PROGRESS IN KNOWLEDGE REPRESENTATION RESEARCH

COMPUTER SCIENCES AND DATA SYSTEMS TECHNICAL SYMPOSIUM

APRIL 16, 1985

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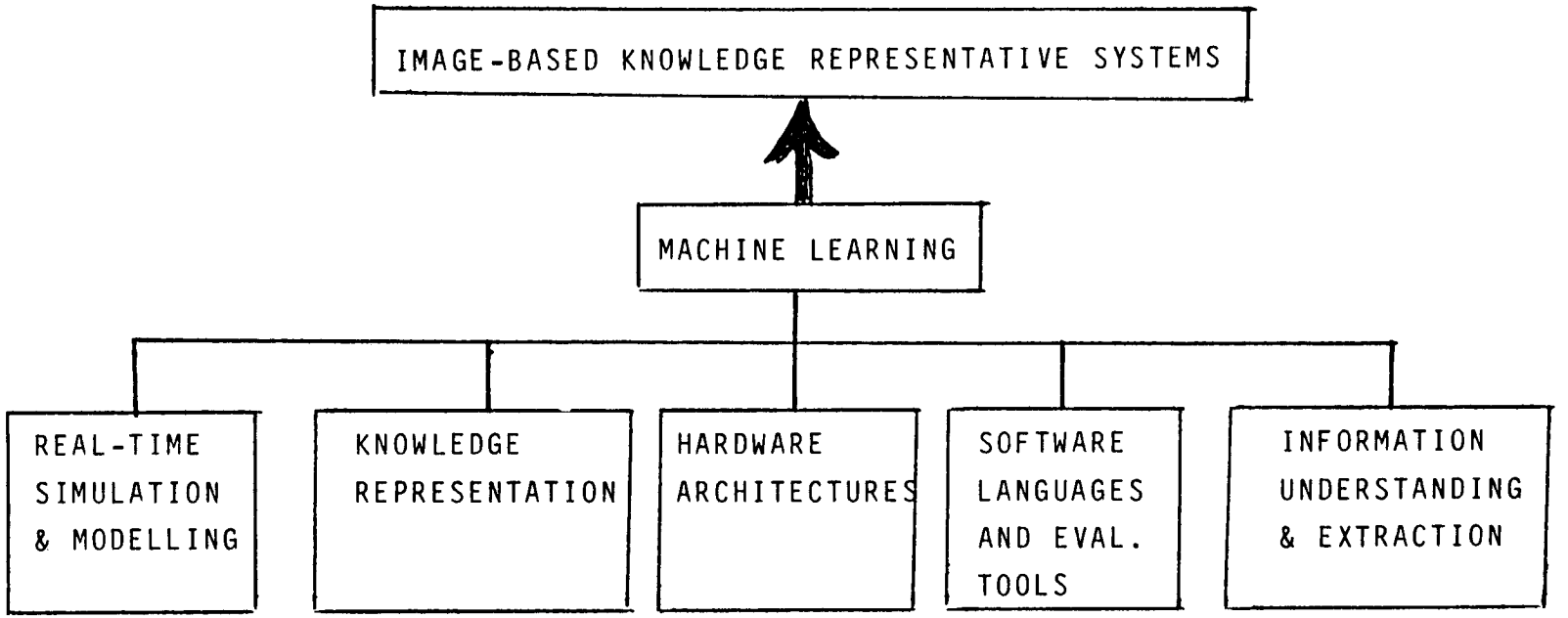
NASA AMES RESEARCH CENTER

KNOWLEDGE REPRESENTATION RESEARCH

GOAL: RESEARCH LEADING TO IMAGE-BASED KNOWLEDGE REPRESENTATION SYSTEMS

OBJECTIVES AND TECHNICAL APPROACH



REAL-TIME SIMULATION AND MODELLING

PRINCIPAL INVESTIGATORS: AMES RESEARCH CENTER
MIT

OBJECTIVE: DYNAMIC SIMULATION AND MODELLING OF PLANNING SYSTEMS WITH REAL-TIME SENSOR INPUTS - DERIVATION OF "ERROR SIGNAL" TO REPLAN NEW ACTIVITY

