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NORTHEAST ARTIFICIAL INTELLIGENCE CONSORTIUM ANNUAL REPORT 1987 Executive Summary

Syracuse University

James F. Brule and Volker Weiss

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, NY 13441-5700

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The Northeast Artificial Intelligence Consortium (NAIC) was created by the Air Force Systems Command, Rome Air Development Center, and the Air Force Office of Scientific Research. Its purpose is to conduct pertinent research in artificial intelligence and to perform activities ancillary to this research. This report describes progress that has been made in the third year of the existence of the NAIC on the technical research tasks undertaken at the member universities. The topics covered in general are: versatile expert system for equipment maintenance, distributed AI for communications system control, automatic photo interpretation, time-oriented problem solving, speech understanding systems, knowledge base maintenance, hardware architectures for very large systems, knowledge-based reasoning and planning, parallel structural, and optimal techniques in vision, and a knowledge acquisition, assistance, and explanation system. This volume provides the executive summary of all work done by the NAIC in 1987.

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1. INTRODUCTION

1.1 The Northeast Artificial Intelligence Consortium

The Northeast Artificial Intelligence Consortium (NAIC) is a collaboration of seven institutions of higher learning organized for the purpose of developing research and education in artificial intelligence (AI) in the northeastern area of the United States. The participating institutions are:

State University of New York at Buffalo, Buffalo NY
Clarkson University, Potsdam NY
The University of Massachusetts at Amherst, Amherst MA
Rensselaer Polytechnic Institute, Troy NY
The University of Rochester, Rochester NY
Rochester Institute of Technology, Rochester NY
Syracuse University, Syracuse NY

1.2 Objectives of the Consortium

The Consortium's *raison d'etre,* advancing the state of research and education in AI in the Northeast, requires that the Consortium not only be open to new ideas and opportunities, but that it pursue them as well. These opportunities must range from new efforts performed by current research teams, through new collaborations between existing research teams, and on to the induction of new research teams into the Consortium. Likewise, these opportunities can be realized through a variety of funding vehicles, as extensions of the current funding environment, the solicitation of new funding from governmental sources, and the development of funding relationships with industry. Finally, vehicles for the transfer of these new developments to the rest of the academic, governmental, and commercial worlds will serve to enhance the value of the Consortium's work, as well as creating further opportunities for new research.

In order to meet these challenges, the Consortium needed to develop a solid foundation of trust, collaboration, and intellectual exchange amongst its various members. The first two years of its life were appropriately devoted to these efforts, members. The first two years of its life were appropriately devoted to these efforts, which were often slow and uneven. Early in the third year, however, it became apparent that the time to actively pursue this growth had come, and significant efforts were made to build up the capabilities to realize these opportunities. An investment above and beyond the original funding terms was made into hiring a full-time Managing Director who would be charged with capitalizing on the resources the Consortium had to offer the various communities identified earlier, as well as bringing a day-to-day management focus to the Consortium's administrative affairs. It was also felt that the time appeared to be ripe to begin a greater collaborative effort between researchers at various institutions.

In retrospect, the goals for this year have been achieved: a technical report series has been created, a series of high-level workshops for the academic community has been instituted, a structure for bringing in new academic and commercial members is in place, new funding sources and research members are being actively pursued, formal relationships with similar organizations have been investigated and realized, and the backlog of administrative work has been completely resolved.

Researchers at each institution have their own expertise and interests, and are addressing a varied group of problems in AI that are of interest to the Air Force and beyond. Each of these problems has been viewed as a more or less distinct task, and as such each research group submitted to the Consortium a complete report covering the research task or tasks undertaken during the past year. Summaries of their work are included in the volumes that follow this one.

The topics under study and the Principal Investigators ("PIs") at each institution are:

VMES: A NETWORK-BASED VERSATILE MAINTENANCE EXPERT SYSTEM
PIs: Stuart C. Shapiro, Sargur N. Srihari
Department of Computer Science
State University of New York at Buffalo
Buffalo, NY 14260
(Volume IIa)

DISCUSSING, USING, AND RECOGNIZING PLANS

PIs: Stuart C. Shapiro (SUNY Buffalo)

Beverly Woolf (University of Massachusetts - Amherst)

(Volume IIb)

DISTRIBUTED AI FOR COMMUNICATIONS NETWORK MANAGEMENT

PIs: Susan E. Conry, Robert A. Meyer

Electrical and Computer Engineering

Clarkson University

Potsdam, NY 13676

(Volume III)

RESEARCH IN AUTOMATED PHOTOINTERPRETATION

PI: James W. Modestino

Electrical, Computer, and Systems Engineering Department

Rensselaer Polytechnic Institute

Troy, NY 12180-3590

(Volume IV)

BUILDING AN INTELLIGENT ASSISTANT: THE ACQUISITION, INTEGRATION, AND MAINTENANCE OF COMPLEX DISTRIBUTED TASKS

PIs: Victor Lesser, W. Bruce Croft, and Beverly Woolf

Department of Computer and Information Science

The University of Massachusetts at Amherst

Amherst, MA 01003

(Volume V)

ARTIFICIAL INTELLIGENCE APPLICATIONS TO SPEECH RECOGNITION

PIs: Harvey Rhody

RIT Research Corporation

Rochester, NY 14623

and

John A. Biles

Computer Science Department

Rochester Institute of Technology
Rochester, NY 14623
(Volume VI)

TIME-ORIENTED PROBLEM SOLVING
PI: James F. Allen
Computer Science Department
The University of Rochester
Rochester, NY 14627
(Volume VII-a)

PARALLEL, STRUCTURAL, AND OPTIMAL TECHNIQUES IN VISION
PI: Christopher M. Brown
Computer Science Department
The University of Rochester
Rochester, NY 14627
(Volume VII-b)

KNOWLEDGE BASE MAINTENANCE USING LOGIC PROGRAMMING METHODOLOGIES
PI: Kenneth A. Bowen
School of Computer and Information Science
Syracuse University
Syracuse, NY 13244-1240
(Volume VIII)

COMPUTER ARCHITECTURES FOR VERY LARGE KNOWLEDGE BASES
PI: P. Bruce Berra
Electrical and Computer Engineering
Syracuse University
Syracuse, NY 13244-1240
(Volume IX)

While the technical tasks were unique to each participating institution, the ancillary goals were commonly agreed to, despite the fact that there were varying degrees of accomplishment at each institution. The primary ancillary goals were to develop greater AI expertise at the university level and to enhance the external recognition of the Consortium and its members. The vehicles for accomplishing these goals were seen to be as follows:

1. expanding faculties
2. increasing the number of graduate students
3. increasing the number of AI courses
4. improving facilities

The pursuit of the remaining ancillary goals was viewed to be useful in the fulfillment of the primary objective as well. These remaining goals are:

1. encouraging and supporting industrial participation in AI
2. expanding funding support
3. developing an active AI community.

