of pulmonary disease in terms of measured data, referral diagnosis, and patient characteristics. The program must operate effectively over a wide range of pathological conditions with a broad clinical perspective about the possible complexity of the pathology.

B. Medical Relevance and Collaboration

Interpretation of standard pulmonary function tests involves attempting to identify the presence of obstructive airways disease (OAD: indicated by reduced flow rates during forced exhalation), restrictive lung disease (RLD: indicated by reduced lung volumes), and alveolar-capillary diffusion defect (DD: indicated by reduced diffusivity of inhaled CO into the blood). Obstruction and restriction may exist concurrently, and the presence of one mediates the severity of the other. Obstruction of several types can exist. In the laboratory at the Pacific Medical Center (PMC), about 50 parameters are calculated from measurement of lung volumes, flow rates, and diffusion capacity. In addition to these measurements, the physician may also consider patient history and referral diagnosis in interpreting the test results and diagnosing the presence and severity of pulmonary disease.

Currently PUFF contains a set of about 250 physiologically based interpretation "rules". Each rule is of the form "IF <condition> THEN <conclusion>". Each rule relates physiological measurements or states to a conclusion about the physiological significance of the measurement or state.

The interpretation system operates in a batch mode, accepting input data and printing a report for each patient. The report includes: (1) Interpretation of the physiological meaning of the test results, the limitation on the interpretation because of bad or missing data; the response to bronchodilators if used; and the consistency of the findings and referral diagnosis. (2) clinical findings, including the applicability of the use of bronchodilators, the consistency of multiple indications for airway obstruction, the relation between test results, patient characteristics and referral diagnosis. (3) Interpretation Summary, which consists of the diagnosis of presence and severity of abnormality of pulmonary function.

C. Progress Summary

Knowledge base:

PUFF is implemented on the PDP-10 in a version of the MYCIN system which is designed to accept rules from new task domains. A typical rule is:

```
If (FVC>=80) and  (FEV1/FVC<predicted-5) then PEAK FLOW RATES ARE
REDUCED, SUGGESTING AIRWAY OBSTRUCTION OF DEGREE
        if (predicted-15<= FEV1/FVC <predicted-5) MILD
        if (predicted-25<=FEV1/FVC <predicted-15) MODERATE
        if (predicted-35<=FEV1/FVC <predicted-25) MODERATE TO SEVERE
        if (FEV1/FVC <predicted-35)               SEVERE
```

This rule compares the ratio of FEV1, the amount of air that can be forced out in the first second of exhalation with the total "forced vital capacity" (FVC) or total amount of lung volume that can be exhaled. The inability to force out a large percentage of air in the critical first second implies the presence of an obstruction in the airway.

Results

The results of the PUFF system are reviewed in more detail in the 1978 SUMEX annual report and [Kunz 78]. A version of the PUFF system is now in routine daily use at Pacific Medical Center. Reports are reviewed by a physician pulmonary physiologist. Over 85 % of the reports are accepted by the physician without change; they are signed and entered into the patient record. Most of the remaining reports are edited on-line to modify a small point in the test interpretation.

Table 1 reviews a study of the agreement in severity of diagnoses made by two MD's and by PUFF rules. This study was made with a less complete rule base than what is currently available in the pulmonary lab. In 94% of 144 cases analyzed in a prospective study, the degree of severity (0=none; 1=mild; 2=moderate; 3=moderately-severe; 4=severe) of OAD diagnosed by the first MD was within a single degree of severity of OAD diagnosed by the second MD. In 96% of the 79 cases for which the first MD diagnosed OAD, the second MD diagnosed the severity of OAD within one level of the severity diagnosed by the first MD. Agreement within one degree of severity of the diagnoses by the first and second MD's was substantially lower in RLD and DD cases. These discrepancies occurred because the second MD consistently called RLD more severe than did the first MD, and he consistently did not diagnose diffusion defects when the first MD diagnosed DD of moderate or greater degree.

	Percent Agreement with 1st MD			
	All 144 cases		1st MD made Dx	
Diagnosis	Second M.D.	PUFF Rules	Second M.D.	PUFF Rules
Normal				
OAD	0.94	0.99	0.96	0.97
RLD	0.92	0.97	0.77	1.00
DD	0.87	0.87	0.60	0.80
Total	0.91	0.94	0.86	0.94

Table 1. Percent agreement within one degree of severity of diagnoses
Approximately 1500 patients have been interpreted by the system.
by two MD's and by the first MD and rules.

In addition to the use of PUFF as a working clinical tool, it has been very useful for evaluation of knowledge representation methods. The original PUFF knowledge base (around 60 rules) represents realistic medical knowledge but is small enough to use for experiments. The PUFF knowledge has been used in the AGE system, the CENTAUR system using a combination of rules and prototypes, and the WHEEZE system, a UNIT-based approach to knowledge-representation.

D. Relevant publications:

[1] "A Physiological Rule-Based System for Interpreting Pulmonary Function Test Results", J.C. Kunz, R.J. Fallat, D.H. McClung, B.A. Votteri, J.S. Aikins, H.P. Nii, L.M. Fagan, E.A. Feigenbaum, HPP 78-154, Stanford Heuristic Programming Project, 1978.

[2] "Prototypes: An Approach to Knowledge Representation for Hypothesis Formation", Aikins, J.S., HPP-79-10 (working paper), 1979. Also Int. Joint Conf. on Artif. Intell., Tokyo, Japan, August, 1979.

[3] "A Physiological Rule-Based System for Interpreting Pulmonary Function Test Results", J.C. Kunz, R.J. Fallat, D.H. McClung, B.A. Votteri, J.S. Aikins, H.P. Nii, L.M. Fagan, E.A. Feigenbaum, Proceedings of Computers in Critical Care and Pulmonary Medicine, IEEE Press, 1979.

[4] "The Art of Artificial Intelligence: Themes and Case Studies of Knowledge Engineering", E.A. Feigenbaum, Proceedings of the IJCAI, (1977). (Also Stanford Computer Science Department Memo STAN-CS-77-612).

