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SUMMARY OF THE NORTHEAST ARTIFICIAL INTELLIGENCE CONSORTIUM (NAIC)

Sharon M. Walter

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Rome Laboratory
Air Force Systems Command
Griffiss Air Force Base, NY 13441-5700

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APPROVED:

SAMUEL A. DINITTO, JR., Chief
Software Technology Division

FOR THE COMMANDER:

RAYMOND P. URTZ, JR.
Technical Director
Command, Control & Communications Directorate

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13. ABSTRACT (Maximum 200 words)

The Northeast Artificial Intelligence Consortium (NAIC) was created by the Air Force Systems Command, Rome Laboratory, and the Office of Scientific Research. This report details the goals, structure, membership, facilities, activities, and achievements of the NAIC over its five-year lifetime.

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Summary of the
Northeast Artificial Intelligence Consortium (NAIC)

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I. Introduction

An increasing phenomenon of recent years is the research "consortium". While all are basically intended to increase the efficiency of resource use by promoting technology transfer, they vary in structure and transfer strategy.

[Havelock; 1988] describes the four most popular models (structures) of what he terms "R&D Consortia" as: 1) University research centers, centered at a single university; an example is the Software Engineering Institute (SEI) at Carnegie Mellon University, 2) multi-university cooperatives, such as the Microelectronics Center of North Carolina (MCNC) consisting of five North Carolina Universities, a research institute, and 7 industrial affiliates which each contribute $250,000 annually, 3) R&D contracting facilities, in which contributing financial partners develop a research plan and pool their resources to execute it, and others are invited to bid for contract awards to complete pieces of the plan, and 4) free-standing R&D organizations in which R&D is planned and performed centrally in a facility designed explicitly and exclusively for that purpose. An example of the third formula, with a single major sponsor, is the Spoken Language program supported by the Defense Advanced Research Projects Agency (DARPA). Under the Spoken Language program, various university and industrial firms are under contract for individual research efforts and are strongly encouraged to share resources and research results with the other members of the program. Free-standing R&D organizations, the fourth consortia model, are exemplified by the Microelectronics and Computer Technology Corporation (MCC). MCC shareholders must participate in at least one of its four major program areas of Software Technology, VLSI/CAD, Packaging/Interconnect and Advance Computer Architectures. Federal legislation of the 1980's aimed at expediting cooperative arrangements among government, industry, and academic agents, and responsible for permitting such an arrangement, are detailed in DARPA Technical Report 88-5685 [Davis and Webber; 1988].

The Air Force's Wright-Patterson Laboratory contracted in October of 1987 with the Miami Valley Research Institute of Dayton, Ohio to create the Center for AI Applications (CAIA). The CAIA , consisting of a number of universities and an industrial affiliate, provides a range of AI application services in response to industry requests and funding. The services include AI application screenings, assessments, prototype development, R&D applications, and training services. The CAIA is a multi-university cooperative patterned, in some ways, after the Northeast Artificial Intelligence Consortium (NAIC).

Although not originated as a "university-only" procurement by the Rome Air Development Center (RADC)* (renamed the Rome Laboratory in 1991), the NAIC was a "multi-university cooperative" made up of seven universities: the State University of New York at Buffalo, Clarkson University, the University of Massachusetts, Rensselaer Polytechnic Institute, the Rochester Institute of Technology, the University of Rochester, and Syracuse University. Much more description and an assessment of the NAIC will be provided in Sections II and III of this report.

[Havelock; 1988] describes three primary transfer strategy orientations of consortia: 1) finished product transfer orientation, 2) generic technology diffusion orientation, and 3) network hub orientation. The NAIC is clearly of the generic technology diffusion orientation, intending to transfer knowledge in its "pre-competitive" phase rather than in the "finished product" form of the finished product transfer orientation. The network hub orientation offers a place where one can go for help on a range of technical problems within a given sphere. It brings together people and resources to be shared by either a very restricted group of paying customers or a larger group representing both potential users and R&D performers. This then, is the orientation of the Wright-Patterson Consortium.

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* Although known as RADC throughout the life of the Northeast AI Consortium, for the rest of this report all references to this US Air Force research laboratory will be made with its current name, Rome Laboratory (RL).

II. Northeast Artificial Intelligence Consortium (NAIC)

A. NAIC Goals and Its Creation

In the early 1980's Rome Laboratory recognized that although Artificial Intelligence technology has the potential to significantly improve Air Force Command, Control, Communications and Intelligence (C^3I) system capabilities, certain conditions existed which were greatly hindering the application of AI to those systems. AI research was being conducted almost exclusively in university laboratories and the successful transfer from basic research was limited and difficult to effect. Also, very little of the research had been directed towards solving military problems, particularly on the scale and scope needed for real-time C^3I systems. If current research is not directed at your particular problem area of interest, it makes sense to incorporate AI-knowledgeable researchers into your facility or train existing personnel in the technology-of-interest. However, the United States has a critical shortage of the qualified researchers and university resources (including facilities) needed to train new AI researchers and practitioners and, for a variety of reasons, the Air Force is unable to effectively compete in recruiting the relatively few AI graduates that are available. Compounding the problem is the fact that a large number of junior professors are leaving their posts for the lucrative salaries offered by industry. The net effect is that Rome Laboratory is not only unable to recruit quality graduates, but finds it equally difficult to obtain training for current employees.

Rome Laboratory decided that a substantial basic research and exploratory development program was needed. To address the personnel and resource deficiencies, Rome Lab sought to develop a long-term relationship with one or more qualified organizations to carry out a series of interrelated research tasks in specifically identified technical areas. In order to facilitate the smooth transfer of AI technology to the military, there was to be a close working relationship among the organizations and Rome Laboratory researchers and a high degree of technical interchange on a regular basis. For similar reasons there was to be a close working relationship with members of Rome Lab's existing contractor community. The program was also to include expansion of the AI research and educational opportunities within the organizations and complimentary educational and training activities at Rome Lab to develop and enhance existing in-house capabilities there.

The procurement vehicle determined to be appropriate for these requirements was a new contracting technique called a Program Research and Development Announcement (PRDA). The following points were among those substantiating the need for the PRDA:

- The broad applicability and complexity of AI technology implied that no single source had the expertise to conduct research necessary to address all the domain problem areas, which included communications, intelligence, and planning. It was anticipated that the broad objectives of the program could only be attained via research projects conducted by a number of sources having specialized capabilities.

- The relative immaturity of the technology and very limited success in military applications dictated the need for new and innovative solutions. Successful applications of AI up to that date had been in commercial systems that did not approach the size, speed and efficiency requirements associated with military systems. Existing techniques simply didn't scale up to meet Air Force requirements.

- Resources (primarily qualified personnel) necessary to adequately perform the required research were scarce and over-extended. AI research communities could be characterized as pockets of excellence, each pursuing a specialty area. While it was felt to be improbable that any one organization was qualified to undertake the entire research program, it was expected that a group of organizations could contribute, with each individual organization conducting research in its own specialty area.

Program Research and Development Announcement (PRDA) #84-01 (see Appendix 1 of this report), entitled "RADC Artificial Intelligence (AI) Research Program", appeared in the R&D Sources Sought Section of the Commerce Business Daily on 9 January 1984. The PRDA described the requirements of the program very briefly and referred interested parties to a longer document, the Statement of Need (SON) (Appendix 2), which was available from Rome Laboratory's Procurement Office. Along with detailed technical research requirements, the SON described the following auxiliary objectives, intended to assist in the transition of research out of the laboratory and to provide necessary AI resources to Rome Lab, which were to be addressed by proposers:

a. Development of cooperative (with and between universities) graduate degree programs.

b. Development of an aggressive recruitment program for quality graduate students.

c. Consideration of the establishment of an undergraduate cooperative program in AI with Rome Laboratory.

d. Improvement, or development of, AI curriculum including recruitment of high quality junior and senior AI faculty.

e. Update of existing equipment and facilities necessary to support expanded AI education programs as well as the proposed research.

f. In order to support Rome Laboratory training needs, inclusion of one or more of the following in the basic program:

    (i) Short-term training courses on-site (i.e.; at Griffiss Air Force Base);

    (ii) Graduate level AI (full-term) courses on-site;

    (iii) Seminars on a regular basis, both on-site and at reasonably convenient locations off-site;

    (iv) Participation in faculty/student resident research programs at Rome Laboratory.

Ten proposals were received in response to the PRDA. Guidance on proposal evaluation was provided by AFSC Pamphlet 70-1 (1 May 1983) which stated that evaluation of reponses to the PRDA would be "based on the PRDA evaluation criteria of new and creative solutions." It continues, "This evaluation criteria allows a subjective evaluation by the technical evaluation team which includes the applicability of individual reponse to the technological needs of the Air Force." The Rome Lab Technical Evaluation Team was made up of a Technology Group with five members, an Applications Group with twelve members, and two advisors.

B. The Winning Proposal

The winning proposal, submitted by Syracuse University [Syracuse University, et al; 1984], offered establishment of an Artificial Intelligence "consortium" in which they would coordinate the research and other, "ancillary" activities of eight universities, including themselves. Responsibility for technical activities were to be vested in a Principal Investigator at each university. According to the Syracuse proposal, a Managing Director and two Co-Research Directors were to assume primary administrative and technical responsibilities, respectively. A committee of Principal Investigators and Lead Researchers from each member institution were to form a committee to advise the Directors on Consortium programs.