Some of these goals and objectives (such as recruiting more students and faculty, improving facilities, and fostering a working relationship with industry) are driven largely by individual institutions. Despite this, the Consortium has begun to be of great help in propagating the name and image of both the Consortium and its individual members: by fostering interaction between its members, speaking on behalf of the entire Consortium, and sponsoring workshops, symposia, and other events. Progress in each of these areas ultimately affects all the others, since each of these subgoals is intertwined with the ultimate mission of the Consortium.

2. MANAGEMENT STRUCTURE

2.1 Inter-School

Director: Volker Weiss

Managing Director: James Brulé

Administrative Secretary: Jeanette Fernandes

Committees: Executive Committee:

UMass (1 year): W. Bruce Croft

SUNY Buffalo (1 year) Stuart C. Shapiro

Clarkson University (2 years): Susan Conry

Syracuse University (2 years): Kenneth Bowen

As part of the increased investment in the Consortium, the management structure was modified. The Director remains the responsible individual named in the prime contract. Reporting to the Director and the Executive Committee is the Managing Director, whose responsibilities are to implement the plans formulated by the Executive Committee on behalf of the Consortium, manage the day-to-day operations of the Consortium, and maintain administrative liaisons between member institutions, RADC, and administrative bodies within Syracuse University relative to the Consortium. The Administrative Secretary reports to the Managing Director, and along with the Managing Director forms the full-time administrative component of the Consortium. This component prepares reports, organizes NAIC meetings and briefings, aids in the establishment of committees and advisory boards, facilitates the electronic networking of Consortium members, arranges vendor presentations, organizes educational efforts, and represents the Consortium at an administrative level to other universities, funding sources, and the commercial sector.

The Managing Director was hired following a national search, and began his efforts on June 1, 1987. The Administrative Secretary was hired on September 1, 1987. The former Administrative Assistant (Andrea Pflug) left the Consortium on August 1, 1987. Thus, the accomplishments of the new administrative group (including the processing of over 4,000 pages of documentation) represent barely one-half year's effort to date.

2.2 Intra-School

The Principal Investigators at each institution are responsible for both the technical and ancillary functions at their respective institutions. The Principal Investigators are as follows:

Stuart C. Shapiro
Sargur N. Srihari
State University of New York at Buffalo
Susan Conry
Robert Meyer
Clarkson University
Victor Lesser
W. Bruce Croft
Beverly Woolf
University of Massachusetts - Amherst
James W. Modestino
Rensselaer Polytechnic Institute
James F. Allen
Christopher Brown
University of Rochester
Harvey Rhody
John Biles
Rochester Institute of Technology
P. Bruce Berra
Kenneth A. Bowen
Syracuse University

3. TECHNICAL TASKS

Detailed descriptions of research tasks under investigation at each of the member institutions of the Consortium are found in subsequent volumes. Short descriptions of the current year's research at each institution and their plans for the next year follow.

3.1 VMES: A Network-based Versatile Maintenance Expert System

State University of New York at Buffalo

Principal Investigators:

Stuart C. Shapiro, Sargur N. Srihari

Research on the Versatile Maintenance Expert System (VMES) project is concerned with issues in the development of a system that could diagnose faults in an electronic circuit and interact with a maintenance technician. During 1987 our research on this project had two distinct but two overlapping phases: consolidation of work done during the previous two years and developing new directions of research.

In the first phase we emphasized several aspects of versatility. The original aspects of "versatility" originally defined by the VMES project included: ability to diagnose a device that has been designed so recently that there has not been time to train technicians in its diagnosis; ability to diagnose a device that is so experimental that it has not been cost effective to design extensive automatic testing systems; ability to diagnose a wide range of devices from a similar family of devices; ability to serve at various maintenance levels (field, depot, etc.); ability to interact flexibly and in a "user-friendly" fashion. Significant achievements of the first phase of the VMES project, all of which were consolidated during the first half of 1987, were in the area of device representation and fault diagnosis. These were: development of an improved diagnostic strategy that uses suspect ordering criteria, introduction of a new model of connections that enables VMES to diagnose connection problems such as interrupted wires and bad contact points, and incorporation of both logical and physical device models to ease user interaction and speed up diagnosis.

In the second phase of our work we began to focus on an actual physical device so as to examine the interactions of logical and physical models. We also began to explore how to accommodate analog components, in addition to the digital components previously handled. A more complex control structure to handle diagnosis at different levels of knowledge began to take shape.

3.2 The Natural Language Planning Project: Discussing, Using, and Recognizing Plans

SUNY Buffalo / University of Massachusetts - Amherst

Principal Investigators:

Stuart C. Shapiro, Beverly Woolf

Overview:

This project is a joint SUNY Buffalo (UB) / UMass project devoted to the investigation of a knowledge representation design compatible with the intensional knowledge representation theory previously developed by Dr. Shapiro and his co-workers, and capable to providing a natural language interacting system with the ability to discuss, use, and recognize plans. The project officially got underway on August 14, 1987. The last few months of 1987 were devoted to reviewing the extensive literature on planning, working on the software to be used jointly by the UB and UMass researchers, and developing and experimenting with an initial design of a representation of plans.

Objectives:

The objectives of this project are to:

1) Design a representation for plans and rules for reasoning about plans within an established knowledge representation/reasoning (KRR) system;
2) Enhance the KRR system so that it can act according to such plans;
3) Write a grammar to direct an established natural language processing (NLP) system to analyze English sentences about plans and represent the semantic/conceptual content of the sentences in the representative designed for objective (1);

The resulting NLP system should be able to:

1) Accept sentences describing plans, then add the plans to its "plan library;"
2) Answer questions about the plans in its plan library;
3) Accept sentences describing the actions of others, and recognize when those actions constitute the carrying out of a plan in its plan library.