CURRENT STATUS:
- O LONG-RANGE RESEARCH PROGRAM CURRENTLY BEING REDEFINED
- O EXISTING SIMULATION FACILITIES BEING REDIRECTED TO SUPPORT ACTIVITY
- O EVANS & SUTHERLAND PS-350 SYSTEM BEING INSTALLED IN AUTOMATION SCIENCES LABORATORY TO VALIDATE/EVALUATE TECHNOLOGY PLAN - OPERATIONAL MAY 1985
- O DEMONSTRATION OF AUTOMATED CRYOGENIC TRANSFER TO BE USED TO VALIDATE SIMULATION/MODELLING SYSTEM - BEING DONE IN CONJUCTION WITH JSC

ISSUES: INTERACTION OF REAL-TIME SENSOR SYSTEMS WITH PLANNING SYSTEMS
- O IMPACT ON HARDWARE AND SOFTWARE ARCHITECTURE
- O IMPACT ON PLANNING SYSTEMS
- O ROLE OF HUMAN IN THE AUTOMATED PLANNING SYSTEM

REAL-TIME SIMULATION AND MODELING

The interaction between task planning and execution systems with the "external world" and the operator is not widely understood at the present time. Of particular interest is the derivation of the "error signal" (difference signal in symbolic notation between the expected action and the actual action) and its interaction with the planner in real-time. Issues being investigated are the role of the operator in the planning cycle, the interpretation and translation of the symbolic "error signal" into a new planning requirement and a resulting analog correction signal, the interpretation (understanding) of the sensor data, and the display/explanation of the data to the operator.

To understand the above issues, a feasibility study is being undertaken to automate the transfer of cryogens between a helium dewar and an instrument. Coupling and uncoupling of cryogenic fill values are also included in the study. This effort is being done in conjunction with NASA JSC, which has provided the procedures used by the astronauts in a manual transfer feasibility study and which will provide a sample valve. Target mission is the Space Infrared Telescope Facility (SIRTF).

KNOWLEDGE REPRESENTATION

PRINCIPAL INVESTIGATORS: AMES RESEARCH CENTER
STANFORD UNIVERSITY
UNIVERSITY OF CALIFORNIA, BERKELEY
SRI, INTERNATIONAL

OBJECTIVE: DEVELOPMENT OF DOMAIN-INDEPENDENT KNOWLEDGE REPRESENTATION TOOLS WHICH CAN BE USED BY THE AGENCY IN THE DEVELOPMENT OF APPLICATION-SPECIFIC EXPERT AND PLANNING SYSTEMS. INTEGRATION OF KNOWLEDGE-REPRESENTATION TECHNIQUES TO MACHINE LEARNING ALGORITHMS.

CURRENT STATUS:

- RESEARCH IN KNOWLEDGE REPRESENTATION TECHNIQUES APPLICABLE TO EXPERT SYSTEMS, PLANNING SYSTEMS, AND FAULT DIAGNOSTICS SYSTEMS IN THIRD YEAR OF STUDY - PRELIMINARY TOOLS EXPECTED TO BE DELIVERED FOR EVALUATION LATE CY 1986
- PRELIMINARY APPLICATIONS BEING DEVELOPED TO EVALUATE TOOLS FOR MULTI-USER/DISCIPLINE ENVIRONMENT AND EXPLANATION CAPABILITIES
- INTEGRATION OF FUZZY SET THEORY INTO KNOWLEDGE REPRESENTATION ALGORITHMS BEING EVALUATED - PRELIMINARY DATA INDICATES THAT THEORY HAS PRACTICAL APPLICATIONS TO DOMAINS WHERE KNOWLEDGE IS UNCERTAIN OR UNRELIABLE. RELIABILITY OF DECISIONS COULD BE AS HIGH AS 70 PERCENT.

ISSUES:

- COMMERCIAL KNOWLEDGE REPRESENTATION SYSTEMS INADEQUATE FOR DEEP AND COMPLEX SYSTEMS. REQUIRES SKILLED KNOWLEDGE ENGINEER. NOT EFFICIENT FOR ALL TECHNICAL DOMAINS.
- COMMON PROGRAMMING LANGUAGE AND SYSTEMS REQUIRED FOR TRANSFER OF RESEARCH TOOLS - PROGRESS BEING MADE TO ESTABLISH "STANDARD ENVIRONMENT"
- "GLAMOUR PROBLEM" - CONCERN EXISTS THAT TOO MUCH IS BEING PROMISED WITHOUT IN-DEPTH UNDERSTANDING OF THE UNDERLYING PROBLEMS - COULD ENDANGER EFFORT

