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Interim Report
October 1989

# NORTHEAST ARTIFICIAL INTELLIGENCE CONSORTIUM ANNUAL REPORT - 1988 Executive Summary

Syracuse University

Volker Weiss and James F. Brule'



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ROME AIR DEVELOPMENT CENTER
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The Northeast Artificial Intelligence Consortium (NAIC) was created by the Air Force Systems Command, Rome Air Development Center, and the 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 fourth 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 photointerpretation, time-oriented problem solving, speech understanding systems, knowledge base maintenance, hardware architectures for very large systems, knowledge based reasoning and planning, and a knowledge acquisition, assistance, and explanation system.

This volume provides the executive summary of all work done by the NAIC in 1988.


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1988 Annual Report

Volume 1

# Executive Summary

Volker Weiss
James F. Brulé



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# 1.1 INTRODUCTION

## 1.1.1 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

## 1.1.2 Objectives of the Consortium

The Consortium's *raison d'etre* has been advancing the state of research and education in AI in the Northeast. Where 1986 had been a year of restructuring and seminal growth towards these objectives, 1987 has been a year of consolidation and accomplishment. In 1988, several new collaborative efforts were undertaken, new research teams were inaugurated, and in general the NAIC began to assume the characteristics of a "real" consortium: a sense of professional collegiality emerged and pervaded the dealings of the individual members in a variety of arenas.

Seminars were presented at several campuses on a variety of topics of interest to the Consortium, satellite workshops were sponsored, and workshops of national stature were underwritten. Attention was drawn to the Consortium through its co-sponsorship of activities national (AAAI, IEEE) and regional (Association for Intelligent Systems Technology, local IEEE chapters) organizations, and a live satellite teleconference introducing the NAIC was broadcast to IBM sites across the eastern seaboard. A high quality color brochure was produced and disseminated. This was the year that the NAIC came of age.

As part of this effort, last year's accomplishments have been solidified: the technical report series has grown to include over 70 titles, active participation with industry has been achieved (particularly with Texas Instruments and Rockwell), and new relationships with similar organizations have been forged and maintained. For the first time, money from new contracts has been integrated into the Consortium, and in the height of collaboration, a project involving researchers at four schools has been initiated.

As ever, 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. Where in previous years virtually all of these tasks had been independent, now a quarter of them are collaborative in a formal sense, and in an informal sense, each project is the beneficiary of the input and observations of other Consortium researchers, gleaned from annual and topical meetings. Reports of their accomplishments in the past year are included in the volumes that follow this one; executive summaries are included later in this volume.

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

DISCUSSING, USING, AND RECOGNIZING PLANS
PIs: Stuart C. Shapiro (SUNY Buffalo)
Beverly Woolf (University of Massachusetts - Amherst)
(Volume 2)

VMES: A NETWORK-BASED VERSATILE MAINTENANCE EXPERT SYSTEM
PIs: Stuart C. Shapiro, Sargur N. Srihari, Shambhu J. Upadhyaya
State University of New York at Buffalo
(Volume 3)

DISTRIBUTED AI FOR COMMUNICATIONS NETWORK MANAGEMENT
PIs: Robert A. Meyer, Susan E. Conry
Clarkson University
(Volume 4)

DISTRIBUTED PROBLEM SOLVING FOR DYNAMIC PLANNING IN THE PRESENCE OF TIME CONSTRAINTS
PIs: Susan E. Conry, Robert A. Meyer (Clarkson University)
Victor Lesser (University of Massachusetts)
(Volume 5)

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

PIs: Victor Lesser, W. Bruce Croft, and Beverly Woolf
University of Massachusetts - Amherst
(Volume 6)

AUTOMATIC PHOTOINTERPRETATION

PIs: James W. Modestino, Arthur C. Sanderson
Rensselaer Polytechnic Institute
(Volume 7)

ARTIFICIAL INTELLIGENCE APPLICATIONS TO SPEECH RECOGNITION

PIs: Harvey Rhody, John A. Biles
Rochester Institute of Technology
(Volume 8)

PARALLEL VISION

PIs: Christopher M. Brown, Randal Nelson
University of Rochester
(Volume 9)

TIME-ORIENTED PROBLEM SOLVING

PI: James F. Allen
University of Rochester
(Volume 10)

KNOWLEDGE BASE MAINTENANCE USING LOGIC PROGRAMMING METHODOLOGIES

PI: Kenneth A. Bowen
Syracuse University
(Volume 11)

COMPUTER ARCHITECTURES FOR VERY LARGE KNOWLEDGE BASES

PI: P. Bruce Berra
Syracuse University
(Volume 12)

# 1.2 MANAGEMENT STRUCTURE

## 1.2.1 Inter-School

Director: Volker Weiss
Managing Director: James Brulé
Administrative Secretary: Jeanette Fernandes
Executive Committee:
Rochester Institute of Technology (two years): Harvey Rhody
University of Rochester (two years): James Allen
Clarkson University (one year): Robert Meyer
Syracuse University (one year): Kenneth Bowen

The management structure was retained from the previous year, which had been modified in light of the increased investment in the Consortium. The Director remains the responsible individual named in the prime contract. The Managing Director reports to the Director and the Executive Committee; his 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. A half-time secretary was retained for much of the year to assist in the development of technical report series and other literature production. 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.

### 1.2.2 Intra-School

The Principal Investigators at each institution, indicated below by asterisks, are responsible for both the technical and ancillary functions at their respective institutions. The Principal Investigators and researchers involved in the projects at each institution are:

Stuart C. Shapiro*
Sargur N. Srihari*
Shambhu J. Upadhyaya*
David Sher
*State University of New York at Buffalo*

Susan E. Conry*
Robert A. Meyer*
*Clarkson University*

Victor Lesser*
W. Bruce Croft*
Beverly Woolf*
*University of Massachusetts - Amherst*

Arthur C. Sanderson*
James W. Modestino*
*Rensselaer Polytechnic Institute*

James F. Allen*
Christopher M. Brown*
Randal Nelson*
Josh Tenenberg
*University of Rochester*

Harvey Rhody*
John A. Biles*
*Rochester Institute of Technology*

P. Bruce Berra*
Kenneth A. Bowen*
Howard Blair
*Syracuse University*

## 1.3 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.

### 1.3.1 Discussing, Using, and Recognizing Plans (SUNY-UMass): Vol. 2

The UMass group has developed a framework for using plans to understand multi-sentential narratives. The framework includes an architecture for disambiguating example- or case-based anaphora, such as in the word "situation" which is used to refer to a set of events or objects. These Model Anophora are distinguished from demonstrative pronouns, (e.g, him, her, and it, which refer to discourse segments. The larger Model Anaphora are handled through use of a focus stack and a backward search through a set of candidates describing the state of affairs of objects and people in the narrative.

The framework additionally uses a hybrid of domain knowledge, traditional planning, and "reactive-planning" techniques to help understand a deep theory behind the actions of objects or the goals of people in the narrative.

### 1.3.2 Versatile Maintenance Expert System (SUNY,Buffalo): Vol. 3

Research on the Versatile Maintenance Expert System (VMES) project is concerned with issues in the development of a system to diagnose faults in an electronic circuit. The system reasons using a structural-functional model of the device. The model is built using a library of primitive components. During 1988 the SUNY group's accomplishments were in the following areas:

- a systematic method for initial candidate ordering which takes into account the structure of a device and the relationships of its components with both correct and incorrect outputs;

- an interface for encoding devices in a previously developed method of device representation;
- sequential circuit diagnosis;
- the migration of deep knowledge to shallow knowledge;
- natural language graphics;
- continuing development of the new revision of the Semantic Network Processing System (SNePS-2).

In the remainder of this summary, a few more details in each are given.