The KRR system to be used is SNePS (Shapiro 1979), and the NLP system to be modified for this purpose is CASSIE (Shapiro & Rapaport 1987). The UB group is responsible for enhancing SNePS/CASSIE according to the objectives listed above. The UMass group is responsible for testing the enhanced system in the specific domains of tutoring and space launch narratives. Communication and feedback between the two groups will greatly improve the work of both.

3.3 Distributed Problem Solving

Clarkson University

Principal Investigators:

Susan Conry, Robert Meyer

The AI research performed at Clarkson University during 1987 has continued to concentrate on the study of distributed problem solving systems, using communications network management and control as the problem domain. This section gives a brief introduction to the problems of interest and a short review of the work completed in the previous years. Volume III documents the principal research accomplishments of 1987.

Activity at Clarkson has focused in three areas: distributed planning, distributed knowledge base management, and an environment for the development of distributed systems. Significant progress has been achieved in distributed planning, and our distributed development environment has matured. Work on a distributed knowledge base manager (KBM) has been driven, to some extent, by the requirements for knowledge base access generated from the planner.

Planning work has centered around further investigation of multistage negotiation as a cooperation paradigm for distributed satisfaction problems. In our domain these problems arise from the need to restore service for multiple disrupted communications circuits in a network with decentralized control and limited localized knowledge about global network resource availability. The first is the phase involving plan generation. This has been especially interesting in that new insight has been gained concerning the degree of nonlocal knowledge necessary in formulating feasible local choices.

Work in distributed planning has also led to formulation of an algebra of conflicts to be used in reasoning during negotiation. The planning problems we find in the communications systems domain involve distributed resource allocation problems in which hard local constraints must be enforced in a global plan. This year, we have devised mechanisms which enable an agent to reason about its own local constraints and exchange knowledge concerning the impact of nonlocal actions, incorporating new knowledge in a consistent manner. These mechanisms appear to be particularly interesting because they seem to be applicable to a wide class of distributed constraint satisfaction problems.

During 1987 our distributed development environment, SIMULACT, has matured. It has been used as a testbed environment in investigations of planning issues and in managed distributed knowledge base functions. Over the course of the year, SIMULACT has been converted to Common Lisp, enhanced user interface facilities have been incorporated, and the system has been implemented on a network of Lisp machines. Experiments have been performed to determine the extent to which process management overhead impacts apparent distributed system performance in single processor and multiple processor configurations. In addition, SIMULACT has been demonstrated running distributed applications at the AAAI Annual Meeting and at NAIC meetings.

Work on the Knowledge Base Manager has been driven largely by needs perceived in distributed planning. Much of the progress has been in identifying the forms of the interface and query processing required by the planner. In addition, we have investigated the feasibility of a natural language interface, primarily as a debugging tool. While designing the KBM, we uncovered certain limitations arising from the knowledge representation scheme initially chosen for communications circuits. A moderate set of revisions to the design of the knowledge base has been completed as a result of changing the representation of circuit knowledge. These changes were also incorporated into GUS, which we developed in previous years as a tool for knowledge acquisition in the communications network domain.

3.4 Automatic Photo Interpretation

Rensselaer Polytechnic Institute

Principal Investigator:

James W. Modestino

The RPI task has been concerned with the development of expert systems techniques for automated photointerpretation. More specifically, our efforts have been directed toward the development, implementation and demonstration of techniques which will mimic the job of a trained photoanalyst in interpreting objects in monochrome, single-frame aerial images. This is a difficult task which requires a combination of numerical and symbolic image processing techniques.

During the course of this effort we have developed a novel hierarchical, region-based approach to automated photointerpretation. Basically, this approach proceeds by first segmenting the input image into disjoint regions which differ in tonal or textural properties. The spatial relationships between different regions is then expressed in terms of the associated adjacency graph where nodes represent regions and the connectivity indicates regions which are spatially contiguous. Based upon knowledge of the underlying spatial adjacency graph, together with various self and mutual region attributes or features, the problem is then that of assigning interpretations, or object categories, to each of the nodes. This is generally a computationally explosive task. The novelty of our approach is that we have been able to develop a computationally feasible approach to this symbolic interpretation process.

The advantage of our approach is based upon two important properties. First, we model the interpretation process as a Markov random field (MRF) defined on the adjacency graph. Secondly, we make use of an efficient stochastic relaxation process to find the most likely interpretation. The first assumption allows us to localize the search for good interpretations while the second helps in avoiding the otherwise computationally explosive nature of the search for optimum interpretations.

Our major effort during FY 1987 has been in refining this region hierarchical approach, improving the initial segmentation process and, finally, demonstrating the approach on real-world aerial photographs. The Final Report for FY 1987 documents much of this progress.

3.5 Plan Recognition, Knowledge Acquisition, and Explanation in an Intelligent User Interface

The University of Massachusetts at Amherst
Principal Investigators:
W. Bruce Croft, Victor Lesser, Beverly Woolf

The NAIC-affiliated AI group at the University of Massachusetts has completed a number of projects this year in the area of intelligent interfaces. These projects have made important contributions towards our goal of supporting cooperating users in their interaction with a computer and tutoring them about the expertise residing in the knowledge bases they are using. Our research has concentrated on issues in planning, plan recognition, knowledge representation, knowledge acquisition, cooperative and distributed problem solving, and intelligent tutoring. Advances in each of these areas are essential for a system to be able to understand the goals of a user, relate these goals to other users' goals, formulate plans to accomplish the goals, and successfully execute these plans in interactive environments. We have emphasized the importance of techniques that can deal with open-ended domains where the actions of agents are not completely predictable but are generally purposeful. We feel that domains with these characteristics are found in many important applications.

In the area of planning and plan recognition we have completed implementation of a new plan recognition formalism (GRAPPLE) that provides a hierarchy of procedural descriptions or plans specifying typical user tasks, goals, and sequences of actions to accomplish goals. Included within this formalism is a framework for meta-plans and first-principles knowledge.