Several other committees, made up of representatives from the member institutions, were to ensure that ancillary program objectives were achieved. An Education Committee was to find solutions to specific education needs, to work out the details of joint Consortium member programs, and to advertise for faculty and students on behalf of the Consortium. The Communications Committee was to formulate general communications plans for the Consortium, arrange for the preparation of proposals to obtain necessary communications equipment, and attend to all other matters of Consortium interest related to communications. The Equipment and Facilities Committee was to determine critical equipment needs and goals. This Committee was to formulate plans to obtain the necessary equipment for further pursuit of key research tasks, arrange equipment sharing between member instituitions where feasible, and to organize proposals to other agencies and foundations for equipment funds. Finally, the Seminar and Training Committee was to establish a seminar series with speakers from within the Consortium and from industry and academia outside the Consortium.

Consortium-wide activities and plans in education and training included cooperative Graduate degree programs (allowing liberal credit transfers among member universities), an Undergraduate Cooperative Program (to make formal arrangements for Undergraduate student assignments to Rome Laboratory), short-term training courses at sites convenient to Rome Lab technical personnel, expansion of AI educational opportunities, monthly technical seminars, and establishment of faculty/student resident research programs at the Laboratory.

The Syracuse proposal acknowledged a critical need for new equipment to support expanded AI research within the contractual group and stated its intention to "submit proposals for research equipment to NSF, DoD, corporate foundations, and potential industrial benefactors on a regular basis" with "at least one major proposal per school per year."

Rome Laboratory in-house research was to be positively affected and technology transfer encouraged by a close working relationship between Consortium members and Rome Lab personnel, the "possibility" of sabbatical leave by faculty members being spent at the Laboratory, and the development of Graduate programs in which Rome Lab engineers would spend one or more semesters at Consortium schools pursuing formal studies in AI.

Communications among research groups, Rome Lab and the Syracuse University management office were to be supported by a newsletter, "liberal telephone use", and electronic message capabilities using CSnet, MILnet, and ARPAnet.

And finally, the Syracuse proposal was supportive of Industrial/Consortium interaction and noted that "the synergism from such cooperative interaction is important and will result in considerable leverage of work accomplished per unit expenditure."

The seven universities proposed as subcontracters to Syracuse were:

Clarkson University

Colgate University

University of Massachusetts

Rensselaer Polytechnic Institute

Rochester Institute of Technology

University of Rochester

State University of New York at Buffalo

C. The Contractual Agreement

In hindsight, the single greatest obstruction to the full success of the Consortium was the metamorphosis of the Syracuse proposal into a Government Contract. Whereas it is often the case that a technical proposal is directly incorporated into a formal contract as a sufficient legal statement of the tasks to be performed, it was determined at that time that many of the tasks described in the proposal were insufficiently defined, their completion insufficiently measurable, to constitute tasks of a clear and enforecable contract.* The recommendation was that "Such issues as faculty sabbaticals, scholarships, MS or PhD programs, industrial scholarships, graduate curricula, transfer of people among universities, industry and Government, may be worthwhile endeavors, but hardly appropriate for contracting" and "should be handled outside of the contract and could be part of a consortium responsibility when one is established." The Contract, then, lists as its formal technical requirements only the activities directly related to the nine technical investigations proposed. A separate section of the Contract contains the following:

"The objective of this program is first and foremost to develop AI technology. However, universities are urged and encouraged to address some of the broader needs of RADC and the AI community. Some of these needs can be accomplished in conjunction with this contract; others fall outside the scope of this contract but do fall within the purview of what universities consider to be within their charter.
These ancillary objectives are:

1. Increase the pool of AI talent by:

a. Development of cooperative educational programs (out of scope).

b. Development of an aggressive and cooperative AI graduate recruitment program (out of scope).

c. Considering the development of AI coop programs (out of scope).

d. Recruitment of high quality graduate students to perform research on this contract (in scope).

e. Improving the AI curriculum and expand university AI capabilities by recruitment of high quality AI faculty to perform research on this contract (in scope).

2. Develop strong ties to industry who will be the eventual implementers of the products of this research and development (out of scope).

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* This determination is described in a letter, dated 3 June 1983, addressed to the Rome Laboratory Command and Control Directorate from the Contracting Division Chief of that date.

3. Participate in faculty/student resident programs at RADC (out of scope).

4. Assist in improving RADC AI capabilities by scheduling AI training courses at Griffiss AFB (out of scope)."

The contractors could not be held accountable for these activities and Rome Lab could not specifically provide remuneration for time and resources expended on them.

A five-year contract was awarded to Syracuse University on 13 December 1984.

D. NAIC Membership and Their Technical Tasks

The five year NAIC contract was initiated with the first nine of the technical efforts described below. The rest of the projects were added to the NAIC contract by Within Scope, Engineering Changes (formally negotiated modifications to the contract that did not change its scope) as they were determined to be required. Projects listed here as numbers 1, 2, 3, 12, 15, 16, 17, and 18 were funded by the Air Force Office of Scientific Research (AFOSR). Rome Laboratory sponsored the other projects. Total funding for the NAIC was $8.746M.

Details of NAIC technical work can be found in annual technical reports, published by Rome Lab during the existence of the Consortium. For the final three years of the Consortium, individual technical efforts were described in individual volumes and summarized in each year's Executive Summary. Each Executive Summary, besides describing the technical tasks, chronicles NAIC activities towards pursuit of the ancillary goals: faculty and student growth, AI facility improvements, seminars, Consortium-Industry interaction, and other NAIC activities.

For each project, the reference for the final technical report is provided.

1. Inference Techniques for Knowledge-Base Management [Bowen; 1991]

Principal Investigator: **Dr. Kenneth A. Bowen, Syracuse University, Syracuse, New York**

The focus of this project was the development of logic programming-based machinery for the management of large complex knowledge bases of a highly dynamic character, together with the development of mathematical foundations for such systems. The work was centered around the construction and study of certain *meta-level* extensions to Prolog (*metaProlog*). The primary tasks of the project included:

- Continued development of the metaProlog system: construction of an efficient metaProlog compiler, development of sophisticated memory-management methods, the development of suitable interfaces to non-metaProlog external databases, and the study of co-routining and concurrency.

- Development of knowledge representation formalisms in metaProlog, including analogs of frames, semantic nets, etc.

- Study of the expression of generic database management and knowledge base reason maintenance approaches in metaProlog, with special attention devoted to maintenance of static and dynamic integrity constraints, reason maintenance, and daemons.

- Construction of one or more experimental demonstration systems using the machinery developed.

- Exploration of semantic foundations for both classical logic programming as well as non-standard approaches showing potential for dealing with the theoretical problems which arise in knowledge base maintenance.

2. Architectures for Knowledge-Base Management [Berra, et al; 1991]
Principal Investigator: **Dr. P. Bruce Berra, Syracuse University, Syracuse, New York**

The focus of this research was on the development of algorithmic, software and hardware solutions for the management of very large knowledge bases (VLKB). It was approached from electronic and optical points of view; the electronic approach based on traditional digital computer technology, and the optical approach concerned with the higher speed and massive inherent parallelism of optics and their possible use in storage, transport and processing of very large knowledge bases.

Work in this effort included:

- Design of a parallel back-end database machine, to reduce the amount of fact data transferred from secondary storage while responding to a user query;

- Analysis of the Concatenated Code Words (CCW) surrogate file approach for VLKB management in a variety of ways including simulation on a Connection Machine and the development of a demonstration system;

- Development of the Dynamic Random Sequential Access Method (DRSAM) for handling very large dynamic databases;

- Investigation of the use of optics in the management of VLDBs for storage, transport and processing.

This effort was concluded with Fiscal Year 1988.

3. Multisource Knowledge Acquisition [Lesser and Croft; 1991]
Principal Investigator: **Dr. Victor R. Lesser, University of Massachusetts, Amherst, Massachusetts**

This project focused on two basic and interrelated research questions: 1) how to automate the acquisition, integration, and maintenance of a global understanding of a complex process from multiple, distributed local perspectives, and 2) how to automate this "understanding" to support users in their cooperative interaction with the system and other users by assisting in the execution of tasks and by explaining the reasons behind the actions and decisions involved in reaching the current state of the system. The task domains within which these issues were studied are: software development, office procedures, project management, and tutoring.

Achievements within basic research areas are as follows:

- In Knowledge Representation, where the goal was to provide a framework for representing realistic models of complex open-ended domains, the results were:
  - a knowledge representation framework that integrates activity models, agent descriptions, object specifications and relationships;
  - meta-plans as a specification technique for large and complex plan libraries and domain-dependent exception handling routines;
  - integration of empirical knowledge which represents soft domain constraints into classic hierarchical plan formalisms through the addition of a truth maintenance system;

- integration of planning and simulation techniques for validating plans in complex, dynamic environments.

* In Knowledge Acquisition, where the goal was to develop techniques for user specification of plans and dynamic acquisition at run-time of new and revised plans, the results were:
  - an approach for knowledge acquisition based on the assimilation of new and revised plans with existing specifications;
  - a cognitive model for how people recall their activities and an interface based on this model that can be used to acquire plans, display and modify plans;
  - a formal model of plan exceptions, and techniques for detecting, classifying and learning from them.