VM

A. Technical Goals

The Ventilator Manager program (VM) interprets the clinical significance of time varying quantitative physiological data from patients in the ICU. This data is used to manage patients receiving ventilatory assistance. An extension of a physiological monitoring system, VM (1) provides a summary of the patient's physiological status appropriate for the clinician; (2) recognizes untoward events in the patient/machine system and provides suggestions for corrective action; (3) suggests adjustments to ventilatory therapy based on a long-term assessment of the patient status and therapeutic goals; (4) detects possible measurement errors; and, (5) maintains a set of patient-specific expectations and goals for future evaluation. The program produces interpretations of the physiological measurements over time, using a model of the therapeutic procedures in the ICU and clinical knowledge about the diagnostic implications of the data. These therapeutic guidelines are represented by a knowledge base of rules created by clinicians with extensive ICU experience.

The PMC and SUMEX computers will be linked by telephone. The physiological measurements are generated every 2-10 minutes by the PMC computer system. It will be provided to VM in real time using the phone link. Information, suggestions to the clinicians, and/or requests for additional information will be sent back to the ICU for action.

B. Medical Relevance and Collaboration

To assist in the interpretation process, VM must be able to recognize unusual or unexpected clinical events (including machine malfunction) in a manner specifically tailored to the patient in question. The interpretation task is viewed as an ongoing process in the ICU, so that the physiological measurements must be continually reevaluated producing a current clinical picture.

This picture can then be compared with previous summary of patient status to recognize changes in patient condition upon which therapy selection and modifications can be made. The program must also determine when the measurements are most likely to be sensitive to error or when external measurements would be of diagnostic significance.

VM offers a new approach toward more accurate recognition of alarm conditions by utilizing the history and situation of the patient in the analysis. This is in contrast to the use of static limits applied to measurements generated to fit the "typical patient" under normal conditions. Our program uses a model of interpretation process, including the types and levels of conclusions drawn manually from the measurements to provide a summary of patient condition and trends. The program generated conclusions are stated at levels more abstract than the raw data; for example, the presence of hemodynamic stability/instability rather than in terms of heart rate and mean arterial pressure. When the data is not reliable enough to make these conclusions, additional tests may be suggested. The recognition of important conclusion for which external verification is sought, will also elicit the suggestion for confirming tests from the program.

C. Progress Summary

VM has been demonstrated using actual patient data recorded on magnetic tape. The input to VM is the values of 30 physiological measurements provided on a 2- or 10-minute bases by a automatic monitoring system. The output is in the form of suggestions to clinicians and periodic summaries (see example case below).

Example Case

The following case demonstrates the current state of development of the system. The data used in this example were obtained from a post-cardiac surgery patient from the ICU at Pacific Medical Center. The terms VOLUME, ASSIST, CONTROLLED MANDATORY VENTILATION (CMV), and T-PIECE refer to specific types of ventilatory assistance. The output format is:(a) ..time of day.., (b) generated comments for clinicians, starting with "**", and (c) commentary in {}.

```
..1350.. ..1351..
** SYSTEM ASSUMES PATIENT STARTING VOLUME VENTILATION.
                                              {monitoring started}
** HYPERVENTILATION                           {diagnostic conclusions
** TACHYCARDIA                                 based on monitored data}
** PATIENT HYPERVENTILATING.                  {suggested therapy based on
** SUGGEST REDUCING MINUTE VOLUME              diagnosis}
..1400..
. . .
..1450..
** HYPERVENTILATION
** TACHYCARDIA
** PATIENT HYPERVENTILATING.
** SUGGEST REDUCING MINUTE VOLUME
..1500..
** HYPERVENTILATION
** PATIENT HYPERVENTILATING.
** SUGGEST REDUCING MINUTE VOLUME


Current conclusions:                {summary information}
HYPOTENSION PRESENT for 41 MINUTES
HYPERVENTILATION PRESENT for 33 MINUTES
SYSTOLIC B.P. LOW for 46 MINUTES
{etc.}
```

```
Conclusions:       {time of day}   |.....|.....|.....|.
                                   13    14    15    16
HEMODYNAMICS -- STABLE                        ====
HYPERVENTILATION -- PRESENT            =     == == ====
HYPOTENSION -- PRESENT                   ====  ========
TACHYCARDIA -- PRESENT                 ==== ==

patient is on ASSIST                         =====   ==
patient is on CMV                        ====     ===
patient is on VOLUME                   ==
patient is on NOT-MONITORED        ====

Goal is CMV                            ================
Goal is VOLUME                     ====
                                   |.....|.....|.....|.
                                   13    14    15    16
```

The availability of new measurements requires updated interpretations based on the changing values and trends. As the patient setting changes--e.g., as a patient starts to breathe on his own during removal (weaning) from the ventilator--the same measurement values lead to different interpretations. In order to properly interpret data collected during changing therapeutic contexts, the knowledge base includes a model of the stages that a patient follows from admission to the unit through the end of the critical monitoring phase. Recognition of the appropriate patient context is an essential step in determining the meaning of most physiological measurements.

The majority of the knowledge of the VM program is concerned with the relations between the various concepts known by the program. These concepts include: measurement values, typical therapeutic decisions, diagnostic labels, and physiological states. The connections between concepts are represented by a form of production rules using the structure "IF premise THEN action."

The rules in VM are of the form:

IF facts about measurements or previous conclusions are true

THEN

1) Make a conclusion based on these facts;
2) Print out suggestions for the clinician;
3) Establish expectations about the future values of measurements.

A sample VM rule is shown below.

```
STATUS RULE: STABLE-HEMODYNAMICS
DEFINITION: Defines stable hemodynamics for most settings
APPLIES to patients on VOLUME, CMV, ASSIST, T-PIECE
COMMENT: Look at mean arterial pressure for changes in
    blood pressure and systolic blood pressure for maximum
    pressures.
IF
  HEART RATE is ACCEPTABLE
  PULSE RATE does NOT CHANGE by 20 beats/minute in 15 minutes
  MEAN ARTERIAL PRESSURE is ACCEPTABLE
  MEAN ARTERIAL PRESSURE does NOT CHANGE by 15 torr in 15 minutes
  SYSTOLIC BLOOD PRESSURE is ACCEPTABLE
THEN
  The HEMODYNAMICS are STABLE
```

Figure 1. Sample VM Interpretation Rule. The meaning of 'ACCEPTABLE' varies with the clinical context--i.e., whether the patient is receiving VOLUME or CMV ventilation, etc. This rule makes a conclusion for internal system use. Similar rules also make suggestions to the user.

An extended description of the VM program can be found in a Ph.D. thesis to be available shortly as a Stanford technical memo.