We have also built a testbed system (POLYMER) for developing replanning, negotiation, and knowledge acquisition techniques. Exceptions that occur during interactive plan execution are handled by constructing explanations from the current knowledge base and then using this structure as the basis for negotiation between affected agents. This approach can be viewed as a special case of explanation-based learning. Another important aspect of knowledge acquisition is the design of interfaces based on cognitive models of the way people view their activities. A prototype system based on this idea has been started this year. We have also started research on how cooperative agents can negotiate to resolve conflicts in their viewpoints.

Several dissertations were completed this year. One was a Ph.D. thesis on knowledge acquisition. This thesis developed the idea of assimilating new knowledge with similar knowledge already in the knowledge base. An M.S. project was completed that developed a scheduling system for representing and reasoning about time. Another Ph.D. thesis, that produced an object-oriented graphic interface for decision support, is in its final stages of preparation.

Also this year, we designed and began implementation of a question/answering system for qualitative reasoning about complex engineering systems. The system allows a user to design and build environments to teach concepts such as statics, thermodynamics, and kinematics. Building these interfaces required extensive knowledge engineering with educators, psychologists, and physicists.

In sum, this year we have seen the completion of several projects, continued development of others, and the beginnings of still others in the area of intelligent interfaces. This work represents a major advance in a number of areas with regard to the previous year.

3.6 Speech Understanding Research

Rochester Institute of Technology

Principal Investigator:

Harvey Rhody

The primary goal of the RIT NAIC project is the development of techniques that can be applied to the most difficult type of speech understanding system: the speaker independent, continuous speech, large vocabulary system. The problems posed by this type of system require an approach that is fundamentally different from the kinds of low level acoustically based engineering approaches that have traditionally been applied to speech recognition problems.

The major goals of our speech understanding effort are the development of techniques to (1) derive an intermediate <u>phonetic</u> representation of spoken utterances from any speaker, (2) measure the quality of the match between errorful phonetic representations of input utterances and phonetically based lexical entries, (3) efficiently search large lexicons, and (4) incorporate syntax and domain knowledge in differentiating between plausible and implausible parsings of phonetic strings.

Our research on automatic phonetic analysis has proceeded along three related lines: (1) the development of low level feature extraction techniques that are designed to preserve information that is most closely associated with phonetic content, (2) the development of a feature based, speaker independent phonetic space, and (3) the development of learning based techniques for classifying featural representations of speech signals into phonetic categories. An example of our work in the first area is the development of a formant tracker that makes use of statistically based machine learning principles. An example of our work in the second area is the development of a relatively simple feature space that can be used to classify vowels produced by a diverse group of speakers based on formant frequency patterns. An example of our work in the third area is a tree search technique for classifying segments of spoken utterances into broad phonetic categories.

The goal of our work in phonetic string analysis is to develop methods to derive word sequences from an analysis of undifferentiated (i.e., without word boundaries) phonetic strings. This type of analysis is complicated not only by the presence of phonetic transcription errors, but also by the possibility that any segment in the input string may represent three different types of errors (substitution, omission, or insertion). A project is just underway that provides a uniform way to address all three types of errors. A project that is slated to begin early in 1988 will extend this work by incorporating syntax and domain knowledge in the string parser.

3.7 Time-Oriented Problem Solving

The University of Rochester

Principal Investigator:

James Allen

In the past year we have made progress in several areas relating to problem solving in temporally complex domains. The principle results are the following:

- an extension of the interval-based theory of time (developed in previous years under RADC funding) to allow two different forms of time- points;
- a generalized model of plan recognition, both as a formal theory and as a family of practical recognition algorithms (Henry Kautz, Ph.D., 1987);

- the formulation of two distinct forms of abstraction useful for planning and the investigation of their properties (Tenenburg, 1987);
- an extension to the STRIPS representation of action that allows indirect effects and effects that are dependent on context (Weber, to appear);
- the development of an initial version of the RHET representation system, extending the HORNE system (see Miller & Allen, 1987).

Each of these projects is described in more detail in Volume VII-a. Another important event this year is that the HORNE system, completed in 1986, has been distributed to over 50 different research sites in the last year, including places such as Advanced Decision Systems, SRI International and MCC.

In the project on formal temporal models, we axiomatized a theory of time in terms of intervals and the single relation MEET and showed that this theory subsumes Allen's interval-based theory. We then extended the theory by formally defining the beginnings and endings of intervals and showed that these have properties we normally would associate with points. We distinguished between these point-like objects and the concept of *moment* as hypothesized in discrete time models. Finally, we examined the theory in terms of each of several different models.

Henry Kautz completed his Ph.D. thesis which involved the first formal description of the plan recognition process and completed an initial implementation of a plan recognizer that uses action abstraction to reduce the combinatorial explosion found in simple plan recognition algorithms. The result is a family of plan recognition algorithms, each of increasing complexity and cost. Most notable is this system's ability to handle observed actions that are actually steps in two plans being executed simultaneously, actions that are only vaguely specified, and the ability to accept observed actions in any temporal ordering.

We have completed the first phase of the implementation of the RHET system, a knowledge representation language based on our previous representation system, HORNE. This work included design of the basic system including all the features of HORNE extended with a version of conniver-like contexts, full equality reasoning in contexts, a TMS and an extended type reasoning system. This system will be tested in some realistic application in natural language and planning applications in early 1988.

We also explored different uses of action abstraction in planning systems. Josh Tenenburg's Ph.D. thesis, to be completed in early 1988, defines two forms of abstraction: one found by simply relaxing the conditions under which actions may apply, and the second by using a predicate mapping framework to define analogies between actions. With the first, he developed a theory in which it can be shown that if a fully specific plan exists for some problem, then there exists an abstract solution to an abstraction of the problem. While this might seem an obvious property, many previous models of abstraction do not guarantee this. With the second form, based on analogy, the opposite property can be proven: an abstract solution to a problem guarantees the existence of a fully concrete solution.

