-computer interaction group is developing a quantitative theory of that predicts learning, transfer, and performance for a wide range of computer-tasks, e.g. text editing, Kieras & Polson (1985).

SOFTWARE AVAILABLE ON SUMEX

A set of programs has been developed to perform the microstructure text analysis described in van Dijk & Kintsch (1983) and Kintsch & Greeno (1985). The program accepts a propositionalized text as input, and produces indices that can be used to estimate the text's recall and readability.

REFERENCES

1. Fletcher, R.C.: Understanding and solving word arithmetic problems: A computer simulation. Technical Report No. 135, Institute of Cognitive Science, Colorado, 1984.

2. Kieras, D.E. and Polson, P.G.: *The formal analysis of user complexity.* Int. J. Man-Machine Studies, 22, 365-394, 1985.

3. Kintsch, W. and van Dijk, T.A.: *Toward a model of text comprehension and production.* Psychological Rev. 85:363-394, 1978.

4. Kintsch, W. and Greeno, J.G.: *Understanding and solving word arithmetic problems.* Psychological Review, 1985, 92, 109-129.

5. Polson, P.G. and Kieras, D.E.: *A formal description of users' knowledge of how to operate a device and user complexity.* Behavior Research Methods, Instrumentation, & Computers, 1984, 16, 249-255.

6. Polson, P.G. and Kieras, D.E.: *A quantitative model of the learning and performance of text editing knowledge.* In Borman, L. and Curtis, B. (Eds.) Proceedings of the CHI 1985 Conference on Human Factors in Computing. New York: Association for Computing Machinery. pp. 207-212, 1985.

7. Polson, P.G. and Jeffries, R.: *Instruction in general problem solving skills: An analysis of four approaches*. In (Eds.) Siegel, J., Chipman, S., and Glaser, R. Thinking and learning skills: Relating instructions to basic research: Vol.1. Hillsdale, N.J.: Lawrence Erlbaum Associates, pp. 414-455.

8. Polson, P.G., Muncher, E., and Engelbeck, G.: *Test of a common elements theory of transfer*. In Mantei, M. and Orbeton, P. (Eds.) Proceedings of the CHI 1986 Conference on Human Factors in Computing. New York: Association for Computing Machinery. pp. 78-83, 1986.

9. van Dijk, T.A. and Kintsch, W.: *STRATEGIES OF DISCOURSE COMPREHENSION*. Academic Press, New York, 1983.

10. Young, S.: A theory and simulation of macrostructure. Technical Report No. 134, Institute of Cognitive Science, Colorado, 1984.

11. Walker, H.W. & Kintsch, W.: Automatic and strategic aspects of knowledge retrieval. Cognitive Science, 1985, 9, 261-283.

National AIM Project: MENTOR -- MEDICAL EVALUATION OF THERAPEUTIC ORDERS

Principal Investigators: Stuart Speedie, Ph.D. (SPEEDIE@SUMEX-AIM)
School of Pharmacy
University of Maryland
20 N. Pine Street
Baltimore, Maryland 21201
(301) 528-7650

Terrence F. Blaschke, M.D. (BLASCHKE@SUMEX-AIM)
Department of Medicine
Division of Clinical Pharmacology
Stanford University Medical Center
Stanford, California 94305

Contact: either PI

The goal of the MENTOR project is to implement and begin evaluation of a computer-based methodology for reducing therapeutic misadventures. The project uses an on-line expert system to continuously monitor the drug therapy of individual patients and generate specific warnings of potential and/or actual unintended effects of therapy. The appropriate patient information is automatically acquired through interfaces to a hospital information system. This data is monitored by a system that is capable of employing complex chains of reasoning to evaluate therapeutic decisions and arrive at valid conclusions in the context of all information available on the patient. The results reached by the system are fed back to the responsible physicians to assist future decision making.

Specific objectives of this project include:

1. Implement a prototype computer-based expert system to continuously monitor in-patient drug therapy that uses a modular medical knowledge base and a separate inference engine to apply the knowledge to specific situations.

2. Select a small number of important and frequently occurring drug therapy problems that can lead to therapeutic misadventures and construct a comprehensive knowledge base necessary to detect these situations.

3. Design and begin implementation of an evaluation of the prototype MENTOR system with respect to its impact on the on the physicians' therapeutic decision making as well as its effects on the patient in terms of specific mortality and morbidity measures.

The work in this project builds on the extensive previous work in drug monitoring done by these investigators in the Division of Clinical Pharmacology at Stanford and the University of Maryland School of Pharmacy.