D. Relevant publications:

Fagan, L.M., Kunz, J.C., Feigenbaum, E.A. and Osborn, J.J.: A symbolic processing approach to measurement interpretation in the intensive care unit. Proc. Third Annual Symposium Computer Applications in Medical Care, Silver Spring, Maryland, October, 1979, pp. 30-33.

Fagan, L.M., Shortliffe, E.H. and Buchanan, B.G.: Computer-based medical decision making: From MYCIN to VM. Automedica 3(2), 1980.

Fagan, L.M.: VM: Representing Time-Dependent Relations in a Medical Setting, Ph.D. dissertation, Stanford University (forthcoming).

Osborn, J.J., Fagan, L.M., Fallat, R.J., et al: Managing the data from respiratory measurements. Med. Instrumentation, November-December, 1979. (Winner of the 'Best Article of the Year' Award for AAMI - 1979.)

II. Research Plans

A. Long Range goals and plans

The main emphasis of this project has switched from the development of the PUFF system to the extension and evaluation of the VM system. This change is consistent with the goals of the NIH proposal, the current use of PUFF in a clinical setting and the research questions that remain in the VM portion of the project. Some long term interests, such as consensus building between experts, will be examined using both application areas.

The long range goal of the VM project is to develop and evaluate an interpretation system that will improve patient care in the ICU. Toward this goal, we plan to extend the rule set, provide better models of physiology and therapy, and start a formal evaluation of the program's therapeutic advice.

The rule set in VM will be extended to handle a greater number of patients. The current emphasis of the program has been on the management of post-surgical patients with normal pre-operative status. We will continue to concentrate on post-surgical patients, but the knowledge base will be augmented to handle patients with additional problems noted before surgery or those who have an unusual response to therapy after surgery. The majority of this knowledge will be used to create a more detailed classification of the patient population and the corresponding generation of expectations.

These rule set extensions will ultimately be limited by representation of the underlying cardiopulmonary physiology and the therapeutic plans used in the ICU. Still other improvements will come from a better model of the mechanical ventilator and other instrumentation. Each of these models will provide a structure upon which to build the rule base, and are motivated by the special problems of evaluating the patient's status in a dynamic clinical setting. These problems include the evaluation of the relationship between actual and anticipated response to therapy and the the recognition of a particular therapy step in the context of a larger therapeutic plan (e.g., the process of removing a patient from the ventilator when the patient has an underlying lung disease).

In order to determine the appropriate areas for these model building activities and to insure acceptance by physicians, a careful prospective validation will be carried out to identify the accuracy of the advice of the program.

III. Interactions With The SUMEX-AIM Resource

A. Collaborations and medical use of programs via SUMEX

The PUFF/VM project requires very close collaboration between investigators at two institutions separated by fifty miles. This kind of collaboration, in which program development and testing proceeds concurrently on the same application system, requires a computer network facility for sharing of code, data and ideas. SUMEX has been used at PMC for running programs developed concurrently by Stanford and PMC staff, and data has been taken from the PMC computer system and transferred to SUMEX on magnetic tape for program development and testing. The SUMEX staff has developed a cooperating set of computer programs to allow the PMC computer and the SUMEX/2020 systems to actively exchange files and program data and output. This link is required for real-time testing of VM. SUMEX staff had the necessary resources to design and implement this vital link mechanism. The link is now undergoing final testing, and it will dramatically contribute to the effectiveness of the research environment for VM.

We also use the SUMEX system for purposes other than program development. A joint PMC-Stanford report of VM was prepared entirely through the the word communications and processing capabilities of SUMEX. Investigators from the two institutions have collaborated in writing reports together; the separate contributions are prepared on SUMEX, edited and merged with an exchange of messages but without ever requiring actual meetings. We have also used the system for trading bibliographic information with other AIM users. We have also experimentally run the Internist program using SUMEX.

B. Sharing and interactions with other SUMEX-AIM projects

We have participated in the AIM workshop and had very fruitful interaction with a number of other SUMEX users, directly influencing our perception of important problems and potentially appropriate solutions. Personal contacts at other conferences, at Stanford AI weekly meetings, and at PMC with visiting members of the AIM community, have also been very helpful in keeping abreast of the current thinking of other members of the AI community and with members of the medical community interested in computer based physiological analysis and diagnosis. We believe that the use of a common machine and the existence of the AIM conference encourages increased recognition and better communication with other AIM workers. Within AIM we most closely collaborate with the MYCIN, MOLGEN and DENDRAL projects, who share common space, common techniques, and common attitudes.

C. Critique of resource management

The SUMEX community continues to be an extremely supportive environment in which to do research on uses of artificial intelligence in clinical medicine. The community has two equally vital resources -- the people with knowledge and interest in AI and the facility on which AI system development can proceed. They are equally excellent as resources, helping hands when faced with problems, and friendly support for continued productive research. The availability of INTERLISP; of a facility on which routine data processing functions (eg. manipulating magnetic tapes and making long listings) can take place; and of message-sending among remote users are all vital functions for our project. SUMEX provides them in an environment which is friendly and reliable. Management of the SUMEX facility is consistent and excellent.

D. Needs and plans for other computational resources

The future goals of the project (as described above) will require considerable computational requirements in the near future. These requirements will come in the form of active development of a large INTERLISP program, and extensive testing of the program in a clinical environment. We hope to perform as much of the evaluation work as possible on the 2020. System development of the program will probably continue on SUMEX during off-hours or be off-loaded to the spare time on the 2020. All subsidiary text processing tasks have been off-loaded from SUMEX to avoid the high load average situation during the day. The storage of usable versions of the program and the test files used in the evaluation of the program will require about 1000 additional pages on the SUMEX computer.

The process of validation then will require running VM in real time so that PUFF/VM researchers can compare system interpretations of patient state with the actual state as determined by careful concurrent clinical evaluation. We believe that we can effectively use 3-4 hours per day of running VM in a real time test mode during the initial validation period. As the system operation becomes more predictable in 1981, longer running times will be required to identify system problems, and we predict the need to run the system for a full eight hour shift each day on an intermittent basis.