The final area concerns the representation and use of actions when reasoning about in a complex world. Our approach, based on the notion of action generation, has important improvements over the pervasive STRIPS representation of actions as well as recent more formal theories, including the treatment of indirect effects, low-level actions, and action co- occurrence. The preliminary results are encouraging and this project will be completed as part of Jay Weber's Ph.D. dissertation (expected early 1989). Future work will include a more general representation of action and time that allows actions to have durations, thereby allowing serial action composition and requiring the generalization of preconditions to include properties that must hold during the action.

3.8 Parallel, Structural, and Optimal Techniques in Vision

The University of Rochester

Principal Investigator:

Christopher Brown

The vision group at Rochester has spent the year investigating various aspects of parallel computer vision, with the goal of building behaving, real-time systems that perform multi-sensory integration. What sets our current work apart is a commitment to the idea that an intimate coupling of sensory and motor capabilities is a way to make progress on the vision problem. Behaving animals have such a coupling, and its benefits have been demonstrated analytically in several papers from Rochester and elsewhere. The year has shown progress in building hardware and software to implement the theory.

- Hardware Developments: We have acquired special-purpose parallel pipelined hardware for low-level vision, and have upgraded our 16-

processor Butterfly Parallel Processor with faster CPUs and floating point hardware. The Butterfly is now connected with the rest of the vision hardware (the pipelined device and a fast Sun/3) via the VME bus.

- Individual Activities: David Sher completed his Ph.D. and is now at the State University of New York at Buffalo. He and Chris Brown are continuing collaborative work. Paul Chou is continuing his extension of Sher's probability-based feature detection, and will finish his thesis in 1988. Paul Cooper is exploring theoretical properties of his parallel object recognition algorithm. Bob Potter is implementing Chou's evidence-combination algorithm on the Butterfly. Chris Brown and Nancy Watts have been working on principal view computations in the domains of solid planar polyhedra and the "blobs and sticks" domain of Paul Cooper.

In summary, our work this year broadened its focus from the optimal selection of feature detectors in a Bayesian framework. Those results were used this year and continue to be used in a working system that applies a Markov Random Field formulation of the segmentation (objecthood recognition, figure-ground separation) problem. Further, this year our work moved in the direction of acquiring and commissioning real-time vision hardware and using the hardware in applications. Theoretical work continues to be important, and this year we made progress on the theory of principal views and convergence properties of two sorts of parallel networks: connectionist nets for recognition and Markov Random Field models of segmentation.

3.9 Computer Architectures for Very Large Knowledge Bases

Syracuse University

Principal Investigator:

P. Bruce Berra

The focus of our research is on the development of algorithmic, software and hardware solutions for the management of very large knowledge bases (VLKB) in a real-time environment. We assume a logic programming inferencing mechanism and a relational model for the management of the knowledge base. The interface between the inferencing mechanism and the extensional data base becomes one of partial match retrieval. During 1987 we have conducted research on many aspects of this problem as indicated in this report.

We completed the analysis and simulation of surrogate file structures. We considered concatenated code words (CCW), superimposed code words (SCW) and transformed inverted lists (TIL). Our primary technique will be CCW but we will also utilize SCW and TIL in some of our research. In addition to good overall performance CCW offer some interesting additional attributes. Namely, relational operations can be performed directly on the surrogate file when it is structured using CCW. The further development of this has become the doctoral dissertation topic of one of the students on the program. This work has a direct effect on the set of operations each surrogate file processor will be required to perform and therefore on its design.

We have begun working on a demonstration system that will be used to interface with a logic programming language, generate surrogate files and manage a knowledge base. The system consists of Prolog, specially developed modules and the INGRES database management system.

We have extended the TIL concept to the management of very large dynamic knowledge bases. This has let to the development of a new access method which we call the dynamic random-sequential access method (DRSAM). This has become the doctoral dissertation topic of one of the students on the project.

In a very large knowledge base the number of rules may be so large that special architectures may be required for the management of the rules. We have investigated the use of CCW for the management of the rules and have developed an associative memory approach. The approach is based on guarded horn clauses and mode declarations in a parallel logic programming context.

Another area that we have been investigating is the potential role of optical storage, interconnection and processing in the management of VLKB. We have developed approaches to the processing of digital light signals coming from optical storage media via optical interconnection. The division between types of processes is between those that do not require intermediate storage and those that do. The performance of a robust set of relational operations through optical means has become the doctoral dissertation topic of one of the graduate students on the project.

Finally, all of the above work supports the long range development of a VLKB architecture. During this year we were able to provide considerably more detail regarding the specifications for that system.

3.10 Knowledge Base Maintenance using Logic Programming Methodologies

Syracuse University

Principal Investigator:

Kenneth Bowen

This project is concerned with the development of automated machinery for the management of large complex knowledge bases of a highly dynamic character. This includes the maintenance of ordinary integrity constraints as well as sophisticated reason maintenance systems. The work is being carried out from the point of view of certain "meta-level" extensions of Prolog, generically baptized "metaProlog."

<u>Project Tasks</u>:

(1) Development of the metaProlog system and its theoretical basis.
  Principal goals:
    Construction of an efficient metaProlog compiler
    Development of a theoretical semantics for the metaProlog idea
    Development of sophisticated memory-management methods
    Development of suitable interfaces to non-metaProlog external databases
    Study of co-routing and concurrency

(2) Development of knowledge representation formalisms in metaProlog, including frames, semantic nets, blackboards, etc.

(3) Expression of generic database management and knowledge base reason maintenance approaches in metaProlog. Special attention to:
    maintenance of static and dynamic integrity constraints
    reason maintenance
    daemons

(4) Construction of demonstration systems using foregoing machinery.

(5) Study of the use of metaProlog in the construction of backtracking-based and assumption-based reason maintenance systems for knowledge bases.

(6) Study of hardware support for aspects of these systems.

4. ANCILLARY GOALS OF THE CONSORTIUM

The ancillary goals of the Consortium can be described as increasing the level of expertise in artificial intelligence at three levels: internal to the Consortium; between Consortium members and other entities (academic and commercial); and in the community at large.