KNOWLEDGE REPRESENTATION

Knowledge representation research is underway to correct the present deficiencies of commercial expert building tools, i.e., capability to reason, represent knowledge, and acquire knowledge from input data; verify and explain the heuristic rules used in the manipulation of the knowledge and the execution of the decision; ability to interact with multiple knowledge domains and coorelate the knowledge represented in each domain; and the ability to learn as more knowledge is acquired. The current research involves areas of planning, representation of knowledge, fault diagnostics, and uncertainty (where knowledge is unknown or unreliable). The research tools are being evaluated in limited applications to validate their potential relative to the above stated objectives and to understand their impact on the need for skilled vs. unskilled knowledge engineers and on the performance of the hardware and software architectures. A limited set of the tools will be available for Agency evaluation during late CY 1986.

The integration of the knowledge representation research will hopefully lead to machine learning algorithms and executive controllers for multiple expert systems/planners/diagnostic systems. Research is this field is very complex and breakthroughs/technology readiness for user applications cannot be forecasted with any degree of certainty.

HARDWARE ARCHITECTURES

PRINCIPAL INVESTIGATORS: AMES RESEARCH CENTER
STANFORD
SYMBOLICS, INC.
TRW, INC. (ROLE BEING DISCUSSED)
UNIVERSITY OF ALABAMA (SDI CENTER OF EXCELLENCE IN OPTICAL COMPUTING)

OBJECTIVE: DEVELOPMENT OF A SPACE-BORNE VHSIC SYMBOLIC PROCESSOR WITH 15 TIMES THE PERFORMANCE OF THE CURRENT JAPANESE 5TH GENERATION MACHINE; DEVELOPMENT OF INTERFACES TO PROVIDE FRONT-END OPTICAL PROCESSING CAPABILITY AND OPTICAL READ-WRITE DISK STORAGE; DEVELOPMENT OF AN OPTICAL PROCESSOR WHICH WILL PROVIDE A FACTOR OF 10 IMPROVEMENT IN PERFORMANCE TO THE VHSIC SYMBOLIC PROCESSOR.

CURRENT STATUS:
- DETAILED DEFINITION OF VHSIC SYMBOLIC PROCESSOR ARCHITECTURE UNDERWAY - TARGET DATE FOR CRITICAL DESIGN REVIEW 3RD QUARTER, FY 1986. CURRENT STUDIES SHOW APPROXIMATELY TWO TIMES PERFORMANCE OF THE CURRENT JAPANESE 5TH GENERATION MACHINE (PSI) USING THE IDENTICAL TEST CASES RUN IN PROLOG.
- VHSIC CHIPS FOUND APPLICABLE TO THE PROCESSOR - TRW'S CONTENT ADDRESSABLE MEMORY CHIP COULD BE CRITICAL ELEMENT IN PROCESSOR DESIGN

- WITH OPTICAL PROCESSOR FRONT-END AND OPTICAL READ-WRITE DISK STORAGE, VHSIC SYMBOLIC PROCESSOR COULD POTENTIALLY MEET THE NEEDS OF ALL PROJECTED SPACE STATION AUTOMATED SYSTEMS AND SCIENTIFIC EXPERIMENTS.
- LABORATORY TESTS TO INVESTIGATE TECHNIQUES REQUIRED TO INCREASE THE SPEED OF THE PROGRAMMABLE LCD MASKS - CRITICAL ELEMENT IN OPTICAL PROCESSOR. CRITICAL DEMONSTRATION SET FOR LATE CY 1986 TO DETERMINE FEASIBILITY OF OPTICAL PROCESSOR FOR SPACE-BORNE APPLICATIONS.
- OPTICAL READ-WRITE DISKS APPEAR TO BE VIABLE SOLUTION FOR DATA NEEDS OF SYMBOLIC PROCESSOR - REQUIREMENTS FOR CONTROLLER UNKNOWN AT THE PRESENT TIME. DATA TRANSFER SPEEDS COULD BE LIMITING FACTOR.