E. Recommendations for future community and resource development

We perceive the evolution of our AI capability as moving from a highly speculative development state, for which the interactive development capabilities of SUMEX are vital, to a more stable but still changing validation-and-evaluation state. Ultimately we foresee rather stable specification of a program for routine clinical use. Thus, we see the need to transfer our AI techniques from the SUMEX PDP-10 to a local host. For this transfer, a principal long-range need is for software systems that will allow us to run AI systems on a mini-computer after they have been developed on the more powerful SUMEX facility. If the validation of PUFF/VM in the PMC clinical setting shows the programs to be effective in health care, then we hope and expect to be able to provide the capability on a routine basis.

We would also like to encourage SUMEX's role as a facilitator of information transfer between AIM users. This can happen by scheduling on-line demonstrations that any other user can "connect to," or by providing a common depository for AI and medicine information. This might take the form of on-line bibliographies, collecting common user packages, or connecting common research interests together. This communication service would compliment the technical service facilities currently provided by the SUMEX staff.

9.2.7 Simulation of Cognitive Processes

Simulation of Cognitive Processes

James G. Greeno
Alan M. Lesgold
Learning Research and Development Center
University of Pittsburgh

SUMMARY OF RESEARCH PROGRAM

Project Rationale

Our goal continues to be contribution to increased theoretical understanding of basic cognitive processes involved in reading, problem solving, and other tasks requiring cognitive skills. The form in which we theorize is computer simulation of human performance. Models of cognitive processes stand as hypotheses about the components of human information processing and the ways in which they interact in significant cognitive tasks.

Medical Relevance

Increased understanding of basic cognitive processes is relevant to medical needs in two ways. One form of relevance involves performance of tasks in the practice of medicine. One of us (Lesgold) collaborates in research on cognitive processes in radiology. Understanding of the nature and organization of these processes, and those in other domains of medical practice, should provide principles useful in the design of medical training and the arrangement of conditions for more efficient delivery of medical services. The second form of relevance of basic research in cognition to medical needs is in development of understanding of the cognitive requirements of elementary skills such as reading and arithmetic computation, in which cognitive deficits can constitute sever disablement. Improved understanding of these basic skills should provide principles useful in improvement of diagnosis and therapy for learning disabilities.

Highlights of Research Progress

--Accomplishments this past year

Progress was made in the study of basic processes in reading skill, where preliminary findings suggest that children whose speed of vocalizing words develops slowly are destined to be slow in acquiring poor reading skill (Lesgold, 1979). Progress in Anderson's ACT system and in our own empirical work will enable more computer simulation work on reading in the coming year. Comprehension of quantitative concepts was studied, with development of a hypothesis relating the outcome of problem understanding and choice of an arithmetic operation through an abstract representation of a quantitative action (Heller, 1980). Developmental changes in quantitative understanding were identified in a study of children from 5 to 8 years of age (Riley & Robinson, 1980). Children's understanding of computational procedures was studied, and instruction based on procedural analogies was found to be helpful in remedying systematic procedural flaws in children's performance (Resnick, 1979). A simulation model and a formal analysis of preschool children's counting skills were developed, providing some progress on the question of what constitutes understanding of a general principle relevant to a cognitive procedure (Greeno, Gelman & Riley, 1978). A theory of problem-solving set and constructions was developed in the domain of high school geometry proof problems, based on an idea of schematic knowledge (Greeno, Magone & Chaiklin, 1979).

--Research in progress

Research is continuing on all these topics.

We will briefly describe four research projects that depend on SUMEX and are most directly relevant to AIM goals.

(1) Work has begun on a study of the acquisition of radiological skills. The general strategy is to start with empirical data and proceed to simulations of novice (first-year residents) and expert cognitive processing during film reading. The final stage will be the development of learning mechanisms that transform novice models into expert models. We use protocols of beginning residents, fourth-year residents, and senior radiologists gathered in relatively naturalistic film-reading situations along with eye movement data and studies of what subjects see in the first seconds of examining a film. Current work on the computer simulation part of the project is directed at development of an anatomy database to underpin representations of films and to provide a language for describing feature analyzers and higher level knowledge structures and their outputs. In general, it is expected that the novice model will be similar in form to that of HEARSAY-II, while the expert model will have a somewhat more "compiled" form, perhaps looking more like some of the diagnostic programs on SUMEX. At this point, only the novice model has been considered in any detail.

(2) Another study of spatial information processing is focused on alternative cognitive representations of information in diagrams. Venn diagrams are presented along with verbal keys that indicate probabilities of events. In solving simple computational problems, subjects identify figures in the diagrams that they use in organizing the numerical information needed for calculations. Subjects differ in the level of complexity of forms that they identify, indicating that individual differences in spatial information processing affect performance in this task in a fundamental way. Simulation models are being constructed using Anderson's ACT program in the SUMEX system. These models represent alternative forms of spatial information available to a problem solver, and permit investigation of the consequences of alternative forms of spatial information for the inferential processes required of a problem-solving system.

(3) A collaborative project with John Anderson is focussed on learning of problem-solving skills. Anderson and Greeno are developing simulation models, using ACT, representing different stages in the

acquisition of cognitive procedures for solving geometry proof problems. Greeno's contribution to the project involves simulation of learning new procedural skills that make use of previously known schemata that are used in representing problems. Problems being addressed include (a) acquisition of productions for instantiating a schema in a new context, thus making available the problem-solving procedures previously learned in different contexts; (b) acquisition of new procedural attachments required for solving new kinds of problems in a familiar domain; and (c) acquisition of complex schemata formed by combining components of simpler schemata that were known previously.

(4) We are conducting a formal analysis of acquisition of the syntax of simple arithmetic sentences. The problem is a form of the language acquisition problem, and we are developing a system patterned after Anderson's (1976) Language Acquisition System (LAS), which depends on semantic representations of the referents of sentences in acquiring syntactic parsing rules. Our project involves an extension of this idea, since the referents of arithmetic sentences are sequences of actions, rather than spatial arrangements of objects as Anderson used. The programming in this project is done in SAIL through the SUMEX system.

(5) Work continues on the longitudinal study of children's development of reading skill. This work is expected to facilitate modelling of different forms of reading acquisition problems by providing examples of different children's progress in acquiring various components of effective word recognition.

List of Relevant Publications

Greeno, J. G., Gelman, R., & Riley, M. S. Young children's counting and understanding of principles. Paper presented at meetings of the Psychonomic Society, San Antonio, November, 1978.

Greeno, J. G., Magone, M. E., & Chaiklin, S. Theory of constructions and set in problem solving. _Memory and Cognition_, 1979, _7_, 445-461.