4.1 Development of Internal AI Expertise

4.1.2 Interaction between Consortium members

Interaction between members of the Consortium has grown to take on many forms: collaborative research, both sponsored directly by RADC and the Consortium and ancillary to that formal structure; regular meetings of the Executive Committee (every six weeks), the annual meeting, two "focus" meetings per year, a workshop series, regular visits, etc. Each of these meetings were well-attended, and instrumental in the continued recognition of the Consortium's identity. Proceedings, notes, and attendee lists have been published as technical reports by the Consortium as indicated.

The following formal meetings were held this year:

RADC/NAIC Technical Fair
April 9-10, 1987
Griffiss Air Force Base
(93 attendees)
WR-8701 (206 pp)

Annual Meeting
June 29 - July 1, 1987
Blue Mountain Lake, NY
(31 attendees)
WR-8702 (413 pp)

Natural Language Planning Workshop
September 20 - 23, 1987
Blue Mountain Lake, NY
(31 attendees)
WR-8703 (217 pp)

Fall Focus Meeting on Planning
October 2, 1987
Clarkson University
(43 attendees)
WR-8704 (120 pp)

The RADC/NAIC Technical Fair was held at RADC and was used to encourage a greater awareness in both the RADC and commercial communities of the types of research that the Consortium is engaged in, and to foster new interactions and connections between these groups. Each of the Principal Investigators' work was presented to an audience of almost 100.

The Natural Language Planning Workshop was the first in a series of planned workshops to bring together researchers in a particular discipline from across the country under the sponsorship of NAIC. The principal goal of these workshops is to advance the appreciation of the pragmatic issues of conducting research in the field under discussion. This workshop saw presentations by recognized leaders in the field:

James Allen, *University of Rochester*; Jaime Carbonell, *CMU*; Richard Cullingford, *Georgia Tech*; Sergei Nirenburg, *CMU*; Victor Raskin, *Purdue*; Allen Sears, *DARPA*; Stuart Shapiro, *SUNY Buffalo*; Donald Walker, *Bellcore*; Ralph Wesichedel, *BBN*; Yorick Wilks, *NM State*.

The remaining meetings, the Annual Meeting and the Fall Focus Meeting on Planning, were held as forums for NAIC members to present their work to each other in an atmosphere which promoted open and constructive critical review. Both meetings were attended by individuals from RADC and the community at large.

4.1.3 Faculty and graduate student growth

At present, the schools within the Consortium have achieved the following levels of faculty and graduate student staffing in artificial intelligence research:

School	Faculty	Graduate Students	Research Scientists
State University of New York - Buffalo	6	114	
Clarkson University	6	9	
University of Massachusetts - Amherst	15	84	15
Rensselaer Polytechnic Institute	23	46	
University of Rochester	5	20	3
Rochester Institute of Technology	7	15	
Syracuse University	15	45	

4.2 Development of AI Expertise between Consortium Members and Other Entities

As the Consortium consolidated its own structure, it found itself capable of encouraging and entertaining requests for participation from new institutions, both commercial and academic. The capability of addressing these opportunities was made feasible for the first time by the presence of the Managing Director, and his resources to conduct day-to-day business on behalf of the Consortium at large. Beyond the efforts at invigorating both commercial and academic relationships, other regional entities with overlapping interests and memberships were approached, and the groundwork for close collaboration laid. This has been most successful with the Northeast Parallel Architectures Center, where for the first time additional funds have been earmarked for providing ongoing services to member researchers. This has also led to the creation of a inter-organizational team to continue development on the NAIC workshop series for next year.

4.2.1 Commercial Participation

The Industrial Advisory Board had laid fundamentally dormant over the initial years of the Consortium's existence. Each company was contacted by the Managing Director, and visited where possible, to determine their degree and type of interest in the Consortium, as well as to build the foundation for a newer, more vital commercial participation. New commercial contacts were initiated with the intent of further increasing the visibility of the Consortium, the transfer the results of its work to the commercial sector, and new opportunities for collaboration with industry.

These efforts resulted in a reworking of the definition of commercial participation in the Consortium, due to be implemented in early 1988. Under this new structure, corporations will be offered two levels of participation: as an Affiliate Member, or as a Participating Member. Affiliates will pay a nominal fee to the Consortium, which will entitle them to receive all NAIC technical reports, receive invitations to NAIC workshops and conferences, and to publicize their affiliation with the Consortium. Participating members, who will make the same contribution and receive the same benefits as affiliates, will be those organizations with whom the Consortium is actively pursuing research, in any of the various forms that this may take. It is expected that a given company may sponsor research either directly (or with other companies) in the NAIC, or team with the NAIC for the award of a research grant as either a prime or sub-contractor. The NAIC will take the funds from these memberships and devote them to one of the ancillary goals of the Consortium, such as sponsoring workshops, funding students, etc. To date, three companies are actively pursuing new research opportunities with the NAIC, and more are expected to follow.

4.2.2 New Academic Membership

The hallmark of the Consortium has been the collegial atmosphere which it has engendered, leading to the development of strong cross-institutional collaboration, both formal and informal. The introduction of new academic members has profound implications for the set of relationships which already exist within the Consortium, and it is a tribute to its success that the Consortium is not only willing to entertain proposals from new members, but has defined a procedure for assessing new applications, and is actively seeking such members. At present, five universities in the northeast have approached the Consortium regarding membership, and negotiations are in the early stages with each of them.

4.2.3 National and International Professional Conferences and Publications

MEETINGS ATTENDED BY PI's

CASE Consortium Winter Meeting, Syracuse
Third International Conference on Data Engineering, Los Angeles
DARPA Image Understanding Workshop, Los Angeles
First National Conference on Knowledge Representation and Inference, Bangalore, India
1987 Reliability and Maintainability Symposium, Philadelphia
DIA Artificial Intelligence in Defense Seminar, Washington
Eastern Simulation Conference, Orlando, Florida
All Optical Computing Workshop, Washington DC
International Conference on Artificial Intelligence in Education, Pittsburgh, PA
SPIE Applications of Artificial Intelligence, Orlando, Florida
Meeting of the Niagara Frontier Chapter of the ACM, NY
Seventh International Workshop Conference on Expert Systems and Their Applications in Avignon, France
RADC/CASE Communications Network Management Workshop, Syracuse
National Computer Conference, Chicago
Workshop on Database Machines, Minnowbrook, Blue Mountain Lake
AAAI-87 Sixth National Conference on Artificial Intelligence, Seattle, WA
Optical Artificial Intelligence Workshop, Colorado
ACL Meeting, Stanford, CA
International Joint Conference on Artificial Intelligence, Milan, Italy
OSA Conference, Rochester, NY
International Workshop on Expert Systems and Pattern Recognition in Nowsibirsk, USSR
FJCC in Dallas
Computer Science Seminar, University of Southern California