National AIM Project: SOLVER -- PROBLEM SOLVING EXPERTISE

Principal Investigators:

Paul E. Johnson, Ph.D.
School of Management and
Center for Research in Human Learning
205 Elliott Hall
University of Minnesota
Minneapolis, Minnesota 55455
(612) 376-2530 (PJOHNSON@SUMEX-AIM)

James R. Slagle, Ph.D.
Department of Computer Science
136 Lind Hall
University of Minnesota
Minneapolis, Minnesota 55455
(612) 373-0132 (SLAGLE@SUMEX-AIM)

William B. Thompson, Ph.D.
Department of Computer Science
136 Lind Hall
University of Minnesota
Minneapolis, Minnesota 55455
(612) 373-0132 (THOMPSON@SUMEX-AIM)

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 fifteen years considerable progress has been made in synthesizing the expertise required for solving complex problems, most expert systems embody only a limited amount of expertise. 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 knowledge 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, computer hardware diagnosis, offline quality control, financial auditing, management, and law.

SOFTWARE AVAILABLE ON SUMEX

A redesigned version of the Diagnoser simulation model, named Galen, has been implemented on SUMEX. Galen is an expert system which uses recognition-based reasoning in pediatric cardiology.

REFERENCES

1. Johnson, P.E., Moen, J.B., and Thompson, W.B.: *Garden Path Errors in Medical Diagnosis.* In Bolc, L. and Coombs, M.J. (Eds.), COMPUTER EXPERT SYSTEMS, Springer-Verlag (in press).

2. Johnson, P.E., Johnson, M.G., and Little, R.K.: *Expertise in trial advocacy: Some considerations for inquiry into its nature and development*, Campbell Law Review, (in press).

3. Johnson, P.E., *The Expert Mind: A New Challenge for the Information scientist,* in BEYOND PRODUCTIVITY: INFORMATION SYSTEM DEVELOPMENT FOR ORGANIZATIONAL EFFECTIVENESS, Th. M. A. Bemelmans (editor), Elsevier Science Publishers B.V. (North-Holland), 1984.

4. Johnson, P.E.: *What kind of expert should a system be?* Journal of Medicine and Philosophy, 8:77-97, 1983.

5. 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.

6. Simpson, D.E., Rich, E., Dalgaard, K., Gjerdingen, K., Crowson, T., O'Brien, D., Johnson, P.E.: *The diagnostic process in primary care: A comparison of general internists and family physicians.* SOCIAL SCIENCE AND MEDICINE (in press).

7. Spackman, K.A. and Connelly, D.P.: *Knowledge-based systems in laboratory medicine and pathology: A review and survey of the field.* Archives of Laboratory Medicine and Pathology 111:116-119, 1987.

8. Thompson, W.B., Johnson, P.E. and Moen, J.B.: *Recognition-based diagnostic reasoning.* Proc. Eighth IJCAI, Karlsruhe, West Germany, August, 1983.

National AIM Project: ATTENDING Project:
A Critiquing Approach to
Expert Computer Advice

Principal Investigator: Perry L. Miller, M.D., Ph.D.
Department of Anesthesiology
Yale University School of Medicine
New Haven, CT 06510
(203) 785-2802

Our project is exploring the "critiquing" approach to bringing computer-based advice to the practicing physician.

Critiquing is a different approach to the design of artificial intelligence based expert systems. Most medical expert systems attempt to simulate a physician's decision-making process. As a result, they have the clinical effect of trying to tell a physician what to do: how to practice medicine. In contrast, a critiquing system first asks the physician how he contemplates approaching his patient's care, and then critiques that plan. In the critique, the system discusses any risks or benefits of the proposed approach, and of any other approaches which might be preferred. It is anticipated that the critiquing approach may be particularly well suited for domains, like medicine, where decisions involve a great deal of *subjective* judgment.

To date, several prototype critiquing systems have been developed in different medical domains:

1. ATTENDING, the first system to implement the critiquing approach, critiques anesthetic management.
2. HT-ATTENDING critiques the pharmacologic management of essential hypertension.
3. VQ-ATTENDING critiques aspects of ventilator management.
4. PHEO-ATTENDING critiques the laboratory and radiologic workup of a patient for a suspected pheichromocytoma.
5. In addition, a domain-independent system, ESSENTIAL-ATTENDING, has been developed to facilitate the implementation of critiquing systems in other domains.