ISSUES:
- TRANSLATION OF OPTICAL INFORMATION INTO SYMBOLIC REPRESENTATION
- APPROACH TO ACCELERATE DATA TRANSFER RATES BETWEEN DATA STORAGE SYSTEM AND SYMBOLIC PROCESSOR
- LIMITED RESOLUTION OF OPTICAL PROCESSORS RELATIVE TO DIGITAL PROCESSORS

HARDWARE ARCHITECTURES

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An efficient method for translating optical information into symbolic representation is not known at this time. This issue will need to be resolved before the symbolic processor can interact in real-time with the symbolic processor. In addition, the impact of the resolution of optical processors for real-time applications will need to be investigated.

SOFTWARE LANGUAGES AND EVALUATION TOOLS

PRINCIPAL INVESTIGATORS: AMES RESEARCH CENTER
STANFORD UNIVERSITY
LUCID (GABRIEL) - BEING DISCUSSED

OBJECTIVE:
- O DEVELOPMENT OF A "STANDARIZED" PROGRAMMING ENVIRONMENT
- O DEVELOPMENT OF AN EXPERT PROGRAMMING ENVIRONMENT FOR TRANSPARENCY OF LISP, PROLOG, AND ADA
- O DEVELOPMENT OF STANDARD BENCHMARKS TO EVALUATE POTENTIAL SYMBOLIC ARCHITECTURES

CURRENT STATUS:
- O 1500-RULE BENCH MARK CASE IN PROGRESS - EXPECTED TO BE COMPLETED MID-CY 1986
- O TEST CASES FOR EVALUATING NUMERIC AND SYMBOLIC PROCESSORS COMBINING NUMERIC AND SYMBOLIC ALGORITHMS BEING TESTED - REPORT EXPECTED LATE CY 1985; WILL PROVIDE EFFICIENT METHOD FOR EVALUATING WORK STATIONS, PERSONAL COMPUTERS, AND LARGE FRAME ARCHITECTURES FOR BOTH NUMERIC AND SYMBOLIC APPLICATIONS
- O RESEARCH IN THE USE OF FIRMWARE FOR AN EXPERT PROGRAMMING ENVIRONMENT IN 2ND YEAR OF EFFORT - FEASIBILITY UNCERTAIN AT THIS TIME

ISSUES: NONE

SOFTWARE LANGUAGES AND EVALUATION TOOLS

Research in this area is directed at the establishment of a "standarized" programming environment for the development of expert, fault diagnostic, and procedural planning systems. In addition, progress has been made in the "standarization" of ground-based symbolic processors (Symbolics 3600, 3670, and 3640) which will significantly aid in the transfer of software between Centers and NASA-sponsored university research. On-going efforts between Ames, GSFC, and JSC have demonstrated the viability and productivity of such a concept. Expert systems will be applied in many technical disciplines; as a result, there is a need to provide a programming environment based in the use of LISP-like languages (Common LISP is a potential "standard"), Prolog, and ADA since each language is extremely efficient in specific domains. A potential solution is an expert programming system (or automated programmer) which will select the optimum language based on the supplied user inputs and requirements and allow the user to develop the software code in a natural language context. Research in both the use of firmware and software algorithms to accomplish this is currently underway.

The state-of-the-art in architectures (work stations, personal computers, and large-frame machines) are rapidly advancing. There is no current way to efficiently evaluate these architectures for overall performance relative to specific applications and codes; test cases involving numeric and symbolic computations and large (1500 rules minimum) rule-based systems are currently in development and/or evaluation. The use of "standarized" bench marks will allow

correlation of performance data between different machines and permit identification of architectures which are most efficient for specific applications. Tradeoffs between architectures can also evaluated using a common baseline.

INFORMATION UNDERSTANDING AND EXTRACTION

PRINCIPAL INVESTIGATORS: AMES RESEARCH CENTER
MIT
UNIVERSITY OF MICHIGAN
UNIVERSITY OF TEXAS
MACHINE INTELLIGENCE CORPORATION

OBJECTIVE: DERIVE MAXIMUM INFORMATION CONTENT/UNDERSTANDING FROM INCOMING IMAGES

CURRENT STATUS:
- PROTOTYPE SYSTEM WILL BE COMPLETED IN LATE CY 1985 TO EVALUATE TRADEOFFS BETWEEN AN IMAGE-BASED EXPERT SYSTEM AND AN EXPERT IN THE AREA OF UPPER ATMOSPHERIC RESEARCH (AEROSOL PARTICLES)
- USE OF COLOR/IR VISION BEING INVESTIGATED FOR MAXIMUM INFORMATION CONTENT VERSUS GRAY-SCALE APPROACH
- INTEGRATION OF SENSOR INFORMATION AND ITS IMPACT ON MACHINE LEARNING ALGORITHMS UNDERWAY - 1ST YEAR OF RESEARCH