* For Focusing in Plan Recognition, where the goal is to develop techniques for quickly and efficiently arriving at the best interpretation of the actions/data that have currently been observed, the results were:
  - a recognition architecture that exploits heuristics based on user rationality and fully uses available constraints as soon as possible in the recognition process;
  - a new approach to controlling plan recognition, called evidence-based plan recognition, that uses a symbolic representation of current uncertainties in the interpretation and control plans keyed to specific uncertainties to efficiently guide the recognition process.

* In Multi-Agent, Interactive Planning, where the goal is to provide a framework to specify partial plans and for the user(s) to interact with planner(s) to complete these plans based on the dynamics of the specific situation, the results were:
  - an architecture based on a formal model of interactive planning;
  -models for negotiation among user and system, and among systems.

* For Knowledge Display, where the goal is to provide a display framework and tools for the user to effectively interact with an intelligent assistant, the results were:
  - a suite of programming tools that enables authors to browse and explain knowledge in an expert system for tutoring;
  - a graphics object-oriented environment for building simulations of complex environments for decision support.

4. Semantic & Pragmatic Knowledge Representation [Nirenburg; 1991]
Principal Investigator: **Dr. Sergei Nirenburg, Colgate University, Hamilton, New York**

The Colgate University project was devoted to the design of a planner system for the application of Indications and Warning (I&W). The specification of the task evolved from the early direction of intelligent database management toward the emphasis on problem-solving activity. The task was two-pronged:

A. Design of a system to:
   1. accept messages concerning events in a model of a real life subworld as input;
   2. 'understand' these events by detecting the *plans* they are parts of and, whenever applicable, the *goals* pursued by the instigators of these events;
   3. produce suggestions for possible plans of action necessary in connection with the situation in the world.

B. Implementation of this system for the I&W.

This work concentrated on designing the mechanisms and knowledge bases for the problems of plan recognition and plan production and excluded from consideration the problems of perception (speech, graphical, or visual), the problem of understanding natural language inputs, and the actual performance of plans suggested by the system.

This task was discontinued upon the departure of Dr. Nirenburg from Colgate, now at Carnegie Mellon University, in December 1986.

5. Time Oriented Problem Solving [Allen; 1991]
Principal Investigator: **Dr. James F. Allen, University of Rochester, Rochester, New York**

The unifying theme underlying the research carried out under this project is that of producing new knowledge representation formalisms that extend the range of situations in which problem solving systems can be applied. These new formalisms have centered around issues related to time, temporal reasoning, and causation.

Significant progress was made in the following areas:

- The axiomatic specification of an interval-based theory of time that allows for two different forms of time points;
- The development and public release of TIMELOGIC, an implementation in Common Lisp of the interval logic that quickly computes the relationship between arbitrary intervals using a constraint propagation algorithm;
- The development of a non-reified first-order temporal logic that has a well defined syntax, semantics, and proof-theory, and is easily implemented using a type-based theorem prover such as RHET;
- The development of a logic that can represent and support reasoning about simultaneous interacting actions;
- A generalized model of plan recognition, both as a formal theory and as a family of practical recognition algorithms;
- The formal specification of two distinct forms of abstraction for planning systems, one based on reduced models, and the other an extension of inheritance hierarchies;
- A new approach to causal reasoning that rejects overly-strong domain-independent approaches to solving the frame problem in favor of domain-dependent "cause-closure" axioms;
- A statistical/probabilistic approach to action reasoning that explicitly models that action success is not guaranteed, but subject to failure some proportion of the time;
- The development and initial implementation of a problem solver that reasons, acts, and senses in real-time within the ARMTRAK model train domain;
- The development and public release of the HORNE representation system and its extension, RHET, two hybrid logic/frame-based representations for use in general problem solving and natural language understanding.

6. Automatic Photo Interpretation [Modestino and Sanderson; 1991]
Principal Investigator: **Dr. James Modestino, Rensselaer Polytechnic Institute, Troy, New York**

This work focused on the development of expert system techniques for automated photo interpretation, emphasizing the development, implementation and demonstration of techniques which mimic the trained photo analyst in interpreting objects in monochrome, single-frame aerial images. The approach segments the input image into disjoint regions which differ in tonal or texture properties. The spatial relationships between different regions are then expressed in terms of the associated adjacency graph, where nodes represent regions and the connectivity indicates regions which are spatially contiguous. Based on knowledge of the underlying spatial adjacency graph, together with various regional attributes or features, the problem is then to assign interpretations, or objects, to each of the nodes. The novelty of this approach is that of being able to develop a computationally feasible approach to this symbolic interpretation process.

7. Speech Understanding [Rhody, et al; 1991]
Principal Investigator: **Dr. Harvey Rhody, Rochester Institute of Technology, Rochester, New York**

Rochester Institute of Technology's contribution to the NAIC has been research and development of a system of techniques and processes suitable for use in a continuous speech, large vocabulary, speech understanding system. These techniques have been incorporated into a knowledge based system which attempts to capture the knowledge experts use to read and interpret spectograms. This knowledge allows phonetic information to be generated from a raw acoustic waveform. Words are hypothesized from the phonetic transcriptions and a natural language system then analyzes the word sequences to produce a representation of its meaning as an utterance.

System development was made possible by the use of the ESPRIT (Explorer Speech Processing at RIT) system developed at RIT. ESPRIT is a speech research development environment which provides researchers the ability to develop speech and signal processing experiments.

8. Versatile Maintenance Expert [Srihari, et al; 1991]
Principal Investigator: **Dr. Stuart C. Shapiro, State University of New York at Buffalo, Buffalo, New York**

This project began with the objective of developing a versatile expert system for equipment maintenance. A prototype expert system, designed to advise a maintenance technician on testing, evolved into a more versatile system by incorporating features such as model-based reasoning and communication capabilities such as natural language and graphics. The system is called the Versatile Maintenance Expert System (VMES). VMES is versatile across a range of target devices in the circuit domain, across most of the possible faults, across different maintenance levels and across a variety of user interfaces.

Accomplishments of the project can be classified into seven categories:

- Device modeling - structural and functional knowledge and efficient representation,
- Graphic interface,
- Model-based reasoning for diagnosis - initial candidate ordering, reordering and elimination,
- Sequential circuit representation and a general control structure for diagnosis,
- Representation and diagnosis of a device,

- Migration of deep knowledge to shallow knowledge,
- Enhancements to SNePS (Semantic Network Processing System), the system used for the implementation of VMES.

9. Communication System Control [Meyer and Conry; 1991]
Principal Investigator: **Dr. Robert A. Meyer, Clarkson University, Potsdam, New York**

The major objectives of this research were to gain a better understanding of issues that arise in the area of distributed artificial intelligence (DAI) and to investigate the application of DAI in communications network management and control. The strategy followed was to first choose an application problem domain to which DAI might be applicable, having a structure and degree of complexity that make it realistic for investigating relevant problems. The monitoring and control of large communications systems was selected because it is a naturally distributed, complex problem which currently requires cooperation among humans for an effective solution. The model used for a communications network is based on the large scale, world-wide Defense Communication System (DCS), concentrating on network management and control at the subregion level. The subregion level represents a group of several individual sites or nodes in the communications system architecture which are monitored and controlled from a single control center.

Primary results of this effort were in three areas:

- Development of a model for distributed, intelligent network management;
- Design and implementation of a distributed AI system testbed (DAISY);
- Implementation of three distinct systems for testing theories and design strategies for DAI systems.

10. Parallel Vision Systems [Brown; 1991]
Principal Investigator: **Dr. Christopher M. Brown, University of Rochester, Rochester, New York**

This project was integrated into the NAIC as the contract's first (Within Scope) Engineering Change in May of 1986. The work, aimed at improving the qualitative and quantitative state-of-the-art in image understanding, emphasized an AI approach and included theory and implementation of knowledge-based image understanding algorithms. The oldest central themes of the Rochester parallel vision work were massively parallel (connectionist, neural net) computation, and MIMD (multiple instruction stream, multiple data stream) computer hardware and the software to make it useful. Early work involved SIMD-like (data) parallelism on the BBN Butterfly parallel processor, investigation of multi-process scheduling for object tracking, the development of the Rochester Connectionist Simulator, and theoretical studies on pipelined, MIMD, and massively parallel computation.

The final report for this work is combined, in a single volume, with the final report for the Image Understanding and Intelligent Parallel Systems project (described in project review #15).

11. Discussing, Using, and Recognizing Plans [Shapiro, et al; 1991]
Principal Investigator: **Dr. Stuart C. Shapiro, State University of New York at Buffalo, Buffalo, New York; Dr. Beverly Woolf, University of Massachusetts, Amherst, Massachusetts**

This was a joint project of a research group at SUNY at Buffalo and a research group at the University of Massachusetts. Initiated in February of 1987, it was the first such NAIC effort. This project was additionally unique in that it was jointly funded by two Directorates (the Intelligence and Reconnaisance Directorate, and the Command and Control Directorate) at the Rome Laboratory.

The project was devoted to the investigation of a knowledge representation design compatible with the intensional knowledge representation theory embodied by the SNePS (Semantic Network Processing System) language, and capable of providing a natural language interacting system with the ability to discuss, use, and recognize plans. The objectives of this project were to:

- Design a representation for plans and rules for reasoning about plans within an established knowledge representation/reasoning (KRR) system;
- Enhance the KRR system so that it could act according to such plans;
- 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 representation designed (above).

The resulting NLP system accepts sentences describing plans, adds the plans to its "plan library", answers questions about the plans in its plan library, accepts sentences describing the actions of others, and recognizes when those actions constitute the carrying out of a plan in its library.