PUBLICATIONS

1. Miller, P.L.: Expert Critiquing Systems: Practice-Based Medical Consultation by Computer. New York: Springer-Verlag, 1986.
2. Miller, P.L. (Ed.): Selected Topics in Medical Artificial Intelligence. New York: Springer-Verlag (in press).
3. Miller, P.L., Shaw, C., Rose, J.R., Swett, H.A.: Critiquing the process of radiologic differential diagnosis. Computer Methods and Programs in Biomedicine 22:12-25, 1986.
4. Miller, P.L.: The evaluation of artificial intelligence systems in medicine. Computer Methods and Programs in Biomedicine 22:5-11, 1986.

5. Rennels, G.D., Shortliffe, E.H., Miller, P.L.: Choice of explanation in medical management: A multi-attribute model of artificial intelligence approaches. Medical Decision Making 7:22-31, 1987.

6. Mars, N.J.I., Miller, P.L.: Knowledge acquisition and verification tools for medical expert systems. Medical Decision Making 7:6-11, 1987.

7. Miller, P.L., Blumenfrucht, S.J., Rose, J.R., Rothschild, M., Swett, H.A., Weltin, G., Mars, N.J.I.: HYDRA: A knowledge acquisition tool for expert systems which critique medical workup. Medical Decision Making 7:12-21, 1987.

8. Swett, H.A., Miller, P.L.: ICON: A computer-based approach to differential diagnosis in radiology. Radiology (in press).

9. Rennels, G.D., Shortliffe, E.H., Stockdale, F.E., Miller, P.L.: A computational model of reasoning from the clinical literature. Computer Methods and Programs in Biomedicine (in press).

10. Rennels, G.D., Shortliffe, E.H., Stockdale, F.E., Miller, P.L.: A structured representation of the clinical literature and its use in a medical management advice system. Bulletin du Cancer (in press).

11. Miller, P.L.: Exploring the critiquing approach: Sophisticated practice-based feedback by computer. Proceedings of the Fifth World Conference on Medical Informatics: MEDINFO-86, Washington, D.C., October 1986, pp 2-6.

12. Mars, N.J.I., Miller, P.L.: Tools for knowledge acquisition and verification in medicine. Proceedings of the Tenth Symposium on Computer Applications in Medical Care, Washington, D.C., October 1986, pp. 36-42.

13. Miller, P.L., Blumenfrucht, S.J., Rose, J.R., Rothschild, M., Weltin, G., Swett, H.A., Mars, N.J.I.: Expert system knowledge acquisition for domains of medical workup: An augmented transition network model. Proceedings of the Tenth Symposium on Computer Applications in Medical Care, Washington, D.C., October 1986, pp. 30-35.

14. Rennels, G.D., Shortliffe, E.H., Stockdale, F.E., Miller, P.L.: Reasoning from the clinical literature: The Roundsman system. Proceedings of the Fifth World Conference on Medical Informatics: MEDINFO-86, Washington, D.C., October 1986, pp. 771-775.

15. Rennels, G.D., Shortliffe, E.H., Stockdale, F.E., Miller, P.L.: Updating an expert knowledge base as medical knowledge evolves: Examples from oncology management. Proceedings of the American Association of Medical Systems and Informatics Congress 87, San Francisco, May 1987, pp. 228-231.

16. Fisher, P.R., Miller, P.L., Swett, H.A.: A script-based representation of medical knowledge involving multiple perspectives. Proceedings of the American Association of Medical Systems and Informatics Congress-87, San Francisco, May 1987, pp. 233-237.

17. Miller, P.L.: Expert consultation systems in medicine: A complex and fascinating domain. Proceedings of the Annual Meeting of the IEEE (Electro-87), New York, April 1987, pp. 1/2:1-4 (invited paper).

Stanford Project: REFEREE Project

Principal Investigators: Bruce G. Buchanan, Principal Investigator
Computer Science Department
Stanford University
Stanford, California 94305

Byron W. Brown, Co-Principal Investigator
Department of Medicine
Stanford University Medical Center
Stanford, California 94305

Daniel E. Feldman, Associate Investigator
Department of Medicine
Stanford University Medical Center
Stanford, California 94305

The goals of this project are related both to medical science and Artificial Intelligence: (a) use AI methods to allow the informed but non-expert reader of the medical literature to evaluate a randomized clinical trial, and (b) use the interpretation of the medical literature as a test problem for studies of knowledge acquisition and fusion of information from disparate sources. REFEREE and REVIEWER, a planned extension, will be used to evaluate the medical literature of clinical trials to determine the quality of a clinical trial, make judgements on the efficacy of the treatment proposed, and synthesize rules of clinical practice. The research is an initial step toward a more general goal - building computer systems to help the clinician and medical scientist read the medical literature more critically and more rapidly.