A major step in model-based fault diagnosis is the generation of candidate submodules which might be responsible for the observed symptom of malfunction. More dynamic methods, candidate reordering and elimination, were developed.

The system has been successfully ported from the department's UNIX machine using SNePS-79 and Franz Lisp to TI Explorers using SNePS-2 and Common Lisp. The improvement in performance is enormous. It runs at least ten times faster than before.

An interface for encoding devices in the previously developed method of representation was implemented. This is user-friendly and robust, providing for as few key-strokes from the user as possible. It was encoded in Franz Lisp on a VAX to begin with, and was transferred to Common Lisp on a TI Explorer.

In an attempt to enable VMES to diagnose sequential circuits, the following were carried out:

a) a changed representation scheme, with a proposed representation of transition tables for simple sequential circuits;

b) a changed control structure where one not only steps down the structural but also the temporal hierarchy of the device.

The continuing development of the new version of the Semantic Network Processing System (SNePS-2) has proceeded through the year. During this past year, the mainstream of the system's development has been split in two directions: 1) the development and enhancement of the SNePS-2 system itself, and 2) making the system operational and maintainable over seven different computer systems.

The development of the SNePS-2 system has been focussed in three main areas:

1) the Natural Language Interface (NLINT),
2) the SNePS Inference Package (SNIP), and
3) the system's overall efficiency.

The NLINT package, which consists of an augmented transition network (ATN) parser/generator and a lexicon, has been developed to a stage of competence that it is currently being used as the input system of choice for two other RADC sponsored programs here at SUNY at Buffalo. The SNIP package, still under development, has evolved to a point where both forward and backward note-based inference is operational over most of the system's possible types of rules including: or-entailment, and-entailment, numerical-entailment, and-or, and thresh. The VMES project has ceased using the now obsolete SNePS-79 system running on a VAX-11/785, and is now using SNePS-2 as its implementation vehicle on the Texas Instruments Explorer.

The group has stayed as close as possible to the definition of the language "Common Lisp," as described by Guy Steele. They have attempted to get SNePS-2 running on as many different computer systems as possible, thus insuring portability not only within the language, but across architectures as well. The seven vehicles that currently run SNePS-2 are; Texas Instruments Explorer II, Symbolics 36xx, VAX-11/785, Sperry 7000, Encore Multimax, SUN-3/60, and Hewlett Packard 9000. The most difficult portion of this task has been overcoming the idiosyncrasies of the Common Lisps running on some of these target machines. However, all but the HP implementation are currently being supported by essentially the same source code.

This year has seen SNePS-2 go from a half-implemented system, to one that is the knowledge representation vehicle of choice for three RADC sponsored programs being conducted here at SUNY at Buffalo.

### 1.3.3 Distributed AI for Communications Network Management (Clarkson): Vol. 4

This volume describes work done during 1988 at Clarkson University on the task, Distributed Artificial Intelligence For Communications Network Management, of the NAIC research contract with the Rome Air Development Center. The objective of this effort is to investigate potential applications of distributed AI to system control and network management problems for large-scale, world-wide communications networks. This volume includes a brief summary of the typical context in which these problems arise, and outlines the architecture the research group has developed for application of AI technology to these problems. They have identified specific issues which raise fundamental research questions to be resolved in order to bring the application of AI technology to full fruition in this area. The central focus of their work has been to study these questions, proposing answers, and testing the merits of these answers in a realistic simulated environment. They have results, based on implementations which have been tested in their testbed environment, in three important areas. These areas are: multiagent distributed plan generation, constraint-based reasoning in multiagent planning, and multiagent truth maintenance for shared knowledge bases.

The problem domain which forms the context for our work is the management and control of a large scale, worldwide communication system such as the U.S. Defense Communication System (DCS). The group has concentrated on network management and control at the subregion level. The subregion level represents a group of ten to twenty individual sites or nodes in the communications system architecture which are monitored and controlled from a single control center. System wide management and control is distributed over a network of subregion control centers, typically eight to twelve in number. Their view of the role of distributed AI in this environment is to provide cooperating, intelligent, semi-autonomous agents to serve as problem solving assistants to the human controllers. This set of agents must be distributed both spatially and functionally. The spatial distribution is a natural consequence of the underlying communications network and control system architecture which is distributed over a large geographical area. The functional distribution arises from the requirement for multiple, distinct, but related, problem solving tasks in performing network management. These tasks are: performance assessment (PA), fault diagnosis or isolation (FI), and service restoral (SR). During this past year the group has devoted most of their efforts to the service restoral task, and to developing a basis for local multiagent cooperation using a shared knowledge base.

The service restoral task requires distributed planning subject to constraints imposed by network topology and resource availability. They have developed a distributed planner which extends the current work in planning by designating certain objects as resources so that they may be efficiently allocated for effective use in multiple goals. The planner consists of two stages, plan generation and multistage negotiation. During plan generation, agents are required to generate plans which utilize limited system resources in a domain where both the knowledge about resources and the control over these resources are distributed among the agents. After a set of plans has been established, agents must cooperatively select specific plans to execute as many goals as possible, subject to resource constraints. Multistage negotiation has been developed as a means by which an agent can acquire enough knowledge to reason about the impact of local decisions on nonlocal system state and modify its behavior accordingly.

Because no single agent is in control and no single agent has complete knowledge of the entire system state, an important aspect of multistage negotiation is the mechanism for providing agents with nonlocal information. The group has developed a formalism for abstracting and propagating information about the nonlocal impact of decisions made locally. Their work provides mechanisms for determining impact at three levels: locally on the level of plan fragments, locally on the level of goals, and nonlocally. This approach may be viewed as promoting cooperation among agents by using constraint-based reasoning to develop good, local heuristic decision making. This phase of their work is currently in the theory development stage, and will be a major thrust for implementation in the next year.

### 1.3.4 Distributed Planning for Dynamic Environments in the Presence of Time Constraints (Clarkson-UMass): Vol. 5

This task is one which started in August of 1988. Since there were only two months' activity during FY88, the bulk of the effort in FY88 has been devoted to delineating the specific strategy to be employed in building the experimental testbed facility and in beginning the design of the facility.

Their primary goal during the first few months' activity on this task has been one of developing a distributed firefighting simulator. This is necessary in order to provide an environment in which agents can cooperatively plan to contain fires. In order to accomplish this task, a number of issues related to timing, agent synchronization, and management of "thinking time" and "acting time" must be resolved. During FY88, these issues were investigated and the design of a distributed simulator for the firefighting domain was formulated.

The testbed simulator has not been designed simply as a distribution of the existing centralized firefighting simulator. They found that the issues of time and agent synchronization in a multi-agent environment necessitated a complete redesign of the simulation. The new design permits multiple agents to work simultaneously and independently. It includes a facility for defining the characteristics of communications among agents, with available communication media independently specified. In addition, the new simulator will reflect much more realistic terrain representation and a significantly improved fire model than the existing centralized simulator. This simulator will be implemented during FY89.

Other work on this task in FY88 has been concentrated on formulation of mechanisms for handling time and reasoning strategies for adjudicating allocation of time between a "situation assessment" function and a "planning" function in the planner. It seems clear that time is a critical resource for these types of problems. When time is viewed as a resource, proper allocation of time among subtasks is critical in achieving reasonable performance. One problem that is central to development of heuristics for determining time allocations is that of formulating ways of handling the fact that time can be viewed in more than one way. It seems evident that the CPU time associated with the planner is measured in milliseconds to minutes, whereas the time associated with acquiring information regarding the state of the fire may be measured in minutes or hours. Reasoning about actions in an environment such as this requires that the planner understand and be able to deal with these extreme differences in scale. Effectively, there are two types of time: "execution time" and "action time" or "internal time" and "external time." These two types of time share some attributes, but are fundamentally different in others (as far as the planner is concerned). Preliminary research concerning effective ways of modeling time has been initiated in FY88 and mechanisms for experimenting with time (as perceived by agents in the system) have been incorporated in the simulator design.