12. Signal Processing for Remotely Located Sensors [Varshney and Sikka; 1991]
Principal Investigator: **Dr. Pramod K. Varshney, Syracuse University, Syracuse, New York**

This project, added to the NAIC contract in November of 1988, represents an application of distributed Artificial Intelligence (DAI) tools to the data fusion and classification problem. The domain of application is modern C^3I systems where accurate and timely perceptions of friendly and hostile forces are required for effective decision making and battle management. DAI provided a means for interconnecting multiple expert systems that have different, but possibly overlapping, expertise thereby enabling the solution of problems whose domains are outside that of any one expert system or knowledge source. The approach used was a blackboard for information management and hypotheses combination and formulation. The blackboard is used by the knowledge sources for sharing information and posting their hypotheses, just as human experts sitting around a table would do.

13. Intelligent Signal Processing [Rhody and Gayvert; 1991]
Principal Investigator: **Dr. Harvey E. Rhody, Rochester Institute of Technology, Rochester, New York**

Added to the NAIC contract in November of 1988, this project was a joint effort by the Rochester Institute of Technology, the State University of New York at Buffalo, and the Rensselaer Polytechnic Institute. Its goals were to extend the framework of the modern multi-target, multi-sensor surveillance environment and to investigate the adaptation of intelligent signal processing algorithms to that application domain.

A prototype system, called ESSPRIT, was designed and constructed to simulate the radar environment, including transmitters, sensors, targets, noise and stationary objects. The ESSPRIT system provides program visualization in the form of a system block diagram.

Constructed as a discrete event simulator, the system permits maximum flexibility and efficiency in run-time computation.

14. Adaptive Signal Processing for Domain Fusion [Nawab and Lesser; 1991] *Principal Investigator:* Dr. Hamid Nawab, University of Massachusetts, Amherst, Massachusetts

Initiated in February of 1988, this effort was carried out by a team of researchers from the University of Massachusetts and Boston University. Dr. Nawab, of Boston University, participated in this effort as a Visiting Assistant Professor to the University of Massachusetts.

High-level adaptive signal processing (H-LASP) involves the integration of Artificial Intelligence and signal processing in an interpretation system and makes use of a paradigm that allocates processing resources and adjusts parameters of the low-level processing in accordance with the evolving high-level interpretations of the signal-generating environment. The goal of the project was to evaluate and improve the H-LASP paradigm for a realistic task: real-time sound classification.

The achievements of the project can be divided into these major categories:

- Incorporation of the diagnostic reasoning process into a sound classification testbed along with refinements in that process to deal with the more sophisticated theory underlying the new application;

- Formulation and implementation of a practical approach to discrepancy detection for the sound classification task;

- Implementation in the testbed of a sophisticated database using the Generic Blackboard (GBB) system;

- Design of the control component of the testbed through adaptation of a framework developed at the University of Massachusetts for the control of interpretation through analysis of the sources of uncertainty associated with the various evidence gathering mechanisms;

- Design of the control component of the testbed to ensure real-time invocation of the high and low-level knowledge sources while maintaining the integrity of the high-level interpretation within the goals of the system.

15. Image Understanding and Intelligent Parallel Systems [Brown; 1991] *Principal Investigator:* Dr. Christopher M. Brown, University of Rochester, Rochester, New York

Systems that behave in the world are becoming increasingly sophisticated, raising technical problems of sensing and control, and opening new approaches that may make perception easier. Two of the goals of this project were to exploit the ability to maneuver in three dimensions to make some vision problems easier, and to design a system architecture in which multiple objectives (such as moving and observing) can proceed in parallel. The work evolved in four separate directions: 1) increasing functionality for world interaction, in particular, using an advanced MIT-Utah hand for skilled eye-hand tasks; 2) integration with high-level symbolic planners (visual inspection of a model train layout integrated with symbolic planning to achieve goal configurations); 3) integrating low-level functionalities (creating a gaze control system to manage the competing and cooperating demands on the vision system); 4) integrating the vision and robotics system with modern parallel hardware.

This project was integrated into the NAIC in December of 1988. The final report is combined, in a single volume, with the final report for the Parallel Vision Systems project (described in project review #10).

16. Plausible Inference Used for Retrieval from Knowledge-Based Systems [Croft and Cohen; 1991]
Principal Investigator: **Dr. W. Bruce Croft, University of Massachusetts, Amherst, Massachusetts**

One of the primary functions in many knowledge-based applications is the retrieval of objects that satisfy criteria specified in a user's query. The aim of this effort was to demonstrate that plausible inference is an effective computational framework for retrieval of complex objects. Both numerical and symbolic approaches to representing and reasoning with uncertainty were pursued. An experimental setting for the research with test collections consisting of a large number of text objects, a linguistic knowledge base, and a domain knowledge base describing objects and relationships in the domain of the texts, was constructed. Also, techniques for automatically producing complex representations of the meaning of text objects were developed. These techniques provide rich sources of evidence for the plausible inference models, and provide the basis for important applications of text-based intelligent systems.

This project was integrated into the NAIC in December of 1988.

17. Distributed Planning for Dynamic Environments in the Presence of Time Constraints [Conry, et al; 1991]
Principal Investigator: **Dr. Robert A. Meyer, Clarkson University, Potsdam, New York**

The primary goal of this effort was the development of a testbed environment appropriate for research in real time distributed planning. The problem domain selected as an example context was forest firefighting. Much of the effort concentrated on the formulation and implementation of an appropriate agent model and mechanisms for handling time in general, and reasoning strategies for adjudicating allocation of time among various cognitive activities in the planner.

The four major tasks of this effort were to:

- Integrate reflective and reactive planning tasks in a centralized planner;
- Develop mechanisms for adjudicating decisions regarding contention between competing functions that problem solving agents must perform;
- Identify the types of information that are useful in partial global plans to support, for example, multistage negotiation between distributed planning agents;
- Extend reasoning mechanisms developed at Clarkson University to incorporate temporal issues and complex interagent constraints important to real-time adaptive planning.

Integrated into the NAIC in December of 1988, this effort included researchers from Clarkson University and the University of Massachusetts.

18. Strategies for Coupling Symbolic and Numeric Computation in Knowledge-Based Systems [Suk; 1991]
Principal Investigator: **Dr. Minsoo Suk, Syracuse University, Syracuse, New York**

It is widely recognized that coupling symbolic and numerical methods is an effective means of solving many problems in science, engineering, and business. In order to study coupled systems in the context of computer vision, the problem of three-dimensional object recognition from range data in a multiple-object scene with partial occlusion was considered in this study. This problem is encountered in several scenarios such as robot bin-picking, automated industrial inspection, and autonomous navigation. The two main problems encountered when dealing with a multiple-object scene are: 1) combinatorial explosion of the search space of scene interpretations, and 2) generation of spurious scene interpretations. Thus, the issues of representation and constraint propogation/satisfaction were dealt with, primarily with the following objectives in mind:

* Reducing the combinatorial complexity of the search space of possible scene interpretations;

* Ensuring robustness against occlusion.

This effort was started in December of 1988.

E. NAIC Management

At the program start, Dr. Bradley J. Strait of Syracuse University served as the NAIC Program Director, with Dr. Robert F. Cotellessa of Clarkson University serving as the Managing Director. The Project Director, as principal agent of the prime contractor (Syracuse University), represented the NAIC in formal, contractual matters with Rome Lab. In July of 1986, Dr. Volker Weiss of Syracuse University became the Project Director, and the NAIC Executive Committee was established to "provide guidance towards the further development of the NAIC and to assist in some of the management tasks." There would be four institutions represented in the Executive Committee, each by one of its Principal Investigators for two-year, rotated terms. SUNY at Buffalo (2-year term), the University of Massachusetts (2-years), the University of Rochester (1-year term), and RPI (1-year) were the initial members of the Executive Committee. The Executive Committee met frequently, as often as once a month.

The role of Program Manager went unfilled until June 1987 when Mr. James Brule formally assumed that position. As Managing Director, Mr. Brule's responsibilities were 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 among member institutions, Rome Lab, and administrative bodies within Syracuse University relative to the Consortium. It was up to the office of the Managing Director to prepare reports, organize NAIC meetings and briefings, aid in the establishment of committees and advisory boards, facilitate electronic networking among Consortium members, arrange vendor presentations, organize educational efforts, and in other ways represent the NAIC at an administrative level to others.

F. Technical Exchange

Technical exchange meetings, research efforts with participation among two or more NAIC schools, seminars and sabbaticals among member schools, and computer network communication capabilities have helped to transition research among NAIC member universities. Formation of the NAIC Industrial Advisory Board (IAB), joint NAIC/Industry meetings, and other activities have been effective in transitioning technology between the Consortium membership and other institutions.

NAIC Technical Exchange Meetings

Interaction among Consortium members was sparse in the first year of its existence. The turning point came at the March 12-13, 1986 meeting of the NAIC, when Rome Laboratory's

Chief Scientist Dr. Fred Diamond met with Consortium members and Rome Lab Program Managers to discuss expanded activities that were encouraged and would be supported towards development of a more cohesive, interactive group. With that word of encouragement, interaction among NAIC members, and other activities, increased multifold.

Annual NAIC Program Reviews were comprised of presentations of the status and activities of each of the active research projects and, with the exception of the 1986 Review hosted by the University of Rochester, were held at Syracuse University's Minnowbrook Conference Center in Blue Mountain Lake, New York.