ISSUES: NONE

INFORMATION UNDERSTANDING AND EXTRACTION

With the approaching advent of "smart" sensors and complex scientific experiments/facilities, there is an ever increasing need for on-board data compression and preprocessing prior to the data being transmitted back down to the ground. Even then, it is likely that the channel capacity will be severely taxed and will not be able to accommodate all of the sensory data. As a result, there is a need to derive the maximum information content and understanding from images, patterns, and sensors. By understanding the minimum quantity of information required by an expert to make an intelligent decision, one can reduce the data required for transmission to the ground. The research in this area is focused on the above goad. Objectives are to understand the tradeoffs between human understanding and perception and machine processing/intelligence. It is felt that the use of color and infrared vision can increase the information content over that of gray-scale systems by at least a factor of 15; however, the tradeoffs involving the complexities of the hardware and the processing are not well understood at this time. Research is this area is directed towards a better understanding of the pertinent issues involved and the definition of guidelines which can be used to specify the performance characteristics of such a system relative to real-time image-based applications.

RESEARCH "TEST BEDS"

- KUIPER AIRBORNE OBSERVATORY (KAO - C141A) - ASTROPHYSICS APPLICATIONS
  - EXPERT SYSTEMS
  - PLANNING SYSTEMS
  - DIAGNOSTICS SYSTEMS
- EARTH RESOURCES SURVEY AIRCRAFT (U-2 AND ER-2) - UPPER ATMOSPHERIC RESEARCH
  - IMAGE-BASED EXPERT SYSTEMS
- AIRBORNE RESEARCH LABORATORY (CV-990) - SPACE SCIENCE RESEARCH
  - EXPERT SYSTEMS
  - FAULT DIAGNOSTICS SYSTEMS
- ARTIFICIAL INTELLIGENCE RESEARCH LABORATORY, INFORMATION SCIENCES OFFICE
- AUTOMATION SCIENCES RESEARCH LABORATORY, INFORMATION SCIENCES OFFICE
- HUMAN FACTORS RESEARCH LABORATORY (JOINT RESEARCH ROLE BEING DEFINED)
- SIMULATION RESEARCH LABORATORY (JOINT RESEARCH ROLE RECENTLY DEFINED)

CURRENT PROBLEMS WITH EXPERT SYSTEMS

- MAJOR PROBLEM IS DEVELOPMENT TIME AND COST - WITH THE SPACE STATION, ADDITIONAL PROBLEM IS THE HIGH RELIABILITY REQUIRED
- LACK OF TRAINED PEOPLE - SEVERAL UNTRAINED "EXPERTS" CURRENTLY IN EXISTENCE
- DEVELOPMENT OF SUITABLE REPRESENTATIONS FOR EACH DOMAIN
  - BETTER HARDWARE WILL NOT HELP MUCH
  - TRAINED AI PEOPLE REQUIRED
  - EXPERT SYSTEMS FOR COMPLEX DOMAINS AT LEAST 15 YEARS AWAY
- LONG-TERM PERFORMANCE LIMITATIONS
  - LACK OF ABILITY TO LEARN
  - DIFFICULTY OF DOMAIN KNOWLEDGE REPRESENTATION
  - TEMPORAL AND GEOMETRICAL REASONING ABILITY
- INADEQUATE LONG-TERM RESEARCH PROGRAM/FUNDING AND TRAINED KNOWLEDGE ENGINEERS
  - PROVIDE INCREASED FUNDING FOR STUDENTS AT MAJOR AI UNIVERSITIES
  - PROVIDE COOPERATIVE RESEARCH ENVIRONMENT FOR TRAINING OF IN-HOUSE PERSONNEL
  - PROVIDE FUNDS FOR RESEARCH IN EXPERT SYSTEMS
  - PROVIDE SUPPORT FOR PROVEN EXPERT SYSTEM DEVELOPMENT TEAMS

PRESENT LIMITATIONS OF EXPERT SYSTEMS

Knowledge representation.