### 1.3.5. Building an Intelligent Assistant: The Acquisition, Integration, and Maintenance of Complex Distributed Tasks (UMass): Vol. 6

The NAIC research group at the University of Massachusetts has made progress in the development of systems that provide support to multiple users in the accomplishment of tasks on the computer. This work has led to development of several planning and plan recognition systems, as well as applications into several new domains. The systems provide diverse functionality, including the ability to reason about encoded knowledge and to construct and recognize several plans. The systems theyhave built include: a planner that understands (recognizes) the goals of its user, can achieve several goals, and can relate these goals to other users' goals; a planner that formulates interactive plans to accomplish goals, monitor task executions, and run simulations; and another system that resolves conflicts through negotiation.

The GRAPPLE system monitors a user's activities, detects errors, and reasons about the user's plans. It uses domain knowledge to make plausible assumptions about missing values in an open world application. Imprecise knowledge is used to support conjecture conclusions, and to provide improved error detection, prediction, and disambiguation.

POLYMER is a planning and plan recognition system which constructs partial plans and executes them interactively. It uses constraints from agent actions to extend its partial plans. Exception handling is achieved by classifying exceptions and constructing an explanation of how each action may fit into the current plan. A graphical interface is provided for end users based on how people recall their tasks.

They have begun a new project to look at planning in dynamic domains. This work uses simulation techniques in conjunction with classical planning technique to solve a wider class of planning problems.

Negotiation between agents involved in conflicting or inconsistent long-term knowledge plans are handled through yet another system which initiates negotiation, assists the negotiation process, and uses both compromises and integrative bargaining to reach a solution.

The group has also built a suite of programming tools that enable authors to browse and summarize knowledge in an expert system for tutoring. These tools facilitate tracing and explaining the reasoning within an expert system and allow an author to interactively modify system reasoning and response in an intelligent discourse system.

In sum, the group's research this year has focused on issues of inferring and anticipating goals, or communicating and comprehending multiple users and on constructing approachable and informative interfaces. As a result of this research program alone, they can expect to graduate nearly five Ph.D. students in the next year and a half.

### 1.3.6 Automatic Photointerpretation (RPI): Vol. 7

The RPI task has been concerned with the development of expert systems techniques for automated photointerpretation.

More specifically, their 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.

As part of previous efforts on this task, they have developed a novel Markov-Random Field (MRF) based approach to image interpretation which seems ideally suited to the photointerpretation task. This work has been documented in previous annual reports. The research group's major efforts in FY88 have been to further refine this approach and demonstrate its performance on real-world images. They have developed a number of new theoretical results on the MRF approach to image interpretation, have improved the front-end segmentation process, and have been successful in porting this system to an Explorer Workstation. The RPI volume for FY88 documents this progress.

### 1.3.7 Artificial Intelligence Applications to Speech Recognition (RIT): Vol. 8

The RIT NAIC project is the development of techniques that can be applied to speaker independent, continuous speech, large vocabulary speech understanding systems. It is the team's belief that Artificial Intelligence (AI) methods can provide new insight into the extremely difficult task of building these systems. This AI approach is in contrast to the traditional acoustical engineering approaches which have been used in the past.

The ultimate goal of the team's speech understanding research is to demonstrate an end-to-end system starting from the acoustic waveform and ending with a knowledge representation of the utterance. Such a system would provide them with a framework for both demonstrating their speech understanding techniques and comparing them with more traditional methods of speech and signal understanding. The team has completed a speech and signal processing workstation which gives them the capabilities to assemble this end-to-end system.

Within the system there exist several milestones which represent an increase in the level of understanding along the continuum from acoustic waveform to speech understanding. These milestones are:

1) Derivation of the broad phonemic classes which represent the utterance;
2) Derivation of the phonetic transcription of the spoken utterance;
3) The ability to map these (possibly errorful) phonetic transcriptions onto a large vocabulary;
4) A method of extracting only the plausible parsings from these transcriptions; and
5) The ability to build a knowledge representation of the utterance from a plausible parse using all possible sources of syntactic, semantic, and domain knowledge.

At this time there is ongoing research at each of the above levels.

The team has been attacking the broad phonemic classification problem from two fronts. The first has been statistically based classification using both K-means clustering based on Euclidian distance measures and multivariate maximum likelihood distance measures. The second approach has been based on the use of back-propagation neural networks. Both approaches train on low-level features of the signals that are most closely associated with phonetic content.

Their work in the derivation of phonetic transcription has been based on looking for low level features that can be used to classify a segment of known broad phonetic category into the correct phoneme. The team's first research in this area was an expert system to identify fricatives. They have just begun in this past year work on classifying stop consonants. A new project beginning in the last year of the study will use neural network classification techniques to classify vowels from vowel-like segments.

The team made a single attempt at using Dynamic Time Warping (DTW) techniques to parse errorful phoneme strings into words out of a vocabulary of approximately 800 words. They have found that these techniques are computationally expensive and produce many word strings in addition to the correct string. They would like to examine some other less computationally expensive methods and compare their results.

Their work in determining plausible parsings is still under consideration. The team's work in natural language understanding has progressed to the system design phase.

### 1.3.8. Parallel Vision (UofR): Vol. 9

The vision group at Rochester spent the year investigating several aspects of parallel and real-time computer vision with the overall goal of implementing a set of basic sensory-motor behaviors which could serve as a foundation for more sophisticated abilities, and integrating these primary behaviors into multi-modal systems. The emphasis was on behaviors which had relevance to, and could be implemented to work robustly in, a broad range of real-world environments since these are most likely to be useful as fundamental skills.

This work reflects the position that the way to make progress in computer vision is to investigate the sensory-motor coupling that is necessary to carry out specific tasks. Once a basic behavioral repertoire is obtained, its components can be combined and modified to produce systems of increasing sophistication. This approach depends critically on the identification of appropriate foundational abilities. Since organisms, including humans, presumably evolved their present visual sophistication through a process akin to the proposed approach, one obvious source of inspiration is in the primitive visual behaviors of animals. The research group has concentrated on two such areas: gaze control and visual navigation.

This year's active vision work centered around commissioning the Rochester Robot, which consists of a 3 degree of freedom, two-eyed robot head connected to a Puma 761 arm. The camera-robot system is connected to a Datacube image processor, among other computational hardware, which is fast enough to allow real-time visual motion control. The robot has proved to be a fruitful testbed, and a number of behaviors have been implemented, including a vestibulo-ocular reflex (VOR), vergence, and target tracking.

Research also continued into various theoretical aspects of computer vision including parallel evidence combination, parallel object recognition, principal view analysis, and adaptive Kalman filtering.

Individual activities were, briefly, as follows. Paul Chou completed his Ph.D. and is now at IBM T.J. Watson Research Center. Paul Cooper continued his work on parallel object recognition and will finish his thesis in 1989. The Rochester Robot was commissioned with much help from Dave Tilley and Tim Becker. Ray Rimey and Rob Potter with help from Tilley and Tom Olson implemented several gaze-control mechanisms on the robot. Randal Nelson joined the faculty and the vision group this fall, coming from the University of Maryland where he worked on problems in visual navigation. He expects to continue with related work here. Chris Brown's work in 1988 divides into three phases that correspond with the calendar. From January through June he concentrated on reconstruction and segmentation algorithms implemented with Markov Random Fields and data fusion, and to a smaller extent on principle view (or aspect graph) calculations for non-convex polyhedral scenes; this work culminated in papers and the Ph.D. thesis by Paul Chou and the paper by Nancy Watts. From June through August he concentrated on robotics and real-time vision, especially commissioning the Rochester Robot and implementing real-time vision demonstrations; this work is reported in at least three technical reports, one of which has been submitted for publication. From September through December he was at the University of Oxford, where he implemented several versions of the Kalman filter for tracking and parameter estimation, produced a technical report on the subject, implemented a simulator for the kinematic and (to some degree) control behavior of the Rochester Robot, and has been learning about adaptive and optimal control theory.