Research topics of wide interest within the Consortium were selected for each Topical Review Meeting, at which students and faculty of NAIC member institutions presented their current work related to the topic-of-focus. Topical Reviews were held as follows:

Date	Site/Host	Topic
17-18 Oct 85	Colgate	Natural Language Processing
12-13 Mar 86	UMass	Planning and Plan Recognition
25-26 Sep 86	Buffalo	Spatial Knowledge Representation and Reasoning
29 June-2 Jul 87	Minnowbrook	Major Program Review(no topic)
1-2 Oct 87	Clarkson	Fall Workshop on Planning
29-30 Mar 88	AFOSR (Wash., DC)	Vision and Intelligent Signal Processing
13-14 Apr 89	RIT	Neural Nets and Complex Distributed Systems

The RADC/NAIC Technology Fair, April 9-10, 1987, brought greater awareness to the local industrial community of Air Force AI interests and fostered new industry/NAIC relationships. Exhibits by NAIC researchers and other contractors provided an active demonstration of the breadth of emerging applications of expert systems to military systems. Many of the Consortium members also participated at the RADC AI Technology Fair held in Utica, New York on November 14-16, 1988.

The NAIC sponsored a Natural Language planning workshop, "Planning for Future Research: Directions for the Next Decade", September 20-23, 1987 at the Minnowbrook Conference Center in Blue Mountain Lake, New York. The workshop brought together NL technology experts and government laboratory representatives to discuss where the best research opportunities are in the field of Natural Language Processing.

An international workshop on Planning in AI was hosted by the Computer Science Department at the University of Rochester on October 27-29, 1988 [Tenenberg; 1989]. Jointly supported by the Computer Science Department, the American Association for Artificial Intelligence (AAAI), and the NAIC, the thrust of the workshop was to explore the scientific and engineering issues that currently impede progress in the development of systems that solve real planning problems in real environments. The workshop was not limited to robotic applications, but included a broad range of others including Natural Language Understanding, scheduling, and distributed problem solving.

Attendance at NAIC technical meetings included DoD representatives from DARPA, AFOSR, AFHRL, AFWAL, AFSC, FAA, and the NADC.

Seminars and Sabbaticals Among NAIC Members

During a sabbatical to the University of Massachusetts in 1985, Dr. Sergei Nirenburg of Colgate University investigated the definition of new planning primitives for specification of higher level plans. A seven-month sabbatical in 1986 by Clarkson Principal Investigators Dr. Susan Conry and Dr. Robert Meyer to the University of Massachusetts led to initiation of the joint project "Distributed Planning for Dynamic Environments in the Presence of Time Constraints".

Seminar presentations by NAIC members are too numerous to list here in their entirety, but presentations at Rome Laboratory in 1986 included an April 30th presentation by Dr. James Allen, "World Models in Planning Systems", the May 28 presentation by Dr. David McDonald, "Natural Language Generation: Complexities and Techniques", the June 18th presentation, "Discourse Analysis in Natural Language Processing", by Dr. Sergei Nirenbeurg, and the July 18th presentation, "Semantic Network Based Reasoning Systems" by Dr. Stuart Shapiro.

In late May 1986, Dr. David McDonald of the University of Massachusetts delivered a talk on Natural Language Generation (NLG) at Syracuse University, and visited again with Ms. Marie Vaughn on December 1, 1987 to provide a tutorial on the NLG system MUMBLE. Clarkson University hosted a weekly AI seminar on their campus during the summer of 1987. And, in March of 1988, Dr. James Allen of the University of Rochester gave a talk entitled, "Plan Reasoning and Natural Language" at RIT , and one entitled, "The Architecture of Discourse Systems" at SUNY Buffalo.

In January of 1988, the Rochester Institute of Technology instituted a weekly seminar series on the technology and applications of neural networks. The seminar series involves RIT faculty from the Computer Science department, Electrical Engineering and Imaging Science, and staff from the RIT Research Corporation, Eastman Kodak, and Speech Recognition Systems, Inc.

On October 6, 1988, the NAIC jointly sponsored a seminar in Syracuse with the local IEEE Circuits and Systems group. The topic of the seminar speaker, Dr. Sheldon B. Akers of the University of Massachusetts, was "Techniques of Built-In Self Test." Reception of the Fourth Annual Texas Instruments Satellite Symposium, "AI and the Knowledge Worker Productivity Challenge" was co-sponsored with the Syracuse Computer-Aided Software Engineering (CASE) Center on November 10, 1988.

Computer Network Communications

Communication among NAIC members and between Consortium members and the broader AI world were facilitated by computer network interconnections. Member schools were initially unable to communicate over computer lines: the University of Rochester and Rome Laboratory were on the ARPAnet, seven schools were on CSnet, and 7 schools were on BITnet (some schools were accessible on more than one network). By 1987 MILnet, NYSERnet, and ARPAnet interfaces that completed interconnectivity among the NAIC schools were in place.

Technical Exchange Opportunities Between the NAIC and Others

An Industrial Advisory Board (IAB) was formed in June 1985 to "establish interactions between industry and the NAIC in pursuing research, educational, and facility development activities, and to recommend future technical directions of interest." The first meeting of the Board was held at Syracuse University on June 26th. Initial members were: the General Electric Company of Syracuse, New York; Singer Aerospace and Marine Systems of Binghamton, New York; Kaman Sciences Corporation of Utica, New York; the IIT Research Institute of Rome, New York; the IBM Corporation, Kingston, New York; Xerox Corporation, New York, New York; the Niagara Mohawk Power Corporation, Syracuse, New York; United Technologies Corporation, East Hartford, Connecticut; Eastman Kodak Company, Rochester, New York; Sperry Corporation, Syracuse, New York; and PAR Technology, New Hartford, New York. IAB members were invited to attend NAIC annual Program Reviews and Topical Review meetings and received copies of NAIC technical reports.

There was a myriad of NAIC/Industry technical exchange meetings. In July 1987, RPI hosted a visit from Niagara Mohawk representatives to investigate mutual problems in image interpretation, and RIT gave a presentation on the state-of-the-art in Speech Understanding systems and their potential applications to Niagara Mohawk's research staff. Clarkson University, hosted by Texas Instruments, gave demonstrations of their SIMULACT system at the

American Association for Artificial Intelligence (AAAI) Conference in Seattle, Washington, 14-17 July 1987. SIMULACT is a domain independent development and simulation facility designed to permit rapid prototyping, interactive experimentation, and ease of modification of demonstrations of distributed problem solving applications.

Ms. Karen Huff presented the University of Massachusetts NAIC research at the Knowledge Based Software Assistant (KBSA) Conference in Utica, New York in August 1987. The KBSA is a large Rome Laboratory program to provide intelligent tools and an environment for software developers.

As a result of a request initiated by Dr. Bowen of Syracuse University, and with the support of the Rome Laboratory, the Air Force European Office of Aerospace Research and Development (EOARD) arranged to have Mr. Jaakov Levy of the Weizmann Institute in Israel present seminars on logic programming and Concurrent Prolog at Rome Lab, Syracuse University, the University of Massachusetts, Colgate University, Clarkson University, and SUNY at Buffalo.

The Rockwell/NAIC AI Symposium of June 7-8, 1988 at the University Sheraton, Syracuse University, in Syracuse, New York, brought together members of the Rockwell AI Task Force and NAIC Principal Investigators to explore collaboration opportunities.

On December 12, 1988, Syracuse University hosted a three-hour, live, IBM teleconference intended to introduce IBM sites to the NAIC and Syracuse's Northeast Parallel Architectures Center (NPAC) and CASE Center.

Dr. Stuart Shapiro of SUNY at Buffalo took a sabbatical from July 1987 to September 1988 at the University of Southern California/Information Science Institute (USC/ISI) in Marina Del Ray, California. He was accompanied by James Geller who was in the process of completing activities to receive his Doctorate. Dr. Shapiro returned to USC/ISI on December 1st to provide a workshop on SNePS (Semantic Network Processing System).

The University of Rochester, under the direction of Dr. Chris Brown, reports that it has had a substantial Industrial Affiliates Program which includes BBN, GE, Kodak, and Xerox. They have had active research collaboration in the areas of vision, reasoning, and parallel programming environments with each of these affiliates. An annual meeting keeps affiliates abreast of the Rochester work in these areas, and keeps them aware of students and other Rochester personnel with whom there may be common research interests.

Dr. Robert Meyer of Clarkson presented a seminar on truth maintenance in a shared knowledge base at the May 17, 1989 meeting of the Central New York Chapter of the Association for Intelligent Systems Technology, Inc. (AIST). Dr. Meyer was the NAIC participant most visibly involved in technical exchange with a DoD technology user, visiting various sites of the Defense Communications Agency (DCA). On March 28, 1985, he visited the Defense Communications Engineering Center for technical discussions about distributed routing control and rules used in circuit routing and restoral, and three months later met with the DCA in Reston, Virginia where he was provided with software used for simulating distributed circuit control algorithms. During a visit to the DCA Operations Center in Arlington, Virginia in January, 1986, Dr. Meyer observed their daily operations and interviewed personnel engaged in the day-to-day network operation and management. In February of 1986, Dr. Meyer visited Defense Communication System (DCS) sites at HQ DCA-Europe, the DCS station in Feldberg, and the DCS stations at Frankfurt. In May of that year he met with technicians at Scott Air Force Base who work with the digital radios and mutiplexers used in the DCS to review the list of equipment alarms and refine his research team's understanding of the meaning of each alarm. On November 1-8, 1987, Dr. Meyer attended a meeting with Rome Lab and DCA representatives to discuss the potential for a neural network approach to network assessment in a circuit switched network such as the Defense Switched Network. Many more, similar meetings with the DCA were held to discuss the design of future control strategies for the DCS.