NAIC 1987 MEETINGS

Executive Committee Meeting, February 2 at RPI
Executive Committee Meeting, March 27 at Syracuse
Executive Committee Meeting, April 9 at Griffiss AFB
RADC/NAIC Technology Fair, April 9-10 at Griffiss AFB
Executive Committee Meeting, July 1 at Minnowbrook
NAIC Annual Meeting, June 29-July 2 at Minnowbrook
Executive Committee Meeting, September 21 at Minnowbrook
Natural Language Planning Workshop, September 20-23 at Minnowbrook
Fall Workshop on Planning at October 2 at Potsdam
NAIC Executive Committee Meeting, October 22 at Syracuse
NAIC Executive Committee Meeting, December 3 at Buffalo

PUBLICATIONS AND PRESENTATIONS DURING 1987

- **SUNY-Buffalo**

"Modeling for Circuit Diagnosis," presentation by Mingruey R. Taie.

"On Knowledge Representation Using Semantic Networks and Sanskrit," presentation by Sargur Srihari in India.

"Knowledge-based Modeling of Circuit Boards," presentation by Stuart C. Shapiro.

"Device Representation and Graphics Interfaces of UMES," paper by J. Geller, M.R. Taie, S.C. Shapiro, and S.N. Srihari.

"Reasoning About the Temporal Structure of Narratives," dissertation / presentation by Michael J. Almeida.

"Spatial Knowledge Representation and Reasoning," presentation by S.N. Srihari in Avignon, France.

"Toward a Computational Mind," presentation by S.C. Shapiro.

"Representation of Device Knowledge for Versatile Fault Diagnosis," presentation by S.C. Shapiro.

"Use of External Information in Zip Code Recognition," presentation by Jonathan Hull and S.N. Srihari in Milan, Italy.

"A Multi-level Perception Approach to Cursive Script Recognition," presentation by S.N. Srihari and Radmilo Bozinovic in Milan, Italy.

"Device Representation and Graphics Interfaces of VMES," presentation by Mingruey Taie.

"A Representation for Natural Category Systems," a presentation by Sandy Peters.

"Graphical Deep Knowledge for Intelligent Machine Drafting," presentation by James Geller in Milan, Italy.

"Address Block Location: Specialized Tools and Problem Solving Architecture," paper by S.N. Srihari, Wang, Palumbo, and Hull.

"A Model for Belief Revision," paper by Stuart C. Shapiro and Joao P. Martins.

"Semantic Network-based Reasoning Systems," presentation by Stuart C. Shapiro.

"Knowledge Representation for Natural Language Processing," presentation by Stuart C. Shapiro.

"Spatial Knowledge Representation," presentation by S.N. Srihari in Novosibirsk, USSR.

"CASSIE: Development of a Computational Mind," presentation by S.C. Shapiro.

"Knowledge-based Parsing," by J.G. Neal and S.C. Shapiro appeared as a chapter of Natural Language Parsing Systems, edited by L. Bolc.

"CASSIE: Toward a Computational Mind," presentation by S.C. Shapiro.

- **Clarkson University**

"SIMULACT: A Generic Tool for Simulating Distributed Systems," presentation by D.J. MacIntosh and S.E. Conry.

"The Role of Knowledge-based Systems in Communications System Control," presentation by Robert A. Meyer and Charles Meyer.

"A Testbed for Distributed Problem Solving," presentation by Susan E. Conry and Robert A. Meyer.

"A Distributed Development Environment for Distributed Expert Systems," by D.J. MacIntosh and S.E. Conry.

"Machine Intelligence for DoD Communications System Control," by G.M. Adams, C.N. Meyer, and R.A. Meyer.

- **University of Massachusetts**

"A Framework for Representing Tutorial Discourse," paper by Beverly Woolf.

"Knowledge Acquisition Through Anticipation of Modifications," dissertation by Lawrence Lefkotwitz.

"Knowledge Acquisition As Knowledge Assimilation," paper by Lawrence S. Lefkowitz and Victor R. Lesser.

"Meta-Plans that Dynamically Reformulate Plans," paper by Karen Huff and Victor R. Lesser.

"Theoretical Issues in Building an Intelligent Tutor," by Beverly Woolf.

"Multiple Knowledge Sources in Intelligent Tutoring Systems," paper by Beverly Woolf.

"Representing Complex Knowledge in Intelligent Tutors," paper by Beverly Woolf.

"A Framework for Representing Tutorial Discourse," paper by Beverly Woolf and Thomas Murray.

"Reasoning About Exceptions in an Interactive Planning System," paper by Carol Broverman and Bruce Croft.

"Plans and Meta-Plans in an Intelligent Assistant for the Process of Programming," paper by Karen Huff and Victor R. Lesser.

"Multiple Knowledge Sources in Intelligent Tutoring Systems," paper by Beverly Woolf and Patricia Cunningham.

"Meta-Plans," presentation by Karen Huff.

"Reasoning About Exceptions During Plan Execution Monitoring," presentation by Carol Broverman.

"A Survey of Intelligent Technical Systems," presentation by Beverly Woolf.

"KnAc: A Knowledge Acquisition System," presentation by Larry Lefkowitz.

"Tutoring a Complex Industrial Process," paper by B. Woolf, D. Blegen, A. Verloop, and J. Jenson.

"NetLisp: Programming a Network of Lisp Processors," paper by K. Murray and D. Corkill.

"Building a Communicty Memory for Intelligent Tutor Systems," presentation by Beverly Woolf.

"A Framework for Tutorial Discourse," presentation by Beverly Woolf in Milan, Italy.

"When the Perfect Plan is Impossible," paper by B. Woolf and M. Wolf.

"Polymer/SPANDEX," presentation by Carol Broverman.