Reasoning.

Knowledge acquisition facilities.

Verification.

Explanation capabilities.

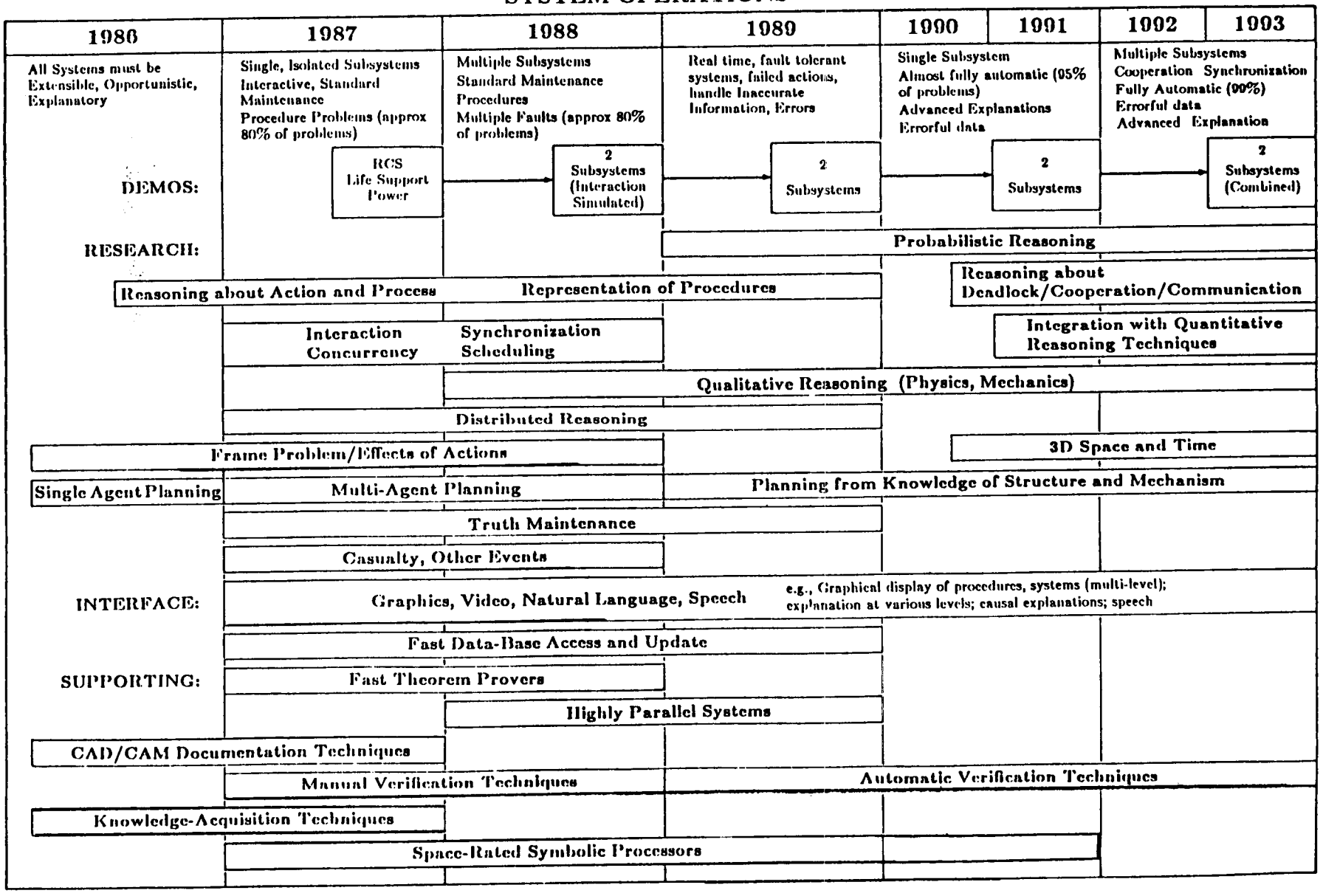
Metaknowledge.