In August of 1989 Dr. Meyer paid a call to Tinker Air Force Base, Oklahoma for information about the meaning of various fault conditions indicated by their TRAMCOM system. The way failure conditions give rise to specific alarms can be represented in a 'fault tree.' Clarkson University worked closely with MIT Lincoln Laboratory to test for the completeness of their fault/alarm data. Clarkson participants later served as consultants to Lincoln Lab on a Rome

Lab project to develop the Expert Technical Controller (ETC) (described briefly in the next section), applying AI to the communications control domain.

Other institutions that became involved in the NAIC through various ventures include: Knowledge Systems Concepts, AT&T Bell Labs, SRI International, Stanford University, Fairchild Laboratory, Lockheed, Philips Labs, Unisys, and Symbolics.

Specific, Transitioned Technology

NAIC technical work has been widely dispersed and is supportive of much continuing research. Industry interaction and technology presentations have surely contributed to transitions of NAIC research that could never be specifically identified but we can, in this section, identify a number of obvious instances of transition.

As a result of the speech work done at RIT within the NAIC, Texas Instruments and Rome Labs co-funded an effort at RIT to develop a speech processing workstation. The workstation, called ESPRIT (Explorer Speech Processing at RIT) is designed to extract and display features from a speech signal (spectograms, pitch, formants, etc.). The workstation provides an intuitive, flexible, extensible, and cost effective development environment for speech (or other signal) research. ESPRIT is in use in the Rome Lab Speech Processing Facility, and for neural net and intelligent signal processing work elsewhere within the Lab.

University of Rochester research into time-oriented problem solving is being applied to DARPA's Pilot's Associate program, incorporated into Intellicorp's Knowledge Engineering Environment (KEE), and has been encapsulated into a tool as the RHET system. It has also been integrated into Kestrel's REFINE system, and is being considered for use in Rome Lab's Knowledge Based Software Assistant (KBSA) program. Pre-RHET systems, embodiments of Rochester's theoretical planning work, have been requested by more than 50 research laboratories and universities in North America, including Advanced Decision Systems, SRI International, and MCC.

The University of Rochester parallel vision research group participated in the first DARPA parallel vision architecture benchmark program. The resulting applications software and other programming libraries and facilities developed at Rochester are being disseminated through BBN, Inc. The Rochester Connectionist Simulator and the Zebra/Zed systems developed by the parallel vision group are available by anonymous file transfer protocol (ftp). Zebra is an object-oriented system for Datacube programming and Zed is a menu editor built on top of Zebra. Together they have been distributed to several hundred sites worldwide.

An NAIC project at the University of Massachusetts has produced a plan recognition formalism called GRAPPLE. GRAPPLE developers have actively participated in semi-annual KBSA technology exchange meetings. Due to this technical exchange, Honeywell, a KBSA contractor, is integrating various aspects of the GRAPPLE formalism into the Framework portion of the KBSA.

NAIC Natural Language Generation software from the University of Massachusetts has been integrated into Text Message Understanding research in other projects sponsored by Rome Lab.

POLYMER, also developed at the University of Massachusetts, is a planning system which constructs partial "plans" and executes them interactively. A preliminary version of an environment to support cooperative, multi-user work, into which POLYMER has been incorporated, is being used at an Olivetti research laboratory to develop advanced applications in the area of office automation. POLYMER is also serving as a testbed within the University of Massachusetts for an effort exploring the development of an integrated environment for the support of multi-user, cooperative work.

Three startup companies are commercializing research developed among the AI faculty at the University of Massachusetts. Frontier Systems is developing a commercial version of UMass' parallel Common Lisp, and Amerinex AI is producing a commercial version of the image-processing operating system developed by the Visions group. The Applied Computing Institute of Massachusetts Inc. (ACSIOM), the recent incorporation of a private research institute established in the immediate proximity of the University, is developing a commercial version of GBB, a software system for building blackboard architectures. ACSIOM will conduct applications research and development under contract with industry, commercialize appropriate elements of UMass Computer Science research, license software, provide consulting and training services to industry, and spin-off local high-tech start-up companies.

As mentioned in the previous section, NAIC researchers from Clarkson University served as consultants on a Rome Laboratory project at MIT's Lincoln Laboratories to develop the Expert Technical Controller (ETC). The ETC is a proof-of-concept expert system designed to assist an Air Force Technical Controller in communications network fault isolation and network control of DCS 'long haul' circuits. The ETC was installed temporarily at the 2045th Information Systems Group at Andrews Air Force Base in Maryland to create and validate the system's knowledge base. Follow-on work, partially funded by the DCA, is developing, and will transfer to Headquarters, Air Force Communications Command (HQ AFCC), the Machine Intelligent Technical Control (MITEC), developed to provide automated fault isolation, circuit restoration, and records keeping in the Technical Control Facility (TCF) environment.

G. Equipment

The NAIC membership, acting individually and as a group, successfully sought industrial, Department of Defense and National Science Foundation (NSF) grants, New York State funding, and University contributions in order to acquire much-needed computer hardware for the update and expansion of their facilities.

In 1985 Sperry Corporation, a member of the NAIC Industrial Advisory Board, donated a Texas Instruments Explorer and an Intellicorp KEE software package to the NAIC. Sperry further offered a 25% discount on similar Explorer packages to any department within any of the NAIC member universities.

With the aid of external funding assistance and manufacturer's discounts, Clarkson and Colgate Universities each received a Symbolics 3670 Lisp Machine in March and April of 1985, respectively. In April of 1986, the Department of Computer Science at SUNY Buffalo purchased a Symbolics 3670, two Symbolics 3640s, and a TI Explorer with funds provided by the National Science Foundation and the University. Tektronix, the following month, donated a 4406 AI Workstation with Common Lisp, Smalltalk, UNIX, and Emacs incorporated.

By far, the most visible acquisition was the result of the efforts of Dr. Susan Conry working closely with the Principal Investigators of the other NAIC schools to submit a proposal, on November 15, 1985, to the DoD University Research Instrumentation Program [Cotellessa; 1988]. Through the program, $250,000 was awarded to the NAIC by AFOSR in order to facilitate the exchange of AI research software on a computer common to NAIC member universities and to foster collaborative research. The award was supplemented by the contribution of $156,250 from the member universities and a grant for four machines by Texas Instruments. In all, seventeen TI Explorers were delivered, complete with software and an agreement to exchange the temporary Beta test site arrangement for TI's next generation processor when it became available. The TI Explorers were distributed within the NAIC as follows:

University	Number of TI Explorers
SUNY at Buffalo	3
University of Rochester	3
University of Massachusetts	3
Colgate University	1
Clarkson University	2
Rochester Institute of Technology	2
Rensselaer Polytechnic Institute	2
Syracuse University	1

Texas Instruments also generously responded to a later proposal by Clarkson University with a grant for twelve microcomputers which were distributed within the NAIC.

Significant enhancement of NAIC institutional AI resources, including some beyond those acquisitions described here, occurred over the course of the NAIC's existence.

H. New Courses, Faculty and Students, PhDs and MSs

Numbers regarding added AI courses, faculty, and students attributable to the Consortium project are difficult to pinpoint due to interaction of other contributing factors. For example, the normal demand for more "high tech" courses has forced member Universities to offer more AI courses and, in turn, hire additional faculty. Also, individual student research can often be directed to more than one research program. There can be no doubt, however, that the support provided by AFOSR and Rome Laboratory within this program had a significant effect on many of these elements and some rough estimates have been made.

RIT reports that the number of faculty members having AI expertise has increased from 1 to 9, including computer science faculty, faculty from other disciplines at RIT, and the full-time employees at RIT Research Corporation's Intelligent Systems Division. While only a single survey-type AI course existed in 1984, there are now both graduate and undergraduate AI concentrations available. M.S. Computer Science graduates from RIT are now employed in the Redcom Corporation, Xerox, Eastman Kodak, and the RIT Research Corporation. RIT does not have a PH.D program in Computer Science.

The Computer Science Department at the State University of New York at Buffalo graduated eleven Ph.D students over the course of the NAIC, two of which were directly supported by the NAIC. Four more Ph.D's "in progress" have been supported. Five new AI faculty have been appointed during the period of NAIC funding, and three new AI courses have been developed.

The University of Rochester reports that NAIC planning work at that school has supported two undergraduates, thirteen graduate students (all of whom earned M.S. degrees and four of which received Ph.Ds), four staff programmers, and three research associates. Graduated Ph. D students are working at Philips Labs, AT&T Bell Labs, Lockheed, and at the University itself. Two new AI faculty members have been added to the Rochester staff as an indirect result of the Consortium funding, and four new AI courses have been offered at the graduate level.