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

Principal Investigator: Bharat Nathwani, M.D.
Department of Pathology
HMR 204
2025 Zonal Avenue
University of Southern California
School of Medicine
Los Angeles, California 90033
(213) 226-7064 (NATHWANI@SUMEX-AIM)

Lawrence M. Fagan, M.D., Ph.D.
Medical Computer Science Group
Department of Medicine
Medical School Office Building
Stanford, California 94305
(415) 723-6979 (FAGAN@SUMEX-AIM)

The PATHFINDER Project is centered on the construction of an expert system for assisting pathologists with the diagnosis of tissue pathology. PATHFINDER research is focused on the domain of lymph node pathology. The project is based at the University of Southern California in collaboration with the Stanford University Medical Computer Science Group. Ongoing AIM research has been addressing fundamental problems of knowledge representation, reasoning strategies, user modeling, explanation, and user acceptance. A pragmatic goal of the project is to provide a valuable diagnostic and educational tool for pathologists with different levels of training and experience by integrating diverse knowledge about lymph node pathology. It is hoped that PATHFINDER basic research on representation and inference in combination with the pragmatic goals of constructing a clinically-relevant diagnostic aid will lead to useful advances in medical computing.

A pilot version of the program provides diagnostic advice on eighty common benign and malignant diseases of the lymph nodes based on 150 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.

AIM Pilot Project: RXDX Project

Principal Investigators:
Robert Lindsay, Ph.D. (313) 764-4227
Michael Feinberg, M.D., Ph.D. (215) 842-4208
University of Michigan
Ann Arbor, Michigan

We are developing a prototype expert system that could act as a consultant in the diagnosis and management of depression. Health professionals will interact with the program as they might with a human consultant, describing the patient, receiving advice, and asking the consultant about the rationale for each recommendation. The program uses a knowledge base constructed by encoding the clinical expertise of a skilled psychiatrist in a set of rules and other knowledge structures. It will use this knowledge base to decide on the most likely diagnosis (endogenous or nonendogenous depression), assess the need for hospitalization, and recommend specific somatic treatments when this is indicated (e.g., tricyclic antidepressants). The treatment recommendation will take into account the patient's diagnosis, age, concurrent illnesses, and concurrent treatments (drug interactions).

The potential benefits to psychiatry include: making relatively skilled psychiatric consultation widely available in underserved areas, including some public mental health facilities where patients are seen by non-psychiatrists and have relatively little direct patient-physician contact; providing non-psychiatrically trained physicians with additional information about psychiatric diagnosis and treatment; avoiding errors of oversight caused by inaccessible patient data; and increased productivity in patient care. Like any good consultant, the program will be able to teach the interested user, and can function as a teaching tool independent of direct clinical application.

PUBLICATIONS

1. Feinberg, M. and Lindsay, R. K.: *Expert systems in Psychiatry and Psychopharmacology*. Psychopharmacol. Bull., 22, 1986, 311-316.

2. Lindsay, R. K. Expert Systems in Psychiatric Diagnosis: Rule-Based Systems. Presented at MedInfo86, Washington, D.C.

3. Feinberg, M. What Psychiatrists Can't Do. Presented at Medinfo86, Washington, D. C.

National AIM Project: DECISION SUPPORT FOR TIME-VARYING CLINICAL PROBLEMS

Principal Investigator: Lawrence Widman, M.D., Ph.D.
Division of Cardiology
Case Western Reserve University
2065 Adelbert Road
Cleveland, OH 44106
(216) 844-3153

Time-varying systems, which include many areas of medicine, science, economics, and business, can be described mathematically by differential equations. They are distinct from the pattern-matching and logic-based domains dealt with so successfully by existing expert system methods, because they can include feedback relationships. It is generally felt that they are best approached by enhancement of existing methods for deep model-based reasoning.

The goal of this project is to develop AI methods for capturing and using knowledge about time-varying systems. The strategy is to address general problems in model-based knowledge representation and reasoning. The intermediate objective is to develop methods which are powerful enough to work in selected realistic situations yet are general enough to be transportable to other, unrelated knowledge domains.