### 1.3.9 Time-oriented Problem Solving (UofR): Vol. 10

The research group has made excellent progress this year on several different aspects of their overall task of exploring problem solving in enriched temporal domains. The main contributions have been the following:

- The development of a domain for motivating their research in real-time execution of plans involving temporally extended actions;
- A new approach to causal reasoning that rejects domain-dependent approaches to solving the frame problem (Weber 1988);
- The formalization of two different types of abstraction in planning and an explication of their properties, one involving the relaxation of operator constraints, and the other an extension of inheritance hierarchies (Tenenberg 1988);
- The public release of the knowledge representation language Rhet, and the addition of new functionality, such as extended type reasoning.

They describe each of these contributions in more detail below. In addition to the research carried out, the group organized and hosted the Rochester Planning Workshop, which took place at the University of Rochester, October 27-29. This workshop received support from both the NAIC and AAAI. In attendance were many of the leading researchers in automated planning, with presentations made by Nils Nilsson, Stan Rosenschein, Drew McDermott, and Ray Perrault, to name just a few. By all reports, the workshop was quite successful, and has helped put the University of Rochester and the NAIC at the forefront of institutions engaged in planning research.

The group has developed a planning domain based on model trains, ARMTRAK, which captures the conceptual simplicity of the blocks world while extending it sufficiently to a planner with more realistic capabilities. Some of the capabilities that this planner must account for are: actions that have non-uniform temporal extent, knowledge acquisition actions, concurrent actions and resource conflicts, a dynamic world that changes while the agent computes, and incomplete knowledge. A simulation based version of ARMTRAK is under development. In addition, the functionality of the simulation is being integrated with the image processing equipment in the vision lab.

For the past twenty years, solutions to the persistence (frame) problem have been based on domain-independent nonmonotonic assumptions, including such favorites as STRIPS, circumscriptive commonsense reasoning, and chronological minimization. There are, however, serious technical and philosophical problems with this paradigm. On close inspection, it becomes clear that the Yale shooting problem should not be solved by a domain-independent mechanism, as is commonly believed. As an alternative, Jay Weber (Weber 1988) has developed a framework for reified logical causal theories that solves the persistence problem using appropriate information about the domain. For example, in the shooting problem it is important to reason that the gun could not have been unloaded since the reasoning agent did not unload it, and no other agent could have unloaded it while the agent was holding it.

An ongoing interest has been in defining a precise notion of abstraction in planning. This has led the group to investigate multi-level representations of the same problem domain. The group's motivation has been in specifying the formal semantics that they would like to hold between the different levels, and seeking those syntactic transformations that will preserve this semantics. They have investigated two methods of abstraction; the first involves extending inheritance hierarchies from object classes to relations between objects and actions over objects. A domain that includes Bottles and Cups at the low level, with relations InBottle and InCup and operations pourBottle and pourCup, could be abstracted to a simpler representation with objects of type Container, the relation InContainer, and the operation pourContainer. Thus, the abstract level does not distinguish between the different object types that are conflated. The second method of abstraction involves relaxing the constraints under which operators can be applied, similar to the approach taken in ABSTRIPS. We have shown how previous methods of doing this would result in inconsistent systems, and demonstrate a set of constraints on the abstraction mapping that ensure both that the abstract levels are consistent, and also that solutions to low level problems have solutions in the abstract space as well.

Rhet is a multi-strategy KR system that does contextual based reasoning (forward and backward chaining) using enhanced horn clauses. Its features include: two major modes for representing knowledge—as Horn Clauses or as frames, which are interchangeable; a type subsystem for typed and type restricted objects (including variables); E-unification; negation; forward and backward chaining; complete proofs (prove, disprove, find the KB inconsistent, or claim a goal is neither provable nor disprovable); full LISP compatibility; upward compatibility with HORNE; contextual reasoning; truth maintenance; frames having KL-1 type features, plus arbitrary predicate restrictions on slots within a frame as well as default values for slots; and a separate subsystem providing advanced user-interface facilities, graphics, and ZMACS interface on the lisp machines. The following features will soon be added: incremental compilation; default reasoning; user-declarable reasoning subsystems; and Allen & Koomen's TEMPOS time interval reasoning subsystem.

## 1.3.10 Knowledge Base Maintenance (SU): Vol. 11

The primary focus of the team's research during the past year was on the development of a mathematical foundation for logic programming. Specific areas of active research work include: stratified knowledge bases, equivalences of non-classical logic programs, multi-valued logic programming, and topological aspects of logic programming. Considerable success was achieved in each of these areas:

They have studied the recursion-theoretic complexity of the perfect (Herbrand) models of stratified logic programs. It is shown that these models lie arbitrarily high in the arithmetic hierarchy. As a consequence, the team obtains a similar characterization of the recursion-theoretic complexity of the set of consequences of a number of formalisms for non-monotonic reasoning. It is demonstrated that under certain circumstances, this complexity can be brought down to recursive enumerability.

Logic programming with nonclassical logics has aroused a great deal of interest (cf. the proposals for incorporating quantitative "certainty factors" of Van Emden, and Subrahmanian, the three-valued logics of Lassez-Maher and Fitting, the four-valued logics of Blair-Subrahmanian and Fitting). The team proposes four semantical notions of equivalences of sentences based on classical and non-classical logics. They show that under certain conditions on the lattice structure of the set of truth values of the logic of interest, three of these notions of equivalence can be captured in terms of results on the convergence of monotone nets in topology, while the fourth can be captured in terms of a property of convergent nets in compact Hausdorff spaces. The team also shows that these net convergence theorems allow them to characterize equivalences of Van Emden's quantitative rule sets, Lassez and Maher's three valued logic programs, and sentences with negation and disjunction as well as pure logic programs. Their work may be viewed as a semantical counterpart of Maher's syntactical characterization of pure 2-valued logic programs.

They define a topology called the query topology on each of two sets—the set of interpretations of a first order language and the set of models of any sentence in the language. The team shows that in each of these cases, the resulting topology is a perfectly normal, $T_4$-space. In addition, the query topology on the set of interpretations is compact. They derive a necessary and sufficient condition for the query topology on the space of models of sentences to be compact and show, in addition, that the completions of canonical logic programs have a compact space of models. The familiar $T_P$ operator may now be viewed as a function from a compact Hausdorff space to a compact Hausdorff space. They show that if $P$ is either covered or function-free, then $T_P$ is continuous in the query topology.

The fact that the space of interpretations of a language is compact Hausdorff allows them to use the well-known theorems in topological fixed point theory to obtain heretofore unknown results on the semantics of logic programming. The team presents one such result—viz. a necessary and sufficient topological condition that guarantees the *J*-consistency (a notion defined in the paper) of completions of general logic programs.

Recent results of Blair, Brown, and Subrahmanian and independently, M. Fitting have shown that the declarative semantics of logic programs when interpreted over sets of truth values possessing some simple lattice-theoretic properties shows remarkably little change. They prove here that the operational semantics (i.e. proof procedures) for such languages also show remarkably little change. The principal result is that under a natural condition of *support*, a straightforward generalization of SLD-resolution is sound and complete w.r.t. processing of queries over these differing logics.

### 1.3.11 Computer Architecture for Very Large Knowledge Bases (SU): Vol. 12

The focus of the group's 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. They approach the problem from electronic and optical points of view. The electronic approach is based on more traditional digital computer technology and they have developed algorithmic and hardware solutions to the VLKB problem. The group assumes 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 database becomes one of partial match retrieval. They bridge the gap between the two parts through the use of a surrogate file structure for the representation of both rules and facts.