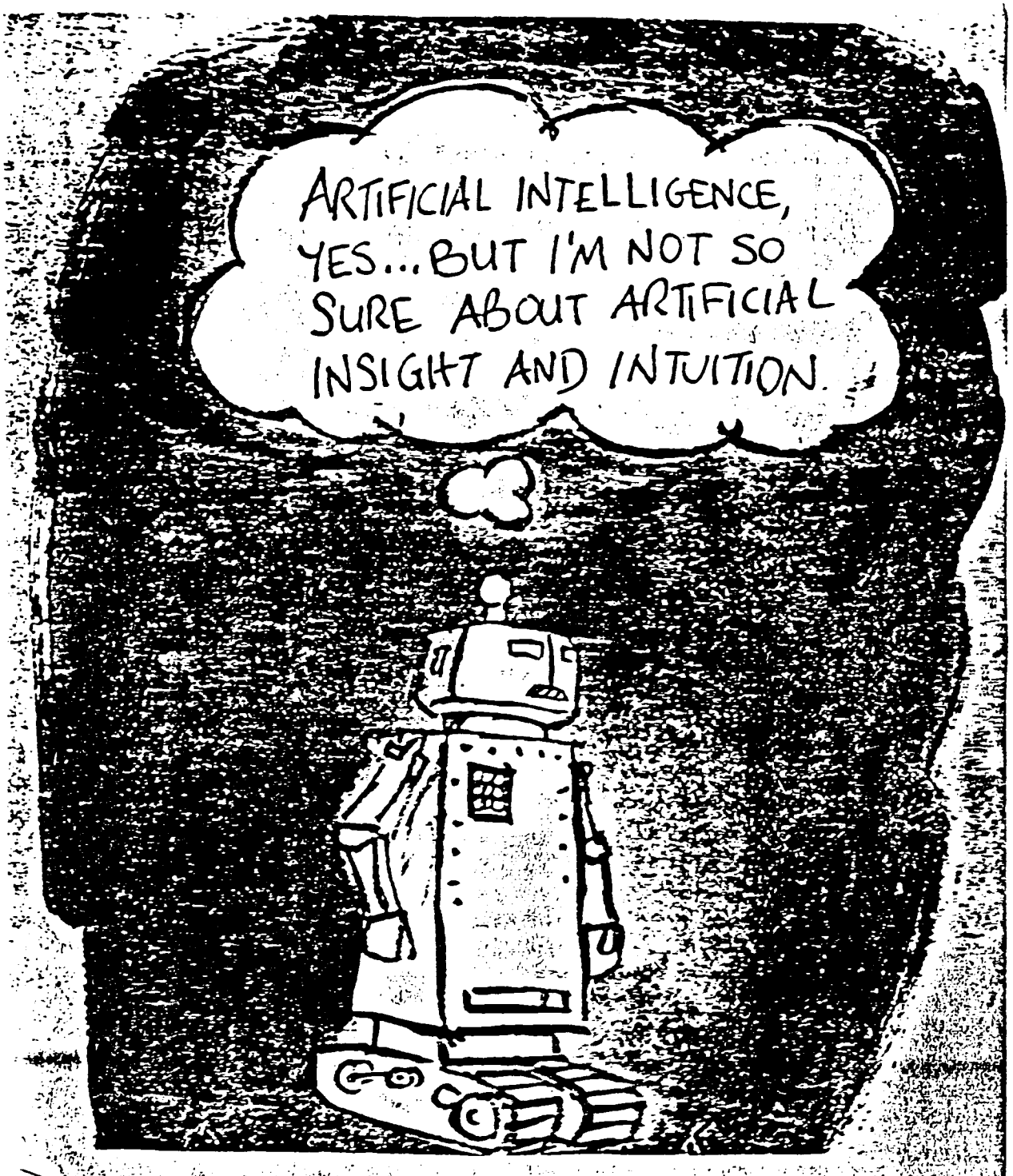
Learning Capability.

LONG RANGE TECHNOLOGY CHALLENGES

- DOMAIN-INDEPENDENT KNOWLEDGE REPRESENTATION AND MODELING
- SENSING AND INFORMATION EXTRACTION AND INTERPRETATION
- MACHINE LEARNING (INTELLIGENCE AND DECISION MAKING)
- NATURAL LANGUAGE INTERFACE
- AI PROGRAMMING LANGUAGES
- INTEGRATION AND APPLICATIONS
  - REMOTE
  - IN-SITU

SYSTEM OPERATIONS





25.