Heller, J. I. The role of "focus" in children's understanding of arithmetic word problems. Paper presented at meetings of the American Educational Research Association, Boston, April, 1980.

Lesgold, A., & Curtis, M.E. Learning to read words efficiently. In A.M. Lesgold & C.A. Perfetti (Eds.), _Interactive processes in reading_, Hillsdale, NJ: Erlbaum, forthcoming.

Lesgold, A.M., Curtis, M.E., Roth, S.F., Resnick, L.B., & Beck, I.L. A longitudinal study of reading. Paper presented at the Annual Meeting of The American Educational Research Association, Boston, April, 1980.

Riley, M. S. & Robinson, M. A theoretical framework for word problem research in arithmetic. Paper presented at meetings of the American Educational Research Association, Boston, 1980.

Funding Support

National Institute of Education
1. Title: Research on Learning and Schooling
2. Principal Investigators: Robert Glaser, University Professor and Co-Director of Learning Research and Development Center, and Lauren B. Resnick, Professor of Psychology and Co-Director of Learning Research and Development Center, University of Pittsburgh
3. Funding Agency: National Institute of Education
4. Grant Number: NIE-G-80-0114
5. Total Award: 1 Dec 1979 to 30 November 1982, $7,879,729.
6. Current Period: 1 Dec 1979 to 30 Nov 1980, $2,625,520 (During the current period, $150,000 of the above has been allocated for Greeno's Research and $67,000 for Lesgold's).

Office of Naval Research and Advanced Research Projects Agency
1. Title: Cognitive and Instructional Factors in the Acquisition and Maintenance of Skill
2. Principal Investigators: Robert Glaser, University Professor and Co-Director of Learning Research and Development Center, and Alan M. Lesgold, Research Assistant Professor of Psychology, University of Pittsburgh
3. Funding Agency: Office of Naval Research (through funds currently provided by the Advanced Research Projects Agency)
4. Contract Number: N00014-79-C-0215
5. Total Award: 1 Jan 1979 to 30 Sep 1981, $1,265,272.
6. Current Period: 1 Oct 1979 to 30 Sep 1980, $420,000.

National Science Foundation and National Institute of Education
1. Title: Invention and Understanding in the Acquisition of Computation
2. Principal Investigator: Lauren B. Resnick, Professor of Psychology and Co-Director of Learning Research and Development Center, University of Pittsburgh.
3. Funding Agencies: National Science Foundation and National Institute of Education
4. Total and current Funding: 1 Dec 1978 to 31 May 1981, $161,238.

Office of Naval Research
1. Title: Analysis of Formal and Informal Reasoning in Problem Solving
2. Principal Investigator: James G. Greeno, University Professor, University of Pittsburgh
3. Funding Agency: Office of Naval Research
4. Contract Number: N00014-78-C-0022
5. Total Award: 1 Oct 1977 to 30 sep 1980, $274,419.
6. Current Period: 1 Oct 1979 to 30 Sep 1980, $92,293.

INTERACTIONS WITH THE SUMEX-AIM RESOURCE

Medical Collaborations and Program Dissemination via SUMEX

The work on development of radiology skills is being done in collaboration with Dr. Yen Wang, Clinical Professor of Medicine, University of Pittsburgh.

Sharing and Interactions with Other SUMEX-AIM Projects

Two of the five projects described in Section 1.3 involve use of Anderson's ACT system in SUMEX. The skill acquisition project involves direct collaboration and programming using the ACT system in Anderson's directory. The project on spatial information processing with diagrams is also programmed in ACT. Access to Anderson's programs through SUMEX has allowed us to avoid costly duplication of his system, which would require translation from INTERLISP into another dialect as well as unnecessary duplication of disk files on another system. The reading work also involves access to ACT, currently for development work and later for actual building of models of reading.

Critique of Resource Management

None

RESEARCH PLANS

Project Goals and Plans

In the near term, we will complete our analysis of learning arithmetic syntax, the analysis of acquiring geometry problem-solving skill, and the analysis of spatial information processing with diagrams. Work on reading will continue for several years. We expect to use new versions of ACT that permit partial matching of production conditions to simulate one or more different types of low-reading-achievement children.

The radiology diagnosis modelling work is expected to continue through an initial phase of novice modelling in interaction with empirical work on chest film reading, after which we will proceed to the expert model and to specification of learning mechanisms. Those mechanisms are expected to include some of the mechanisms proposed by Anderson in his current work as well as mechanisms that take particular account of the need to not have all of the film viewing process excessively concentrated on the highest-probability hypotheses. That is, we see a need to understand how good radiologists come to be able to check films for unexpected pathology (such as tumors) even when seeing evidence for entirely different disorders. We hope that this work will lead to a better sense of how to teach radiologists to exercise this additional care.

Another long-term project is development of a theory of learning elementary arithmetic. Arithmetic is a relatively well structured domain. We now have a considerable body of empirical and theoretical knowledge about the cognitive structures and processes that constitute knowledge of elementary arithmetic. The development of a system that can acquire this knowledge appears to be a feasible goal. At the same time, the task of building a system that acquires both procedural skill and conceptual understanding and integrates these aspects of knowledge raises theoretical questions that seem nontrivial. Therefore, development of a learning system for elementary arithmetic appears to be a productive project for our research program during the next few years. As noted above, we will also use ACT for the reading modeling work.

Justification and Requirements for Continued SUMEX Use

We anticipate continued use of SUMEX in development of simulation programs, particularly in shared use of Anderson's ACT system. Anderson is presently developing the learning capabilities of ACT in a systematic way, and this is very likely to be an important resource for our long-range project on the learning of arithmetic.

Needs and Plans for Other Computing Resources

We depend on SUMEX for a relatively modest, albeit significant, share of our computing needs. We have installed a VAX-11/780 at LRDC and hope to benefit from SUMEX-AIM's experience to continue to improve the cognitive science resources we have locally. We are also exploring possibilities for involvement in any cognitive science network that may develop. In any event, though, having direct access to resources such as ACT as they are developing plays a major role in allowing our work to proceed at the current pace. Complete detachment from ACT would produce a major setback and would waste a lot of staff time in re-inventing the work others already have in place.