In the optical approach they are concerned with the high speed and massive inherent parallelism of optics and how they might be used to advantage in storage, transport and processing of very large knowledge bases.

In the general case a logic programming front end engine requires equal access to all rules and facts. Because of this generality the group has taken a surrogate file approach to the management of the VLKB. Surrogate files are transformations that yield improved performance because of smaller size, more rigid structure and the opportunity for parallel operations. In prior work they analyzed several possible surrogate file structures and selected concatenated code words (CCW) as the approach that offered the most generality and potential performance improvements. Basically, a CCW is a concatenation of transformed values and one can utilize the individual components of the CCW as well as the entire word.

The group has designed a parallel back end database machine. The basic idea of the machine is to reduce the amount of fact data transferred from the secondary storage system while satisfying the user query. In order to do this the CCW files are distributed over many disks which are under the control of many surrogate file processors. The CCW entries are used to greatly reduce the amount of data that needs to be searched in response to a query. Relational data base operations are performed on the surrogate files thus further reducing the amount of data needed to be retrieved. When all operations are complete the results are then sent to the logic programming engine for further use.

Another important advantage of the CCW surrogate file technique is that it can be used for the indexing of rules expressed as logic programming clauses, where the matching between constants, variables, and structured terms is required to test for unifiability. The CCW is obtained from the arguments in the clause as well as the predicate name of the head of the clause. Each code word is divided into a tag field and a value field. The tag field can represent any argument type including lists, structured terms, variables and constants. The value field contains the transformed representation of the corresponding argument according to the content of the tag field. Thus, the CCW approach allows for the representation and processing of rules and facts in a unified manner.

They have analyzed the CCW technique in a variety of ways including simulation on the Connection Machine and the development of a demonstration system. The demonstration system consists of Prolog, INGRES, and specially developed modules. The system allows for the generation and management of surrogate files of various types, the execution of Prolog programs, and the management of rules and facts.

To handle very large dynamic databases they have developed the dynamic random sequential access method (DRSAM). It is based on an order preserving dynamic hashing method derived from linear hashing. The performance of DRSAM was evaluated and found to be efficient for range queries as well as random access. With order preserving hashing, the hashed key values are not generally uniformly distributed over the storage address space. To deal with the nonuniformity they have extended DRSAM with additional control structures.

The use of optics in the management of VLDB's can be divided into three parts: storage, transport, and processing. Storage involves the use of optical disks or holograms. It appears to be feasible to obtain at least two orders of magnitude increase in optical disk transfer rates through the use of multiple beam reads. These data could be input to optical fiber for transport to optical database processors. They have developed an initial design of a system for the performance of various VLKB operations. It can perform selection, projection and equijoin as well as the filtering of ground clauses. The configuration includes two spatial light modulators and a large photodetector array for photon/electron conversion.

## 1.4 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.

### 1.4.1 Development of Internal AI Expertise

Interaction between Consortium members

Interaction between members of the Consortium includes collaborative research, regular meetings of the Executive Committee (approximately every six weeks), the Annual Meeting, "focus" meetings, workshop series, inter-school visits, etc. Where appropriate, proceedings, notes, and attendee lists have been published as technical reports by the Consortium.

The following formal meetings were held this year:

Spring Meeting: "Vision and Intelligent Signal Processing"
March 29-30, 1988
Washington, DC

RADC/NAIC Day
May 11, 1988
RADC
Griffiss AFB, NY

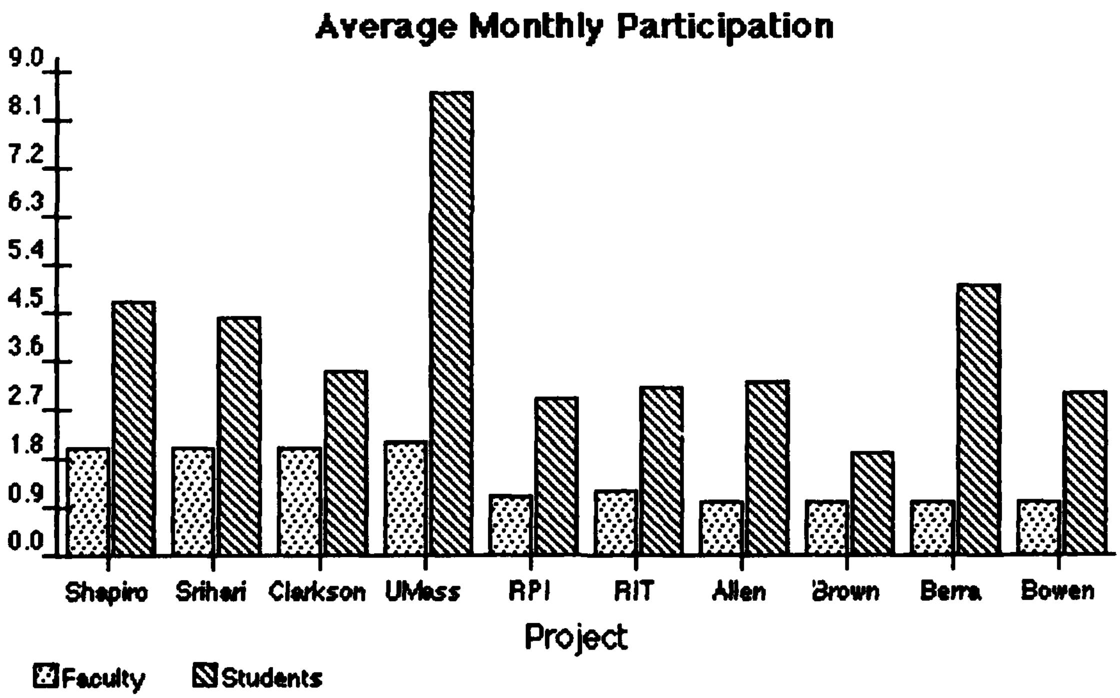
Rockwell/NAIC Artificial Intelligence Symposium
June 6-7, 1988
Sheraton Conference Center
Syracuse, NY

Annual Meeting
August 8-11, 1988
Blue Mountain Lake, NY

Planning Workshop: "From Formal Systems to Practical Systems"
October 27-29, 1988
University of Rochester
Rochester, NY

Faculty and graduate student participation

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




**1.4.2 Development of AI Expertise between Consortium Members and Other Entities**

Commercial Participation

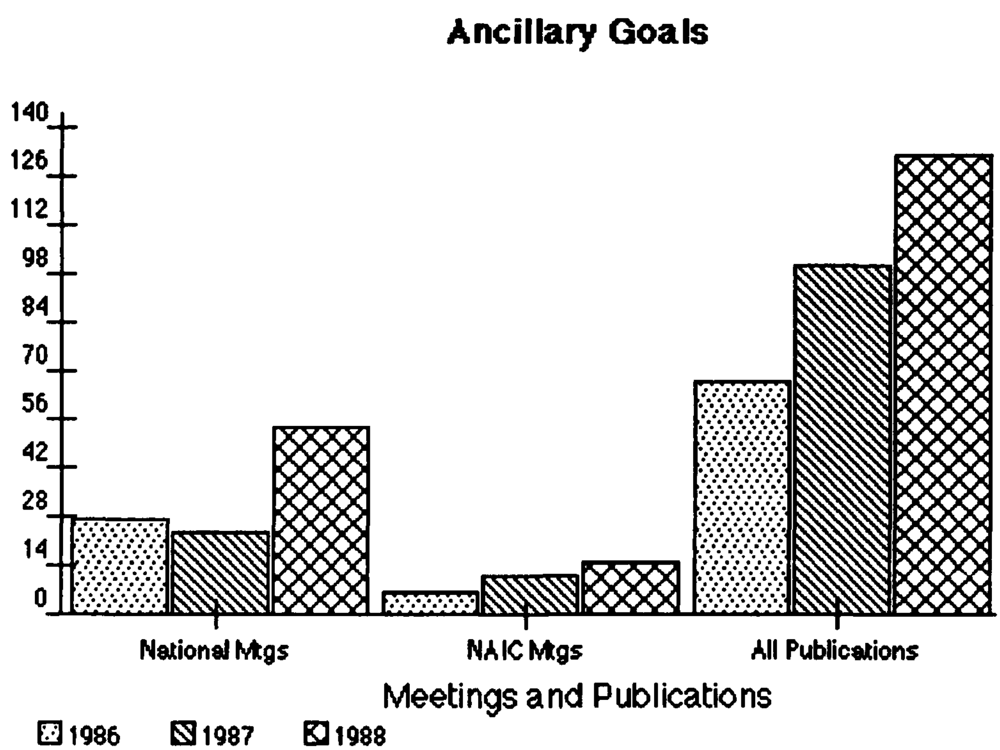
This year, relationships with industry were solidified, and productive arrangements with Texas Instruments and Rockwell International were undertaken. These arrangements took the form of joint conferences and, in the case of Texas Instruments, a donation of twelve Explorer Lisp Machines in support of NAIC research and education.