"Using Partial Global Plans to Coordinate Distributed Problem Solvers," by Edmund H. Drufee.

"Primitive Knowledge Units for Intelligent Tutoring Systems," paper by Beverly Woolf.

"A Counselor Tutor for Personal Development," paper by Beverly Woolf.

- **Rensselaer Polytechnic Institute**

"Texture Classification and Discrimination Using the MRF Model," paper by J. Zhang and J.W. Modestino.

"Image Segmentation Using a Gaussian Mode," paper by J. Zhang and J.W. Modestino.

"Unsupervised at Random Field Model-based Image Segmentation," paper by J. Zhang and J.W. Modestino.

"A Composite Stochastic Model-based Approach to Image Segmentation," by J. Zhang and J.W. Modestino.

"A Model Fitting Approach to Cluster Validation with Application to Stochastic Model-based Image Segmentation," by J. Zhang and J.W. Modestino.

"Low-level Model-based Region Segmentation Schemes," presentation by Jun Zhang.

"Use of Region Merging in the Hierarchial Region-based Approach to Automated Photointerpretation," presentation by J.W. Modestino.

"Generating Clique Functions Based Upon Fuzzy Sets," paper by J. Kannai.

"Texture Classification and Discrimination Using the Markov Random Field Model," paper by J. Zhang and J.W. Modestino.

- **RIT**

"Speaker-Independent Vowel Classification Based on Fundamental Frequency and Format Frequency," paper by Dr. James Hillenbrand and Robert Gayvert.

"Prolog Tool Kits for Knowledge-based System Development," presentation by John Biles.

"Lexical Access from Errorful Phonetic Strings," presentation by J. Hillenbrand and T. Sellman.

"The Role of Static Spectral Properties in Vowel Identification," presentation by J. Hillenbrand and B. McMahon.

"Format Tracking Using Statistical Pattern Recognition," presentation by R. Gayvert and J. Hillenbrand.

- **University of Rochester**

"Computer Visions Systems," presentation by Dr. Christopher Brown.

"Time Oriented Problem Solving," presentation by Dr. James Allen.

"Eye Movements and Computer Vision," paper by D.H. Ballard, C.M. Brown, D.J. Coombs, and B.D. Marsh.

"Natural Language Understanding," paper by J.F. Allen.

"Structure Recognition by Connectionist Relaxation," presentation by P.R. Cooper at Canadian AI Conference.

"A Plan Recognition Model for Subdialogues in Conversations," paper by D.J. Litman and J.F. Allen.

"Moments and Points in an Interval-based Temporal Logic," paper by J.F. Allen and P.J. Hayes.

"When Linguistic Argumentation Provides Conceptual Information," paper by S. Guez.

- **Syracuse University**

"An Initial Design of A Very Large Knowledge Base Architecture," paper by P. Bruce Berra.

"Data Base Computers: Past, Present, Future," presentation by P. Bruce Berra.

"An Architecture for Very Large Rule Bases Based on Surrogate Files," paper by D. Shin and P. Bruce Berra.

"Computer Architecture for the Processing of A Surrogate File to A Very Large Data/Knowledge Base," paper by P. Bruce Berra, S. Chung, and N. Hachem.

"Optical Processing and Very Large Date/Knowledge Bases," presentation by P. Bruce Berra.

"Very Large Knowledge Bases," presentation by P. Bruce Berra.

"An Analysis of Surrogate File Structures for Very Large Knowledge Bases," paper by Bruce Berra.

"An Architecture for Processing Very Large Rule Bases," presentation by Dong Hoon Shin.

"Dynamic Concurrency Control Algorithms for Very Large Distributed Database Systems," paper by Arif Ghafoor and F.Y. Farhat.

"Parallel Architecture for Transformed Inverted Lists, A Surrogate File Structure for A Very Large Data/Knowledge Base," paper by Nabil I. Hachim and P. Bruce Berra.

"Back End Architecture Based On Transformed Inverted Lists, A Surrogate File Structure for A Very Large Data/Knowledge Base," paper by Nabil I. Hachem and P. Bruce Berra.

"Optical Knowledge/Database Machines," presentation by P. Bruce Berra.

"Dynamic Random-Sequential Access Method," presentation by Nabil Hachem.

"Computer Architecture, Data/Knowledge Bases and Optics," presentation by P. Bruce Berra.

"An Interconnection Topology for Fault-tolerant Multiprocessor Systems," presentation by Arif Ghafoor in Berlin, W. Germany.

"Very Large Knowledge Bases," presentation by P. Bruce Berra.

"An Architecture for Processing Very Large Rule Bases," presentation by P. Bruce Berra in Karuzaua, Japan.

"Some Thoughts on the Feasibility of Optical Database Machines," presentation by P. Bruce Berra.

"A Class of Biregular Bipartite Fault-tolerant Interconnection Networks," paper by A. Ghafoor.

"Maximal Binomial Interconnection Networks for Fault-tolerant Multiprocessor Systems," paper by A. Ghafoor.

"Workload Allocation for Distributed Systems," paper by N.S. Bowen, C.N. Nikolaou, and A. Ghafoor.

"Surrogate File Structures for Very Large Data/Knowledge Bases," paper by S.M. Chung and P. Bruce Berra.

"An Initial Design of a Very Large Knowlege Base Architecture," paper by P. Mitkas and P. Bruce Berra.

"Computer Architecture for Very Large Knowledge Bases," presentation by P. Bruce Berra in Mt. Fuji, Japan.

"Some Thoughts on Electronic and Optical Data/Knowledge Base Machines," presentation by P. Bruce Berra, Hiroshima University, Japan.

"An Efficient Communication Structure for Distributed Communication Protocols," paper by A. Ghafoor and P. Bruce Berra.

"Paraconsistent Logic Programming," paper by H. Blair, V.S. Subrahmanian.

"Towards a Theory of Declarative Knowledge," by K.A. Apt, H. Blair, and A. Walker.

4.3 Development of AI Expertise in the Community

During 1987, courses were offered for the professional community, most notably by Rochester Institute of Technology and Syracuse University. Syracuse University continued to advance its expertise in the video presentation of course material, allowing for a greater coverage in the working world, and providing the working student with opportunities to make up lost class work on their own schedules.