9.2.8 Rutgers Computers in Biomedicine Project [Rutgers-AIM]

Rutgers Computers in Biomedicine

Rutgers Research Resource--Computers in Biomedicine

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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 85 researchers and professionals - 37 members, 11 associates, 28 collaborators and 9 users. Members are mainly located at Rutgers. Collaborators are located in several distant sites and they interact, via the SUMEX-AIM and RUTGERS/LCSR facilities, with Resource members on a variety of projects, ranging from system design/improvement to clinical data gathering and testing of expert systems. Our collaborations are described further in section B below. Resource users are located at Harvard University, John Hopkins University, Ohio State University, University of Pennsylvania, University of Pittsburgh, Stanford University and the NIH campus.

Resource activities include research projects (collaborative research and core research) training/dissemination projects, and computing services in support of user projects. The research projects are organized in three main AREAS OF STUDY. These areas of study and the senior investigators in each of these are:

(1) Medical Modeling and Decision Making (C. Kulikowski)

(2) Modeling Belief Systems and Commonsense Reasoning (C. Schmidt and N.S. Sridharan)

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

The training/dissemination activities of the Rutgers Resource include sponsorship of the Annual AIM Workshop - whose main objective is to strengthen interactions between AIM investigators, to disseminate research methodologies and results, and to stimulate collaborations and imaginative resource sharing within the framework of AIM. Starting in 1979, the Workshop is being organized and hosted on a rotational basis by the members of the AIM community, in coordination with the Rutgers Research Resource. The fifth AIM Workshop, organized by the MIT - Tufts Clinical Cognition Project was held in Vermont in May, 1979. The Sixth Workshop is being organized by the SUMEX-AIM Resource and is to be held at Stanford University in August, 1980.

B) Medical Relevance; Collaborations:

During 1979-80 we continued the development of a versatile system for building consultation programs, called EXPERT. This system is being used extensively in the development and study of several medical consultation models - in collaboration with clinical investigators from several specialties.

Problems in rheumatology are particularly important in health care, given the high prevalence and chronic nature of arthritis and related disorders. They also represent an active area of biomedical and clinical research, in which a group of our medical collaborators at the University of Missouri under Dr. Gordon Sharp has been noted for its contributions. The application of A.I. approaches to problems of medical decision making in this domain was facilitated by our collaboration with Dr. Donald Lindberg, Director of the Health Care Technology Center at the University of Missouri.

Our experience with the design of the rheumatology model has shown us that the knowledge engineering tools and know-how that we developed so far in the Resource make it possible to move incrementally and rapidly in the construction of a new medical knowledge base in collaboration with expert clinical researchers. Moreover, this experience is leading us to the development of a methodology for guiding the interaction of medical and computer science researchers in model building. The sequence of developments of a consultation models should follow a natural progression aided at every step by an interplay between the clarification of medical concepts and the application of logical methods of model design. Our work in this area is contributing to a better understanding of a central problem in the application of Artificial Intelligence to the design of expert computer-based systems; namely, what are the representations, the processes and the interface facilities that are needed to acquire, augment, and refine knowledge bases of different types by interacting with specialists in a domain.

In a single year we progressed from an initial model that represents a framework of major findings and diagnostic categories for diffuse connective tissue diseases to a refine model with a broad spectrum of well-defined observational and decision criteria. It is now being validated and further developed through a national network of rheumatology specialists organized by our medical collaborators at the University of Missouri. This work is directly contributing to the organization of clinical knowledge in rheumatology. It has been a notable achievement to have been able to reach a performance of over 90 percent of correct diagnoses on difficult cases of disease at each step of model design.

In ophthalmology, the CASNET/Glaucoma knowledge base was translated into the new EXPERT formalism. The development of the glaucoma knowledge base built in conjunction with the investigators of ONET (ophthalmological network) was supplemented by knowledge of Japanese variants of the disease and the decision rules embodying the clinical judgment of Japanese glaucoma experts. A model for neuro-ophthalmological consultation is being built in collaboration with Dr. William Hart of the Washington University School of Medicine, which is related to the automated interpretation of visual field measurement.

Another collaboration has been in the area of endocrinology, where a thyroid consultation knowledge base was developed in conjunction with Dr. R. A. Nordyke of the Pacific Health Research Institute.

All the above applications have shown the versatility of the basic EXPERT representation scheme for rapidly developing medical knowledge bases. By continued testing and development of various domain models, the current boundaries of applicability of the EXPERT formalism are being explored, and new facilities added as required to improve the consultative performance of the programs developed.

In addition to the direct medical collaboration, we have continued investigating problems of modeling in enzyme kinetics with Dr. David Garfinkel of the University of Pennsylvania.

C) Highlights of Research Progress

1) Medical Modeling and Decision-Making

Research activities during the past year have concentrated on the development and testing of the generalized consultative system scheme (knowledge representation and associated strategies of inference), called EXPERT, and its application to a number of different medical domains.

The structure of knowledge in EXPERT involves two data types: findings and hypotheses. The hypotheses (diagnostic, prognostic and treatment selection) are organized as a partially ordered network (PON) using hierarchical and causal relationships. The findings are organized according to observational constraints. Production rules are used to encode inferences among findings, between findings and hypotheses, and among hypotheses. Because of the PON organization of hypotheses, the knowledge base can be pre-compiled with attendant space and time efficiencies in the performance of the consultation programs that call on the knowledge base for decision-making advice.

Knowledge bases in ophthalmology, rheumatology, and endocrinology have served to test the versatility of the EXPERT formalism. (see I.B above)

There have been a number of significant generalizations of the EXPERT scheme during the current period, which fall in the following categories:

1.1) Representations:

a) The context for Hypotheses-to-Hypothesis rules can be defined (anchored) to include matching against a pattern of other hypotheses as well as findings. This permits both very data-specific contexts, as well as global contexts of disease domains and consultation environments, which are used as triggers for the sets of applicable production rules.

b) Multiple visits of a patient can now be handled by the same scheme. A time representation is being developed currently.

c) Internal functional and logical variables can now be defined for use by the reasoning schemes, hence allowing specification of clinical indices, discriminant functions, transformations among variables, etc.

d) Extension of the logical selector operation in the syntax to apply to hypotheses as well as findings.

e) The current version of EXPERT has been expanded to handle large amounts of knowledge, up to approximately 600 hypotheses, 3,000 findings and 20,000 rules, while retaining its processing efficiency.