Academic Participation

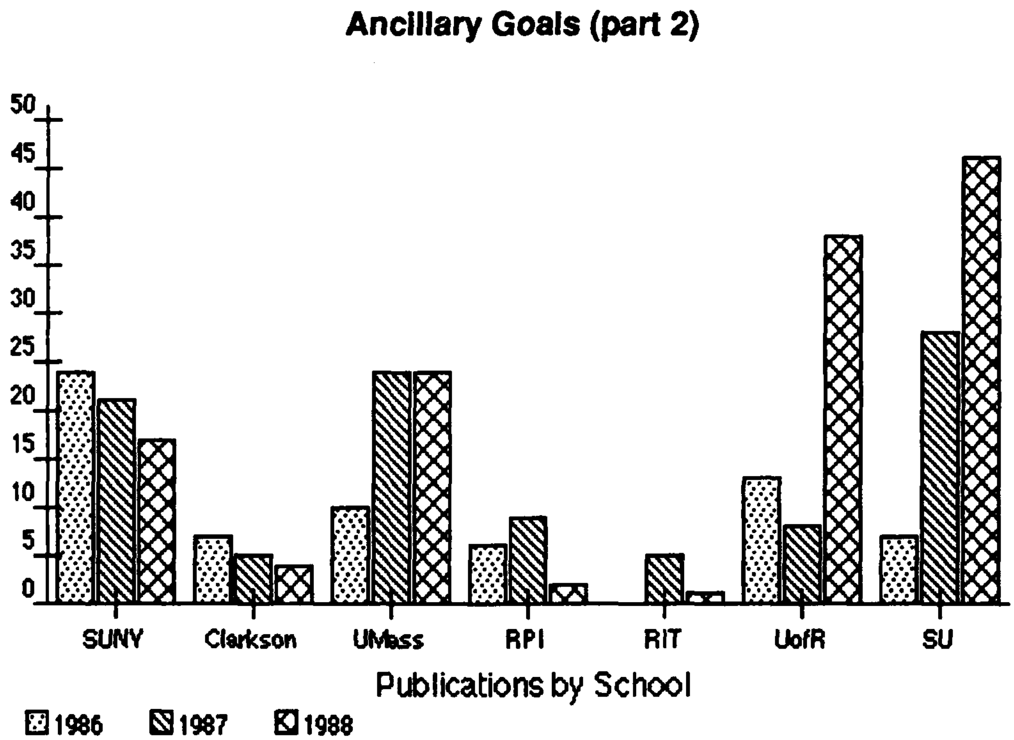
While no formal mechanism for introducing new academic members has been developed, the administration's experience in 1988 has shown that such a formal mechanism has not been necessary. Already, collaborative AI research in support of the NAIC research goals has begun with faculty at Brandeis and Boston University (funded independently of the original NAIC contract), indicating the functional growth of the Consortium.

Growth in Visibility

Over the three full years of the Consortium's life, steady progress has been made towards achieving a greater visibility in professional circles. The following statistics illustrate this growth:




The above chart illustrates the growth in each of the three areas targeted for development: attendance at national meetings, meetings held by the NAIC, and articles published. The attendance and publication figures are for those meetings or articles directly related to NAIC research. In 1988, the NAIC achieved a 175% growth in meetings attended over the previous year, a 36% increase over meetings held, and a 32% increase in articles published. Individual publication statistics are charted below, followed by a list of meetings attended, meetings held, and articles published.




Development of AI Expertise in the Community

During 1988, courses continued to be offered for the professional community. Talks were also given to local groups of computer and managerial professionals interested in AI, such as to the Association for Intelligent Systems Technology.

### 1.4.3 National and International Professional Conferences/Meetings Attended by PIs

26th Annual Meeting of the Association for Computational Linguistics, SUNY-Buffalo, New York
150th Annual Meeting of the British Association for the Advancement of Science, Oxford, UK
1988 Aerospace Applications of Artificial Intelligence Conference, Dayton, Ohio
1988 Minnowbrook Workshop on Database Machines, Blue Mountain Lake, New York
AAAI 1988 Annual Meeting, Minneapolis/St. Paul
AAAI 1988 Workshop on Explanation-Based Learning, Palo Alto, California
AAAI Workshop on Knowledge Acquisition, Banff, Alberta, Canada
Acoustical Society of America Conference, Seattle, Washington
AI Seminar on Robotics and Vision, University of Edinburgh, UK
AIST Annual Meeting, Syracuse, New York
Association for Computing Linguistics Second Conference on Applied Natural Language Processing in Austin, Texas
CAS Seminar on Artificial Intelligence held in Dubrovnik, Yugoslavia
Conference on Computers, Education and Children, Leningrad, USSR
Conference on Neural Networks for Signal Processing, Burlingame, California
DAI Workshop in Lake Arrowhead, California
DARPA Image Understanding Workshop, Washington, DC
DARPA Principal Investigators' Meeting, Dallas, Texas
DARPA Workshop on Integrated Vision Benchmark Architectures, Avon, Connecticut
Eastman Kodak Company Seminar on the Technology and Applications of Neural Networks, Rochester, New York
Eighth International Workshop on Expert Systems and Their Applications in Avignon, France
Fourth ALVEY Vision Conference, Manchester, UK
Hawaii International Conference on Systems Science, Rona, Hawaii
Honeywell Inc./RADC/DCA Technical Meeting, Tampa, Florida
IEEE International Conference on Neural Networks, San Diego, California
Indo-US Workshop on Systems and Signal Processing, Bangalore, India
Industrial Affiliate Meeting at University of Massachusetts, Amherst, Massachusetts
International Conference on Communications, Philadelphia, Pennsylvania
International Conference on Computational Linguistics (COLING-88), Budapest, Hungary
International Conference on Extending Data Base Technology in Venice, Italy
International Conference on Intelligent Tutoring Systems, Montreal, Canada
International Conference on Neural Networks, Denver, Colorado
International Symposium of Computer Work in Kobe, Japan
International Symposium of High Performance Computers in Paris, France
Lexicon Workshop at Brandeis University, Boston, Massachusetts
MetA-88 Workshop on Metaprogramming in Logic Programming, Bristol, England