The tactical approach is to work on well-defined yet complex and interesting problems in the medical domain. We have, therefore, selected the human cardiovascular system as our prototype of a time-varying system, and are developing methods for representing and reasoning about its mechanical and electrical activities in the normal and diseased states.

REFERENCES

1. Widman, L.E. Reasoning about Diagnosis and Treatment in a Causal Medical Model using Semi-Quantitative Simulation and Inference. Workshop on Artificial Intelligence in Medicine, National Conference on Artificial Intelligence, AAAI-87, Seattle.

2. Widman, L.E., Lee, Y.-B., and Y.-H. Pao. Diagnosis of Causal Models by Semi-Quantitative Reasoning (submitted to SCAMC 1987).

3. Widman, L.E., Lee, Y.-B., and Y.-H. Pao. Diagnosis of Causal Medical Models by Semi-Quantitative Reasoning. In: Miller, P.L. (ed.) Topics in Medical Artificial Intelligence, Springer-Verlag (in preparation).

4. Lee, Y.-B. and L.E. Widman. Reasoning about Diagnosis and Treatment in a Causal Time-varying Domain using Semi-Quantitative Simulation and Inference. Workshop on Artificial Intelligence and Simulation, National Conference on Artificial Intelligence, AAAI-86, Philadelphia.

5. Widman, L.E. Representation Method for Dynamic Causal Knowledge Using Semi-Quantitative Simulation. Fifth World Conference on Medical Informatics. 1986: 180-184.

National AIM Project: KNOWLEDGE ENGINEERING FOR RADIATION THERAPY

Principal Investigator: Ira J. Kalet, Ph.D.
School of Medicine
University of Washington at Seattle
Seattle, Washington 98195
(206) 548-4107

We are developing an expert system for planning of radiation therapy for head and neck cancers. The project will ultimately combine knowledge-based planning with numerical simulation of the radiation treatments. The numerical simulation is needed in order to determine if the proposed treatment will conform to the goals of the plan (required tumor dose, limiting dose to critical organs). The space of possible radiation treatments is numerically very large, making traditional search techniques impractical. Yet, with modern radiation therapy equipment, the design of treatment plans might be significantly aided by automatically generating plans that meet the treatment constraints. The project will result in systematization of knowledge about radiation treatment design, and will also provide an example of how to represent and solve design problems with a knowledge based system.

This project has some relevance to computer science as well, in that our approach, if successful, may contribute to a better understanding of design problem solving with knowledge-based systems.

REFERENCES

I. Kalet and W. Paluszynski: A Production Expert System for Radiation Therapy Planning. Proceedings of the AAMSI Congress 1985, May 20-22, 1985, San Francisco, California. Edited by Allan H. Levy and Ben T. Williams. American Association for Medical Systems and Informatics, Washington, D.C., 1985.

W. Paluszynski and I. Kalet: Radiation Therapy Planning: A Design Oriented Expert System. WESTEX-87 (Western Conference on Expert Systems), Anaheim, California, June 2-4, 1987.

I. Kalet and J. Jacky: Knowledge-based Computer Simulation for Radiation Therapy Planning. Proceedings of the Ninth International Conference on the use of Computers in Radiotherapy, Scheveningen, the Netherlands, June 1987. North Holland, 1987.

AIM Pilot Project: COMPUTER-BASED EXERCISES IN PATHOPHYSIOLOGIC DIAGNOSIS

Principal Investigator: J. Robert Beck, M.D.
MIS Butler I
2 Maynard St.
Dartmouth College
School of Medicine
Hanover, NH 03755
(603) 646-7171

Research in artificial intelligence at Dartmouth Medical School focuses on three main areas: 1) knowledge-based systems applied to laboratory medicine and pathology, 2) knowledge acquisition using machine learning techniques, and 3) computer-based instruction using artificial intelligence techniques to critique students' workup plans. These projects have in common the fundamental research questions of how knowledge should be represented and used in a classification approach to problem-solving related to the use of laboratory data.

An interdisciplinary team of computer scientists, physicians, and educators is working on the Computer-based Exercises project. A prototype system is nearing completion, with formative evaluation scheduled for Fall, 1987.

REFERENCES

Beck, J.R., Prietula, M.J., Russo, E.A.: A role for intelligent systems in teaching medical pathophysiology. In: Salamon, R., Blum, B., Jorgenson, M. (eds). Proc. Fifth Conf. Med. Inform. (MEDINFO '86), Elsevier-North Holland, Amsterdam, 1986, 936-938.