1.2) Strategies of Reasoning:

a) A focusing capability, which permits the system to concentrate on only a preselected set of conclusions at a given time. Repeated application of the focusing command gives the user direct control over the "shifting of attention" in the reasoning sequence of the system, which may be an attractive alternative to the program's usual control strategies. It is also a powerful tool to test the effects of hypothesis-induced partitions in the sets of production rules.

b) Strategy selection capabilities have been added, which permit the user to pre-specify the type of scoring strategies used by the system in assessing the effects of propagated uncertainties throughout the space of hypotheses, while interpreting of a given patient's consultation results. This has proven to be a useful tool in adjusting the scoring method to match the degree of structural specification in a model. In particular, for applications where few interdependencies among findings and hypotheses are known and included in a model, it is desirable to strengthen the cumulative components of a scoring function.

1.3) Facilities for Model Updating and Explanations:

a) Compiler of benchmark case changes: The compiling program, XP, has been designed so that on each revision of the model for which it is invoked, it will provide a summary of all significant changes in the conclusions of a set of stored benchmark cases. These can then be retrieved and analyzed for unexpected effects of changes in the rules or the descriptive knowledge structure.

b) The explanation facilities have been generalized, so that supportive evidence or chains of reasoning leading up to a particular hypothesis or conclusion can be traced and assessed. The user can specify the range of uncertainty weights for which he wishes to obtain explanations of the conclusions (i.e., only those hypotheses that are strongly confirmed, only those strongly denied, or any other alternative). Rules can also be ordered according to weight criteria.

1.4) Knowledge-base Transfer Experiments with EXPERT

Experiments were carried out to test the facility with which knowledge bases constructed for other representations can be transferred into the EXPERT formalism. They primarily involved the CASNET model of glaucoma, and demonstrated that the causal structure was, as designed, representable in the EXPERT scheme. It allowed for the explicit specification of hierarchical relationships and rules for the inference of intermediate hypotheses from evidence and final conclusions from patterns of intermediate hypotheses. There were some specialized features of CASNET/Glaucoma that have yet to be added to the new system (use of symmetry relations for binocular findings and hypotheses and the visit-to-visit logic), that are currently under design.

Another experiment, carried out by Dr. Kitazawa in Japan, took part of the CASNET knowledge base and transferred it into the EXPERT representation, and then added new elements (findings, hypotheses, and rules) to adapt the model to his clinical environment. Examination of the INTERNIST-I representation showed the compatibilities between some of its components and those expressible in the EXPERT scheme.

Problems of updating a knowledge base and learning decision rules from a data base of case records are two other areas of investigation. A program for rule learning by five different fuzzy-logic heuristic methods was developed and tested using allergy case study data. Problems of the transferability of large-scale consultation programs to a minicomputer environment have also been investigated.

Clinical investigations in thyroid disease and hypertension (by investigators at Pacific Health Research Institute and the Johns Hopkins School of Medicine, respectively) have been aided by Resource support and development of the BRIGHT system.

2) Modeling of Belief Systems and Commonsense Reasoning

The central role of commonsense reasoning in human thinking makes it a particularly important form of reasoning to study and describe. However, the theoretical frameworks, research methodologies, and analytical tools that have been developed within psychology are not adequate for this task. Consequently, over the past 10 to 15 years, psychologists interested in investigating human reasoning in such "knowledge-rich" domains, have increasingly looked to the research in artificial intelligence in the hope that the tools and research strategies of this discipline can be borrowed, customized, or extended to aid the psychologist in the investigation of human reasoning.

At the broadest level, our research in commonsense reasoning represents one of a handful of research projects that are exploring this intersection of AI and cognitive psychology. We have borrowed, customized and extended the conceptual tools of AI as a result of trying to state, justify and test a knowledge-based theory of one aspect of commonsense reasoning, namely, the problem of <u>how persons recognize the plans and intentions that guide the actions of another person</u>.

Progress toward the achievement of the general goal of applying and/or developing AI approaches for use in developing a cognitive science in psychology can be attained only by providing, at some level of approximation, solutions to four problems. First, a general system framework must be developed within which a knowledge-based psychological theory of some aspect of human cognition can be expressed. The AIMDS system has been the continually evolving framework which we have developed and used to express our theories about commonsense reasoning.

The second and most visible problem is that of representing the knowledge and processes that constitute the psychological theory of plan recognition, person perception and belief attribution. We invented the term BELIEVER in order to distinguish, at least in our mind, those aspects of the implemented code and architecture that represent information processing structures and mechanism that constitute a psychological theory of aspects of human cognitive performance. There have, of course, been many versions of BELIEVER and there is a sense in which the code that constitutes BELIEVER represents several theories. The process of plan recognition requires that mechanisms of retrieval, matching, hypothesis revision, plan generation, inference, categorization, concept specialization or customization and question answering be specified. In non-AI based research in psychology, these various aspects are typically treated as independent areas in which theories are formed and tested. In an AI-based theory such as BELIEVER, there is a "unified" theory of these phenomena in the sense that the way in which these processes interface and communicate with each other has been worked out to yield a functioning system.

The third problem that must be faced is that of developing experimental paradigms which can yield a set of observations that are rich enough to constrain and test an information processing theory of this type. Data from typical psychological experiments yield only a few observations on a single subject and rarely attempt to speak to the way in which various processing mechanisms interface with each other to produce the observed behavior.

Finally, not only must promising experimental paradigms be identified and response protocols collected, but procedures must be devised for representing such data and evaluating it against theoretically interesting hypotheses. This is a very difficult task since the assumptions that underlie the standard statistical tools used in psychology for this purpose are usually at variance with the underlying assumptions of information processing theories.

Over the lifetime of this project we have made forays into each of these problem areas and have learned a good deal about the terrain of each of these problems areas--that of devising the system framework, AIMDS, and that of theory construction, BELIEVER. In the remaining two problem areas our outposts are still at the fringes of the terrain to be searched although we do feel that we at least now have an understanding of the topographies of these areas. This emphasis reflects both our assumptions about the precedence ordering that naturally falls over these problem areas as well as the nature of the collaborative effort that exists between AI and cognitive psychology within the Resource.

3) Artificial Intelligence; Representations and Systems Development

A major part of our effort in this core area continued to be directed to collaborations with investigators in the other applications - oriented projects of the Resource. These collaborations are having an impact on the application areas of the Resource, and they are stimulating work on basic AI issues that are related to designs of knowledge-based systems.