National Science Foundation Principal Investigators' Meeting in Phoenix, Arizona
National Science Foundation Principal Investigators' Meeting, Pittsburgh, Pennsylvania
National Science Foundation Workshop on Range Imaging, East Lansing, Michigan
NATO Workshops on Knowledge-Based Systems and Architectures for Multisensor Fusion
Natural Language and Planning Workshop in Mt. Snow, Vermont
RADC/Ford Aerospace Technical Meetings, Colorado Springs, Colorado
Second Annual RADC Technology Fair, Utica, New York
Seminar on Optical Database Machines, University of Colorado, Colorado
SNePS2 Introductory Meeting at SUNY-Buffalo, New York
Special Interest Group Talks in Artificial Intelligence, University of Reading, UK
Technical Meetings at RADC, Rome, New York
USC/ISI Intelligent Systems Division Weekly Seminar, California
Workshop entitled, "From the Pixels to the Features," Bonas, France
Workshop on Architectures for Intelligent Interfaces, Pacific Grove, California
Workshop on Hypermedia, Schenectady, New York
Workshop on Linguistic Issues of Geographical Spatial Terms, SUNY-Buffalo, New York

**1.4.4 NAIC 1988 Meetings**

Executive Committee Meeting, January 25 at Syracuse University, Syracuse, New York
NAIC Spring 1988 Conference, March 29-30, Hyatt Regency, Washington, DC
Executive Committee Meeting, March 28, Hyatt Regency, Washington, DC
NAIC Day at RADC, May 11, Griffiss AFB, New York
Rockwell/NAIC Artificial Intelligence Symposium, June 7-8, Syracuse, New York
NAIC Annual Meeting, August 8-11, Minnowbrook, Blue Mountain Lake, New York
Executive Committee Meeting, July 18, Bradley/Springfield, Connecticut
Executive Committee Meeting, August 9, Minnowbrook, Blue Mountain Lake, New York
PI Meeting, August 9, Minnowbrook, Blue Mountain Lake, New York
NAIC Subcommittee Meeting, September 27, Syracuse University, Syracuse, New York
NAIC-IEEE Joint Seminar on "Techniques of Built-In Self Test," October 6 at Syracuse University, Syracuse, New York
NAIC Fall Workshop entitled, "From Formal Systems to Practical Systems," October 27-29, University of Rochester, Rochester, New York
NAIC-CASE joint sponsors of the 4th Annual TI Satellite Symposium, "AI and the Knowledge Worker Productivity Challenge," November 10, Syracuse, New York
Executive Committee Meeting, November 15, Utica, New York
Executive Committee Meeting, December 19, Syracuse University, Syracuse, New York

### 1.4.5 Awards

Dr. S.N. Srihari with Dr. Jonathan Hull, research assistant professor of the Department of Computer Science at SUNY-Buffalo, received third place award at the Niagara Frontier Inventor of the Year Award and Dinner on January 29, 1988. The award was for US patents issued to area inventors during 1987. Their patent is titled, "Systems to Recognize Bilinguistic Strings."

The Encyclopedia of Artificial Intelligence, edited by Dr. Stuart C. Shapiro, professor and chairman of the Department of Computer Science at SUNY-Buffalo, and published by John Wiley & Sons, has won a first prize award as the Best New Book in Technology and Engineering for 1987 from the Association of American Publishers Professional and Scholarly Publishing Division.

### 1.4.6 Publications and Presentations During 1988

- ***SUNY-Buffalo***

"A Model for Belief Revision," paper by J.P. Martins and S.C. Shapiro.

"A Propositional Network Approach to Plans and Plan Recognition," paper by S.C. Shapiro.

"Applications of Expert Systems in Engineering," presentation by S.N. Srihari.

"Applications of Expert Systems in Engineering: An Introduction," paper by S.N. Srihari as chapter one in the book, *"Knowledge-Based System Diagnosis, Supervision and Control."*

"Automatic Construction of User-Interface Displays," paper by Y. Arens, L. Miller, S.C. Shapiro, and N.K. Sondheimer.

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

"Connectionist/PDP/Neural Network Models of Computation," presentation by S.N. Srihari.

"Discussing, Using, and Recognizing Plans in SNePS," presentation by Deepak Kumar.

"Discussing, Using, and Recognizing Plans in SNePS: A Preliminary Report on the SNACTor System," paper by Deepak Kumar, Syed Ali, and Stuart C. Shapiro.

"Discussing, Using, and Recognizing Plans," presentation by S.C. Shapiro.

"Intelligent Multi-Media Interface Technology," presentation by S.N. Srihari.

"Models and Minds: A Reply to Barden," paper by Stuart C. Shapiro and William J. Rapaport.

"Multi-Level Model Based Diagnostic Reasoning," dissertation by Zhigang Xiang.

"Natural Language Graphics for Human Computer Interaction," paper by James Geller.

"Object Recognition in a Visually Complex Environment," presentation by S.N. Srihari.

"Representing Plans and Acts," paper by S.C. Shapiro.

"Some Comments on Geographical Spatial Terms," presentation by S.C. Shapiro.

- **Clarkson University**

"GUS: A Graphical System for Capturing Structural Knowledge," presentation by Robert Meyer.

"Maintaining Consistent Beliefs Among Multiple Agents Sharing Knowledge," thesis by Marty Humphrey.

"Reasoning About Nonlocal Impact of Local Decisions in Distributed Planning," paper by S.E. Conry, R.A. Meyer, R.P. Pope.

"Role Recognition in Multiagent Distributed Planning," thesis by Randall Pope.

- **University of Massachusetts**

"20 Years in the Trenches: What Have We Learned?" paper by B. Woolf.

"A Plan-Based Intelligent Assistant That Supports Software Development Processes," presentation by K. Huff.

"An Ada Restricting Assistant," presentation by Philip Johnson.

"An Intelligent Assistant for the Software Development Process," presentation by Karen Huff.

"An Interface for the Specification of Office Activities," paper by Dirk Mahling.

"Applying Artificial Intelligence Techniques to Education, presentation by B. Woolf.

"Case Studies in Example Generation," paper by B. Woolf, D. Suthers, and T. Murray.

"Consultant Tutor for Personal Development," paper by B. Woolf and T. Slovin.

"Directing the Generation of Living Space Descriptions," presentation by Penelope Sibun, Alison K. Huettner, David D. McDonald.

"Discourse Control for Tutoring: Case Studies in Example Generation," paper by B. Woolf, D. Suthers, and T. Murray.

"Evidence-Based Plan Recognition," paper by N. Carver.

"ExGen: A Constraint Satisfying Example Generator," paper by Suthers and Rissland.

"Intelligent Tutoring Systems and Multimedia Communication Systems," paper by B. Woolf.

"Intelligent Tutoring Systems: A Survey," by B. Woolf as chapter one in the book,*"Exploring Artificial Intelligence, Survey Talks from the National Conference on Artificial Intelligence."*

"Knowledge Acquisition for Planners," presentation by Dirk Mahling.

"Knowledge Primitives for Tutoring Systems," paper by B. Woolf, T. Murray, D. Suthers, and K. Schultz.

"Plan Recognition in Open Worlds," paper by K. Huff.

"Plausible Explanations to Cope with Unanticipated Behavior in Planning," paper by W.B. Croft and C. Broverman.

"Primitive Knowledge Units as the Source of the Tutoring," paper by Beverly Woolf.

"Primitive Knowledge Units for Tutoring Systems," B. Woolf, T. Murray, D. Suthers, and K. Schultz.

"Providing Multiple Views of Reasoning for Explanation," paper by D. Suthers.

"Relating Human Knowledge of Tasks to the Requirements of Plan Libraries," paper by D. Mahling and W.B. Croft.

"Working with Expert Teachers to Distinguish Knowledge from Theory," paper by B. Woolf, D. Schultz, and T. Murray.

"Working with Expert Teachers to Distinguish Knowledge from Theory," paper by B. Woolf, K. Schultz, and T. Murray.

- **Rensselaer Polytechnic Institute**

"A Model-fitting Approach to Cluster Validation and Its Application to Model-based Image Segmentation: Further Results," paper by J. Zhang and J.W. Modestino.