Beck, J.R.: Artificial intelligence: A topic for Medical Decision Making? (edit.) Med. Decis. Making 1987; 7:4.

References

1. Barr, Avron, Paul R. Cohen and Edward A. Feigenbaum. *The Handbook of Artificial Intelligence, Volumes I, II, and III*. William Kaufmann, Inc., Los Altos, CA, 1981 and 1982.

2. Congressional Research Service, Library of Congress. The Impact of Information Technology on Science. Science Policy Study Background Report Number 5, Task Force on Science Policy, Committee on Science and Technology, U.S. House of Representatives, September, 1986.

3. Coulter, C. L. "Research Instrument Sharing." *Science 201*, 4354 (1978).

4. Harmon, Paul and King, David. *Expert Systems - Artificial Intelligence in Business*. John Wiley & Sons, Inc., New York, NY, 1985.

5. Hayes-Roth, F., Waterman, D. A. & Lenat, D. B. (Eds.). *Building Expert Systems*. Addison-Wesley, Reading, MA, 1983.

6. Horvitz, E.J., Heckerman, D.E., and Langlotz, C.P. A Framework for Comparing Alternative Formalisms for Plausible Reasoning. Proceedings of AAAI-86, Fifth National Conference on Artificial Intelligence, American Association for Artificial Intelligence, Menlo Park, CA, August, 1986, pp. 210-214.

7. Information Technology R&D Project Staff. Information Technology R&D: Critical Trends and Issues (Summary). Report OTA-CIT-269, Congressional Office of Technology Assessment, October, 1985.

8. Keith A. Lantz et. al. *V - System 4.1 Reference Manual*. December 1, 1983. Computer Systems Laboratory, Stanford University.

9. Keith A. Lantz, David R. Cheriton, and William I. Nowicki. Third Generation Graphics for Distributed Systems. Computer Systems Laboratory. Stanford University, December 21, 1982

10. Lederberg, J. "Digital Communications and the Conduct of Science: The New Literacy." *Proceedings of the IEEE 66*, 11 (1978).

11. Nilsson, N.. *Principles of Artificial Intelligence*. Tioga, Palo Alto, CA, 1980.

12. NLM Planning Panel 4. NLM Long Range Plan: Medical Informatics. Shortliffe, E.H., Panel 4 Chairman , National Library of Medicine, January, 1987.

13. Rich, E.. *Artificial Intelligence*. McGraw-Hill, New York, 1983.

14. Paul S. Rosenbloom, John E. Laird. Mapping Explanation-Based Generalization onto SOAR. Proceedings of the Fifth National Conference on Artificial Intelligence, American Association for Artificial Intelligence, Philadelphia, Penn., August 11-15, 1986, pp. 561-567. Also KSL-86-46 and STAN-CS-86-1111

15. Scheifler, R.W. and Gettys, J. The X Window System. Draft October 1986. To appear in a special issue of the *ACM Transactions on Graphics* -- user interface software

16. Steele, Guy L., Jr.. *Common Lisp - The Language*. Digital Press, Burlington, MA, 1984.

17. *NeWS Preliminary Technical Overview*. Sun Microsystems, Inc., 1986.

18. Waterman, Donald A.. *A Guide to Expert Systems*. Addison-Wesley Publishing Company, Menlo Park, CA, 1986.

19. David C. Wilkins and Bruce G. Buchanan. On Debugging Rule Sets When Reasoning Under Uncertainty. Tech. Rept. KSL 86-30, Stanford University, Knowledge Systems Laboratory, July, 1986. Earlier version appeared in Proceedings of the Fifth National Conference on Artificial Intelligence, August 1986

20. David C. Wilkins, Willian J. Clancey and Bruce G. Buchanan. Using and Evaluating Differential Modeling in Intelligent Tutoring and Apprentice Learning Systems. Tech. Rept. KSL 86-62, Stanford University, Knowledge Systems Laboratory, October, 1986.

21. David C. Wilkins. Knowledge Base Debugging Using Apprenticeship Learning Techniques. Tech. Rept. KSL 86-63, Stanford University, Knowledge Systems Laboratory, December, 1986.

22. David C. Wilkins, William J. Clancey and Bruce G. Buchanan. Knowledge Base Refinement Using Abstract Control Knowledge. Tech. Rept. KSL 87-01, Stanford University, Knowledge Systems Laboratory, January, 1987.

23. Winston, P.. *Artificial Intelligence, 2nd ed*. Addison-Wesley, Reading, MA, 1984.