The following problems are providing foci of collaboration with investigators in the Medical Systems area: (i) Develop a natural language interface between a computer consulting system and a medical user; (ii) Find methods for representing and effectively using several related bodies of medical knowledge at various levels of resolution (anatomical, physiological, causal-associational) for decision making in diagnosis and therapy; (iii) Develop computer tools and design frameworks for facilitating the construction and improvement of expert systems.

The joint intensive work between investigators in this core area and researchers in the Belief Systems area is continuing. Developments in the AIMDS system and in the BELIEVER theory are proceeding in parallel and they are continuing to influence each other.

During this period we put new emphasis on basic problems of expertise acquisition and on related problems of theory formation; we increased our effort in problems of representation, interpretation and model-guided control of natural processes; we continued basic work on problems of knowledge acquisition in the context of a language learning task; and we continued a modest level of effort in programming language development - to provide a supportive programming environment for our research.

Our research on natural language processing has continued with the objective to develop methods that facilitate communication between people (domain experts, users, designers) and computers. We have taken a fresh look at the problem of developing a convenient man machine interface for a glaucoma consultation system. Building on our previous work in this area, we have added several novel features to the design of our interface processor.

We are continuing to study problems of language acquisition/learning to gain insight into the general problem of knowledge acquisition in expert AI systems. However, we have shifted emphasis this year to an approach which assumes a more active teacher-learner dialogue in the language acquisition process. This led to the identification of rules that govern such a dialogue, and to the design of acquisition processes that embody these rules.

Our commitment to a strong AI programming environment resulted in improvements of the Rutgers/UCI LISP system, as well as in other systems programming developments. These efforts are strengthening the tools for design and experimentation that are available to Resource investigators on the RUTGERS/LCSR computer facility.

D) Up-to-Date List of Publications

The following is a list of books, papers and abstracts published in 1978 and 1979 by the Rutgers Resource:

Amarel, S., (1978) "Introduction and Overview for AI in Science and Medicine," in 'Session on AI in Science and Medicine, National Computer Conference 1978', AFIPS Conference Proceedings, Vol. 47, 1978, AFIPS Press.

Amarel, S. (1979) Invited participation in panel on "History of AI: 1956-1961," with E. Feigenbaum (Chm.), J. McCarthy, H.A. Simon, IJCAI-79, Tokyo, Japan, August 1979; also, S. Amarel chaired two sessions on Representations at the IJCAI meeting

Biesel, P., C. Kulikowski, S. Weiss, and Z. Aviur, (1979) "Computer-Aided Acquisition and 3-Dimensional Display of Visual Field Data, Computers in Ophthalmology Conf. St. Louis, April (1979).

Ciesielski, V., (1979) "Natural Language Input to a Glaucoma Consultation System," Presented at the Annual Meeting of the Association for Computational Linguistics, San Diego, August 11-12, 1979.

Ciesielski, V. [ed.] (1979) "Proceedings of the Fourth Annual AIM Workshop, "Computer Science Report CBM-TR-104, Rutgers University, August, 1979.

Ciesielski, V., D. Smith, and P. Biesel, (1979) "Artificial Intelligence in Medicine: Contributions of the Rutgers Resource to the A.I. Handbook," Computer Science Report,

Goldberg, R. (1979) "BRIGHT User's Guide - Version 3.04", Report CBM-TR-95, Department of Computer Science, Rutgers University, January 1979.

Hall, J.S. and N.S. Sridharan, (1978) "Modeling Actions and Processes in AIMDS: An Example", Report CBM-TM-81, Department of Computer Science, and Medicine, Vol. 11, (1 and 2), August 1978.

Kulikowski, C., (1979) "Expert Consultation Systems: Designs for Generality", Hawaii Int. Conf. on Systems Science, Kulikowski, C. and S. Weiss, (1979) "Representation of Expert Knowledge for Consultation: The CASNET and EXPERT Projects", Proc. AAAS Annual Meeting, Houston, January 1979, (in press) [also Rutgers Computer Science Report CBM-TR-98].

Kulikowski, C., (1979) "Representation of Expert Knowledge for Consultation; The CASNET and EXPERT Projects," Report CBM-TR-96, Department of Computer Science, Rutgers University, January 1979

Kulikowski, C., (1979) Current Research in Artificial Intelligence in Medicine in the United States", Proc. Japan-AIM Workshop, August 1979.

Kulikowski, C., (1979) "Computer-based Medical Decision-Making", Computers in Ophthalmology Conf., St. Louis, April, 1979.

Kulikowski,C., (1978) "Artificial Intelligence Approaches to Medical Consultation: A Tutorial Review, American Society of Clinical Pathology, October, 1978.

Kulikowski, C. and S. Weiss, (1978) "Laboratory Computers in the Year 2000", Medical Laboratory Observer, July, 1978, pp. 150-160.

Kulikowski, C.A. and Weiss, S.M., (1978) "The Evaluation of Performance in Empirical and Theoretical Models of Medical Decision-Making", Proc. IEEE Computer Society Workshop in Pattern Recognition and Artificial Intelligence, Princeton, April 1978.

Kulikowski, C.A. (1978) "Artificial Intelligence Approaches to Medical Consultation", Proc. fourth Illinois Conference on Medical Information Systems, May, 1978.

Kulikowski, C.A. (1978) "Strategies of Glaucoma Treatment Planning", National Computer Conference-78, AFIPS Conference Proceedings, Vol. 47, 1978, AFIPS Press, Anaheim.

Mitchell, T.M., (1979) "An Analysis of Generalization as a Search Problem", IJCAI, Tokyo, Japan, August 1979, [also Rutgers Computer Science Report DCS-TR-78]

Mitchell, T.M., (1978) "Version Spaces: An Approach to Concept Learning" PhD Dissertation, Stanford University, December 1978, (Also, Stanford Computer Computer Science Report STAN-CS-78-711, HPP-79-2).

Mizoguchi, M.K., Maruyama, T. Yamada, Y. Kitazawa, M. Saito, and C. Kulikowski, (1979), "A Case Study of EXPERT Formalism", Proc. IJCAI, Tokyo, August 1979, pp. 589-588

Morgenstern, M. (1978) "Transferring Technology from Research Systems to Users", Proc. The Third Jerusalem Conference on Information Technology, Jerusalem, August, 1978.

Nagel, D., (1979) "An Experimentation in Extracting Some Properties of Binary Relations", Department of Computer Science, Rutgers University, CBM-TM (forthcoming)