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

- **Rochester Institute of Technology**

"Intelligent Signal Processing," presentation by H. Rhody and J.A. Biles.

- **University of Rochester**

"A Non-Reified Temporal Logic," paper by F. Bacchus, J.D. Tenenberg, and J.A. Koomen.

"A Versatile Approach to Action Reasoning," paper by J.C. Weber.

"Abstraction in Planning," thesis by Josh Tenenberg.

"Advances in Computer Vision," paper by Christopher Brown.

"Animate Attention Focusing," presentation by C.M. Brown.

"Animate Vision," presentation by C.M. Brown.

"Control in Animate Vision," presentation by C.M. Brown.

"Coordinates, Kinematics, and Conversions in the University of Rochester Robotics Laboratory," paper by C.M. Brown and R. Rimey.

"Domain Dependence in Parallel Constraint Satisfaction," paper by P.R. Cooper and M.J. Swain.

"Extending Inheritance Abstraction to Symbolic Planning Systems," paper by J.D. Tenenberg.

"Hierarchical Parallel System for Computer Vision," presentation by Christopher Brown.

"How To Do Things with Words, Computationally Speaking," paper by J.F. Allen and E.A. Hinkelman.

"Inheritance in Automated Planning," paper by J.D. Tenenberg.

"Kalman Filter Utilities for Tracking and Control," paper by C.M. Brown.

"Large-Scale Parallel Programming: Experience with the BBN Butterfly," paper by T.J. LeBlanc, M.L. Scott, and C.M. Brown.

"Multi-Modal Segmentation Using Markov Random Fields," paper by P.B. Chou and C.M. Brown.

"Multimodal Reconstruction and Segmentation with Markov Random Fields and HCF Optimization," presentation by P.B. Chou and C.M. Brown.

"On the Kinetic Depth Effect," paper by J. Aloimonos and C.M. Brown.

"Parallel Hardware for Constraint Satisfaction," paper by P.R. Cooper and M.J. Swain.

"Parallel Hardware for Constraint Satisfaction," presentation by M.J. Swain and P.R. Cooper.

"Parallel Hardware for Constraint Satisfaction," presentation by M.J. Swain and R.J. Cooper.

"Parallel Pipelined Low-Level Vision," paper by S.L. Colwell and C.M. Brown.

"Parallel Vision with the Butterfly Computer," paper by C.M. Brown.

"Parallelism and Domain Dependence in Constraint Satisfaction," paper by P.R. Cooper and M.J. Swain.

"Plan Reasoning and Natural Language," presentation by James Allen.

"Plan-Based Goal Oriented Classification," paper by J.C. Weber.

"Plan-Based Goal-Oriented Classification," paper by J.C. Weber.

"Progress in Image Understanding at the University of Rochester," presentation by C.M. Brown.

"Range Sensing for Navigation," paper by C.M. Brown.

"Real-Time Vergence Control," paper by T.J. Olson, and R.D. Potter.

"Reasoning About Simultaneous Actions," presentation by James Allen.

"Robust Computation of Intrinsic Images from Multiple Cues," paper by C.M. Brown and J. Aloimonos.

"Structure Recognition by Connectionist Relaxation: Formal Analysis," paper by P.R. Cooper.

"Structure Recognition by Connectionist Relaxation: Formal Analysis," presentation by P.R. Cooper

"The Rhet Programmer's Guide (for Rhet version 14.4)," by B.W. Miller.

"The Rhetorical Knowledge Representation System: A User's Manual (for Rhet Version 14.0)," by J.F. Allen and B.W. Miller.

"The Rhetorical Knowledge Representation System: A User's Manual," publication by J.F. Allen and B.W. Miller.

"The Rochester Robot," C.M. Brown (Ed) with D.H. Ballard, T.G. Becker, R.F. Gans, N.G. Martin, T.J. Olson, R.D. Potter, R.D. Rimey, D.G. Tilley, and S.D. Whitehead.

• **Syracuse University**

"A Class of Distance Regular Topology for Fault-Tolerant Multiprocessor System," paper by A. Ghafoor.

"A Class of Fault-Tolerant Multiprocessor Networks," by A. Ghafoor.

"A Comparison of Concatenated and Superimposed Code Word Surrogate File for Very Large Data/Knowledge Bases," presentation by S.M. Chung and P. Bruce Berra.

"A Covering Problem in the Odd Graphs," paper by A. Ghafoor and P. Sole.

"A Logic Programming Semantics Scheme, Part I," paper by K.R. Apt, Howard Blair, and V. S. Subrahmanian.

"A Logic Programming Semantics Scheme," paper by Howard Blair, H.A. Brown and V.S. Subrahmanian.

"A Relational Algebra Machine Based on Surrogate Files for Very Large Data/ Knowledge Bases," paper by Soon Chung, Donghoon Shin, and P. Bruce Berra.

"A Relational Algebra Machine Based on Surrogate Files for Very Large Data/ Knowledge Bases," presentation by S. Chung, Donghoon Shin, and P. Bruce Berra.

"A $T_4$-Space of Models of Logic Programs and Their Completions, I: Foundations," paper by Aida Batarekh and V.S. Subrahmanian.

"A $T_4$-Space of Models of Logic Programs and Their Completions," paper by Aida Batarekh and V.S. Subrahmanian.

"An Application of Coding Theory in Multiprocessor Interconnection Networks," paper by P. Sole and A. Ghafoor.

"An Application of Coding Theory to Multiprocessor Interconnection Networks," paper by A. Ghafoor and P. Sole.

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

"Approximate Reasoning in Logic Programming," paper by V.S. Subrahmanian.

"Arithmetic Classifications of the Perfect Models of Stratified Logic Programs," presentation by K.R. Apt and Howard Blair.

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

"Bisectional Fault-Tolerant Communication Architecture for Supercomputer Systems," paper by A. Ghafoor, T.R. Baskow, and I. Ghafoor.

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

"Design and Implementation of An Abstract MetaProlog Engine for MetaProlog," presentation by Ilyas Cicekli.

"Distance Transitive Topologies for Fault-Tolerant Multiprocessor Systems," paper by A. Ghafoor and P. Sole.

"Distributed Multimedia Database Architecture," presentation by A. Ghafoor and P. Bruce Berra.

"DRSAM: A Dynamic Hashing Method for the Random and Sequential Access to a Very Large File," paper by N. Hachem and P. Bruce Berra.

"Dynamic Concurrency Control Algorithms for Large Distributed Database Systems," article by A. Ghafoor and F. Y. Farhat.

"Dynamic Key-Ordered File Structures for the Random and Sequential Access To Very Large Data/Knowledge Bases," dissertation of Nabil I. Hachem.

"Foundations of Metalogic Programming," paper by V.S. Subrahmanian.

"Generalized Triangular Norm and Co-Norm Based Semantics for Quantitative Rule Set Logic Programming," paper by V.S. Subrahmanian.

"Generating Proof Trees for Explanations in WAM-based Prolog Systems," paper by Hamid Bacha.

"Hierarchical Work Load Allocation in Distributed Systems," paper by N. Bowen, C. Nicolous, and A. Ghafoor.

"Intuitive Semantics for Quantitative Rule Sets," paper by V.S. Subrahmanian.

"Key-Sequential Access Methods in Very Large Files Derived From Linear Hashing," paper by Nabil Hachem and P. Bruce Berra.

"Mechanical Proof Procedures for Many-Valued Lattice Based Logic Programming," paper by V.S. Subrahmanian.

"Metalogic Programming and Direct Universal Computability," paper by Howard Blair.

"MetaProlog Design and Implementation," paper by Hamid Bacha.

"Optical Content Addressable Memories for Managing an Index to a Very Large Data/ Knowledge Base," paper by P. Bruce Berra and Slawomir J. Marcinkowski.

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

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