Research personnel at Clarkson University have grown from the original two faculty and no graduate students, to six faculty and approximately twelve graduate students. Clarkson reports that there have been four AI Ph.Ds and two AI M.S. degrees awarded over the course of the NAIC, with two more Ph.Ds and three more M.S. degrees in progress. Ph.D graduates are employed by AT&T Bell Labs, IBM T.J. Watson Research Lab, the University of Rochester, and SUNY at Buffalo. New undergraduate courses include an Artificial Intelligence course and a required course in symbolic computation based on the LISP dialect, Scheme. Four new graduate AI courses are: AI Programming, Expert Systems, Advanced Seminar on Planning, and Advanced Seminar on Neural Nets.

The University of Massachusetts has conferred AI Ph.Ds on two graduates and estimates having awarded twenty M.S. AI degrees. Three new AI faculty have been hired, and there has been a 141% increase in their research staff since contract start in 1984. Nineteen new graduate AI courses include: Machine Learning, Robotics, Robotic Theory, Advanced Topics in Computer Vision, Artificial Intelligence and Legal Reasoning, Distributed Problem Solving, Advanced Topics in Natural Language, and Sophisticated Control of Knowledge-Based Systems.

I. Publications

Innumerable technical papers and other publications were produced by the membership of the NAIC over the course of its five-year run. Some that drew particular notice are described here.

The two-volume Encyclopedia of Artificial Intelligence, edited by Dr. Stuart Shapiro and published by John Wiley & Sons, won first prize as the Best New Book in Technology and Engineering for 1987 from the Association of American Publishers Professional and Scholarly Publishing Division.

[MacIntosh, et al; 1989] received a citation as the best paper at the Ninth Workshop on Distributed Artificial Intelligence.

More than two hundred NAIC technical papers, estimated to be only one-third of what has been produced over the course of the contract, have recently been cataloged and made available as an important resource to research scientists at Rome Laboratory. A listing of those papers is included as Appendix 3. The cataloging task will continue.

As a means of acquiring distinction as a research unit, the NAIC distributed a leaflet describing the NAIC and its membership in March 1986. A logo (simulated on page 2) was developed in August of 1987 and a brochure that included a more thorough description of on-going research was available in June 1988. The brochure's cover bears a satellite photograph of the northeastern United States that was provided by Dr. Kamal Jabbour of Syracuse University.

J. Awards

Some very high honors were awarded to NAIC participants over the course of the Consortium life:

In April of 1986 the Knowledge Systems Center of the Sperry Corporation announced the award of $20,000 to the NAIC for Faculty Fellowships. The fellowships, in the amount of $5000 each, were awarded to Dr. Robert Meyer (Clarkson), Dr. Victor Lesser (University of Massachusetts), Dr. James Modestino (RPI), and Dr. Ken Bowen (Syracuse). Each was designated an AI Sperry Fellow and asked to acknowledge Sperry support in pertinent publications.

University of Rochester investigators working in the technical area of parallel vision have been given several distinguished honors including a DARPA Parallel Systems postgraduate fellowship, an IBM Faculty Development Award (Michael Scott) and an ONR Young Investigator Award (Tom LeBlanc).

In recognition of their outstanding contributions to AI planning research, two more University of Rochester researchers received some of the highest honors given in the field of Computer Science. ([Allen, et al; 1990] provides details of the formal planning research carried out at the University of Rochester in temporal planning, plan recognition, and plan abstraction.) Dr. Henry Kautz was awarded the 1989 Computers and Thought Award for his PhD work. His dissertation [Kautz; 1987], completed in 1987 under the supervision of Dr. James Allen, provides the first formal accounts of plan recognition. The Computers and Thought Award, one of the most prestigious distinctions in the field, is given every two years by an international committee of scholars to a researcher who has made significant contributions to Artificial Intelligence. The award carries with it a certificate and the sum of $2000 plus travel and subsistence expenses for attendence at the International Joint Conference on Artificial Intelligence (IJCAI) where the winner may present the Computers and Thought Lecture. This lectureship award was established with royalties received from the book Computers and Thought [Feigenbaum and Feldman; 1963] and is currently supported by IJCAI funds.

Dr. Allen was the recipient of the National Science Foundation Presidential Young Investigator Award. Only a small number of such awards are presented each year, and competition for them is not restricted to AI researchers but rather, among researchers in all scientific disciplines.

III. Summary

The underlying goals leading to the development of the NAIC were to upgrade and increase the volume of AI research directed toward the improvement of Air Force C^3I system capabilities, and to intensify the transfer of that research towards the solution of military problems. The approach took the form of a substantial technical research program with additional, desirable activities focused on education and technology transfer.

The quality of technical research within the program ran the gamut from a few very high-quality efforts, to a more abundant number of mediocre efforts, to a few efforts of poor quality. Some of the successful work has been continued in follow-on projects and included in expanded programs focused on similar technical areas. The poor performance within some projects has been reflected in the reluctance of some Rome Lab and AFOSR Program Managers to support other long-term work within another "consortium"-type of program.

Clarkson University's involvement with the NAIC had an enormous effect on its AI technical capabilities. While some members of the NAIC brought a distiguished record of past AI research to the program, Clarkson and a few other members had not been previously active in AI research. Clarkson investigators are now internationally known as experts in the application of distributed AI in communications network management and control.

Consortium educational activities were to include cooperative educational opportunities among member universities, aggressive faculty and student recruitment, expansion of educational programs for Rome Lab personnel, and an expansion of AI resources within member schools through active pursuit of additional government and industry benefactors. The most successful of these activities involved computer equipment acquisition by NAIC member schools (see the section on Equipment, page 20). Industrial grants, NSF grants, New York State funding, University contributions, and DoD funding have resulted in a significant upgrade in AI Laboratory facilities. Cooperative educational programs within the NAIC and educational programs for Lab personnel, however, were negligible or nonexistent. There are noticible increases in the number of AI courses and faculty at NAIC schools but, as also noted elsewhere in this report, much of the increase can be attributed to the normal demand for more "high tech" courses and, in turn, the need for additional faculty.

Part of the goal of the NAIC was to produce more AI graduate students, thus increasing the accessibility of AI expertise for further Air Force studies. Toward this end, Rome Lab was particularly interested in supporting "domestic" graduate students. So, while there has been some concern with the imbalance of foreign to domestic students over the course of the program (a pervasive problem in United States graduate schools), the fact is that almost all of the students supported have stayed in the US.

The transfer of NAIC technology to other programs, particularly to more advanced research or Air Force application programs, was to be affected by the wide dissemination of research results and, a close working relationship with Industry and Rome Lab personnel and programs. The NAIC holds an excellent record in member participation and publication at National and International AI professional conferences, including the presentation of papers and the chairing of technical conference sessions. In the early years of the NAIC, members published under their University name rather than under the guise of the NAIC. In recent years there has been a significant increase in the visibility of the NAIC as an entity due to reference in publications to the author's membership in the Consortium.

There was extensive interaction among Consortium members after its initial year, including annual technical meetings and Principal Investigator sabbaticals to other NAIC schools. Interaction led to the discovery of a number of common research interests, and joint research and publications. It was only unfortunate that this degree of interaction was not consistent among all of the member schools.

There was no significant NAIC presence within Rome Laboratory to influence Laboratory in-house research and engineer expertise. Faculty and/or student resident research programs and undergraduate cooperative programs, with the exception of one *student's single semester term* at Rome Labs, never materialized

More transfer of NAIC research results to advanced development programs at Rome Lab could have occurred. Closer association and more effective exchange with industry was needed, particularly to clarify Air Force domain problems requiring solution. One particular NAIC technical effort would have, perhaps, fared much better if there had been personnel within the Consortium able to handle classified documents. Although funded, classified work was not felt to be necessary, Rome Lab would liked to have had some researcher access to classified materials, up to the secret level, to better understand and "sanitize" difficult problems for applicable AI research.

The lack of a central, effective management structure to whom the members of the Consortium were contractually responsible was a persistent problem for the NAIC. Consortium activities were neither presented to Rome Lab in an effective manner, nor widely touted within the larger AI community. Also, actual or perceived conflict of interest, because there were participating researchers at the managing school, threatened the unity and cooperative spirit of the NAIC membership. When Mr. Brule joined the NAIC in 1987 as the Managing Director, some headway in drawing the Consortium together as a unit was made, but a more explicit set of responsibilties and duties, and a means of enforcing them was needed.

In initiating the Consortium program Rome Lab had hoped to plant a seed for a long-term relationship among the contractual participants, to 'institutionalize' the NAIC. It was believed that by the end of five funded years the group could find strength in their solidarity, form a legal entity, and pursue AI research as a self-supporting agency. This failed to come about, in part, because University investigators could only act as independent arms of the larger University organizations. University-level support for maintaining the Consortium did not exist, there was little University initiative to seek other agency financial support, and there was no significant degree of University cost-sharing. The latter was felt to be necessary in order to maintain University-level interest in the success of such a venture. Attempts by Rome Lab, *midway through the program,* to gain University-level participation included a special meeting at the Laboratory on May 11, 1988 that brought the Deans and Vice-Presidents of Consortium schools to Rome Lab to discuss the breadth of Laboratory research interests in order to inspire interest in a continued relationship.

Rome Laboratory's Dr. Fred Diamond describes the experience of this Consortium as "a successful experiment." He points out that we made an unusual long-term commitment, a five-year contract, and that the Consortium met its legal obligations. But in addition, he states, "We can note with pride and satisfaction the achievement of many intangibles--seminars and sabbaticals among NAIC members; industry/NAIC technical exchange; technology transfer between and from NAIC members; new courses, faculty and students. As in any successful endeavor, we have learned and gained much from this effort that, in the long run, will benefit the US Air Force and the universities involved."

IV. Acknowledgement

Much of the information incorporated into this report was retrieved, in many cases wholesale, from documentation filed in the Government Contract case file for the NAIC. I cannot give credit where credit is specifically due to the creators of that documentation since authorship was anonymous. However I do wish to acknowledge the considerable contributions of Don Gondek, Jake Scherer, Northrup Fowler III, Don Roberts, and Bob Ruberti to those resources.

Sincerest thanks to Dr. Fred Diamond and, also, to the NAIC membership for their notes and other submissions detailing the ancillary aspects of the Consortium.

I have attempted to make this report as honest and as definitive as possible. Hopefully, the points on which it falls short will not detract from its usefulness toward future such efforts. I

firmly believe in the viability and great utility of the "consortium" as an effective means of advancing technology.

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Appendix 1

PRDA #84-01, "RADC Artificial Intelligence (AI) Research Program"

Commerce Business Daily Announcement, R&D Sources Sought Section (29 December 1983):

A - RADC ARTIFICIAL INTELLIGENCE (AI) RESEARCH PROGRAM. This notice is a Program Research and Development Announcement (PRDA). The Rome Air Development Center is interested in receiving technical and cost proposals in response to this notice. Requirement entail performing a series of interrelated tasks that will provide the AI technology advancement needed to support knowledge-based systems applications to Air Force C^3I mission requirements. In addition, a program to support RADC in-house (tech base) research, education (graduate level courses) and training (short-term/seminars) in AI technology to expand the quantity of AI researchers and faculty is needed. As a by-product, this effort will increase the availability of sources and personnel capable of conducting research and development of AI technology and in the application of that technology to C^3I and other military systems. Thus, the objectives of this program are two-fold: a cooperative technical program among universities (or other qualified sources) to advance AI technology and a non-technical goal which helps meet the long term, broader needs for AI in the DOD as well as the RADC/USAF community. A detailed Statement of Need (SON) and PRDA Guide containing proposal instructions may be obtained by calling C. Wallaesa, 315-330-2326. Proposals are desired by 4:00 PM on 15 Feb 84. Responses must reference PRDA Number 84-01. Questions of a technical nature should be addressed to D. Gondek, 315-330-2748. Contractual and proposal questions may be addressed to C. Wallaesa 315-330-2326. Sources deciding to respond to this PRDA should be alert for any amendments which may be published. Proposals must provide novel or unique concepts, ideas or approaches in order to qualify for evaluation and award. See Note 11 (State size of business. To be considered a small business for this effort, you must have 500 employees or less). This synopsis supersedes synopsis #218-83 for N-4-5012-D, published 30 Sep 83.

Appendix 2

Statement of Need
"RADC Artificial Intelligence Research Program"

1. Background:

Artificial Intelligence (AI) is an emerging technology that has the potential to significantly enhance the capabilities of Air Force Command, Control, Communication and Intelligence (C^3I) systems over the next two decades. In recognition of this fact, RADC has undertaken a vigorous research and development program that will enable the application of AI across a broad spectrum of systems.

A number of factors related to the availability of qualified researchers as well as the current state-of-the-art have influenced both the structure and content of the RADC AI technology program. The following observations are pertinent:

a. Research to date has been conducted almost exclusively in university laboratories. Successful transfer of this complex technology from the basic research arena has been limited and difficult to bring about.

b. Very little of the research has been directed towards solving military problems. Current AI techniques are unlikely to support the scale and scope of real time military systems. Prior to the formulation of the RADC research program, there had been no attempt within the Air Force to focus AI research in the C^3I arena.

c. The United States has a critical shortage of the qualified researchers and university resources (facilities and teaching professors) needed to train new AI researchers and practitioners. For a variety of reasons, the Air Force is unable to effectively compete in recruiting the relatively few AI graduates that are available each year. Compounding the problem is the fact that a number of junior professors are leaving their posts for the lucrative salaries now being offered by industry. The net effect is that not only is RADC unable to recruit quality graduates but is is equally difficult to obtain training for current employees. To a large degree, the same conditions affect many members of RADC's industrial base.

2. Technical Requirements:

A. General - In order to meet C^3I mission requirements, a substantial basic research and exploratory development program is needed by RADC. The focus for this effort is a series of interrelated tasks that will provide the technology advancement needed to support knowledge-based systems applications to Air Force C^3I mission requirements at RADC.
To address the personnel and resource deficiencies cited above, RADC seeks to establish a long term relationship with one or more universities (or other qualified sources) to carry out the required research. In order to facilitate smooth transfer of developed AI technology to the military, the program must provide for a close working relationship between universities (or other qualified sources) and RADC researchers, and include a high degree of technical interchange on a regular basis. Close working relationships to members of RADC's industrial base are needed for similar reasons. The program must include both expansion of university

research and education in AI and complimentary educational and training activities at RADC to develop and enhance existing capabilities at RADC.

B. Scope - The scope of the research program must be broad to insure that the technology base required to support C^3I applications is available. The program needs to support research in knowledge acquisition, representation and management; search techniques, AI programming languages; speech understanding; planning and problem understanding; expert system technology. The specific focus for the research is specified below:

C. Detailed Technical Requirements

(1) Basic Research Program - Research Tasks

a. Basic research is required to develop advanced software and hardware architectures for knowledge-based systems sufficient to overcome fundamental limitations in current knowledge base implementation, managment and maintenance techniques.

b. Research is needed to investigate relevant inference techniques in order to develop maintenance of reason methodologies which will provide behavior assessment under change for large, volatile knowledge bases whose structure may correspond to formal logic or to more traditional, ad hoc representations.

c. Research leading to software and hardware architectures to support efficient logic programming is also needed. Exploitation of inherent parallelism, elimination of processing bottlenecks and implementation of unique secondary storage organizations pertinent to a logic programming systems environment are germane to this requirement.

d. Basic research is also required to extend primitive knowledge acquisition techniques to support automated acquisition, integration and maintenance of a global understanding of a complex process from multiple distributed local perspectives. A system for monitoring the process of complex, distributed tasks, assisting in their execution, and describing previously completed tasks is needed. Also required are mechanisms that will enable the system to acquire, model, interpret and record the information necessary for generating a natural language description or exploration of past and present task states, including actions and decisions leading to the particular state.

(2) Exploratory Development Program - Research Tasks

a. Advances in the technology related to time oriented problem solving are needed. Computer representations of time have historically been discrete references to an absolute time scale. Yet humans almost exclusively use relative and imprecise terms (e.g., day after tomorrow, soon, now). Methods for dealing with such notions and computer representations for time oriented relationships need to be developed.

b. Knowledge representation schemes with natural language input/output which will provide for quasi-intelligent storage, management retrieval of event information in indication and warning systems are needed. This includes investigation of applicability of such schemes as semantic nets, quasigraphs, et al for representing current information.

c. Development of AI based techniques that are applicable to the automation of systemcontrol for large communications networks is required. Included are exploitation of AI for performance monitoring and assessment, traffic control and routing, fault detection and other communications control functions.

d. Research is needed to raise the qualitative and quantitative performance levels of automatic Photo Interpretation by following a knowledge-based approach and applying the principles of artificial intelligence. This includes investigation of knowledge directed image segmentation and use of automatic selection of measurements for classification as well as higher order classification.

e. Speech understanding - investigation oriented toward the application of artificial intelligence techniques to reduce the dimensionability of the signal while preserving all of the information relevant to speech recognitions, is needed.

f. Research directed at the application of expert systems technology to digital electronic equipment diagnosis and maintenance is also required. Expert systems that exceed capabilities currently available with built-in-test (BIT) equipment and automatic test equipment (ATE) are needed.

(3) Exploratory Development Program - Education & Training Tasks

The conduct of a quality research program that addresses C^3I problems is the primary objective of this AI program. However, to insure that the research is brought out of the laboratory and to provide necessary AI resources to RADC, a number of auxiliary objectives must be attained. Therefore, the university(s) (or other qualified sources) considered by RADC to conduct the research must provide a plan for expanding their own capabilities and indicate a program to support RADC training needs. Plans for expanding current academic/educational capabilities should include:

a. Development of cooperative (with and between universities) graduate degree programs.

b. Development of an aggressive recruitment program for quality graduate students.

c. Consideration of the establishment of an undergraduate cooperative program in AI with RADC.

d. Improving/developing AI curriculum including recruitment of high quality junior and senior AI faculty.

e. Updating existing equipment and facilities necessary to support expanded AI education programs as well as the proposed research.

f. In order to support RADC training needs one or more of the following need to be included in the basic program.

(i) Conducting short term training courses on-site (i.e.; at Griffiss AFB).

(ii) Providing graduate level AI (full term) courses on site.

(iii) Conducting seminars on a regular basis both on-site and at reasonably convenient locations off-site.

(iv) Participating in faculty/student resident research programs at RADC.

NOTE: The actual conduct of education and training of government personnel (civilian and military) will not be a part of any contract(s) resulting from this PRDA.

Appendix 3

On-Hand NAIC Publications

Author(s):Title

Adams, Gerald Michael, Charles N. Meyer, and Robert A. Meyer; Machine Intelligence for DoD Communications System Control

Ali, Syed S.; Knowledge Representation for Natural Language with Structured Variables

Allen, James F., Patrick J. Hayes; A Common-Sense Theory of Time

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