Project: Knowledge Representation and Knowledge Acquisition

Participants: Henry Lum, SI
Claire Wolfe, SI
Bruce G. Buchanan, Stanford University

Status: Work in progress
Grant

Project Description:

By working on PROTEAN, an expert system which determines the three-dimensional molecular structure of a substance from NMR (nuclear magnetic resonance) data, the blackboard model BB1, which is a framework for knowledge representation and control, is examined.

Reference:

Clancey, W.J.: "Acquiring, Representing, and Evaluating a Competency Model of Diagnostic Strategy", Stanford HPP Report 84-2, February 1984.

26.

Project: Reasoning With Uncertainty

Participants: Henry Lum, SI (grant monitor)
Lotfi Zadeh, U.C. Berkeley

Status: Work in progress
Grant

Project Description:

"Fuzzy Logic" is one way to handle uncertainty in reasoning. This project focuses on the further development of fuzzy logic.

References:

Zadeh, L.A.: "A Computational Theory of Dispositions", Proceedings of the 1984 International Conference of the Association for Computational Linguistics.

Zadeh, L.A.: "Test-Score Semantics as a Basis for a Computational Approach to the Representation of Meaning", U.C. Berkeley Memorandum No. UCB/ERL M84/8, January 1984.

27.

Project: Fuzzy Rule-Making for Failure Detection and Expert Systems

Participants: Henry Lum, SI (grant monitor)
Tom Sheridan, MIT

Status: Work in progress
Grant

Project Description:

This project will investigate the use of fuzzy logic in diagnosis of failures in complex space systems.

28.

Project: System Procedural Knowledge Engineering Tools

Participants: Henry Lum, SI
Mike Georgeff, SRI

Status: Work in progress
Contract

Project Description:

"Active intelligent systems need to be able to represent and reason about actions and how those actions can be combined to achieve given goals. This knowledge is often in the form of sequences of actions or procedures for achieving given goals or reacting to certain situations.

[In the tools being developed] the knowledge representation has a declarative semantics that provides for incremental changes to the system, rich explanatory capabilities, and verifiability. The scheme also provides a mechanism for reasoning about the use of this knowledge, thus enabling the system to choose effectively between alternative courses of action."

Reference:

Georgeff, M.: "Development of an Expert System for Representing Procedural Knowledge", contract report, December 1984.

29.

Project: Information Understanding

Participants: Henry Lum, SI (grant monitor)
Richard Volz, U. of Michigan

Status: Work in progress
Grant

Project Description:

Under a grant to the University of Michigan, Richard Volz is investigating the integration and fusion of sensor information for use by expert systems. It is hoped that this research will contribute to space-borne robotics applications.

30.

Project: Symbolic Processor Architectures

Participants: Henry Lum, SI (grant monitor)
Edward A. Feigenbaum, Stanford University

Status: Work in progress
Grant

Project Description:

This long-term project undertakes to develop a symbolic processor architecture which can equal or surpass a fifth generation computer in performance.

References:

Long, C.: "Framework for Circuit Design", Stanford HPP Report 83-45, December 1983.

Dietterich, T.G.: "Learning About Systems that Contain State Variables", Stanford HPP Report 84-10, May 1984.

31.

Project: Inference Engine Evaluation

Participants: Claire Wolfe, SI
Rafael Villegas, SI
Vivian Frederick, De Anza College

Status: Work in progress
In-house

Project Description:

"The strengths and weaknesses of several existing inference engines (such as MRS, EMYCIN, AGE, OPS5) are being evaluated for various types of applications and appropriate inference engines are being maintained for use throughout NASA. An intra-agency class will be conducted this summer (1985) to familiarize people with the Symbolics Lisp Machine and available expert system building tools."

32.

Project: Robotics Perception Laboratory

Participants: Scott Starks, University of Texas
Veena Bhatia, SI
Harold Fujii, SI
Rajiv Mehta, FSN

Status: Work in progress
In-house

Project Description:

An experimental robotics laboratory is being established to test various sensor hardware and software for robot perception systems. Laboratory and educational robots are being acquired to equip the lab. This work will contribute information needed for determining requirements and specifications for the SMART program (see applications project 9).

33.

Project: Concept Design of Intelligent Iconic Processors

Participants: Wun Chiou, SI
Carolyn Banda, SI (Informatics)

Status: Planning stage
In-house

Project Description:

The goal of this project is to develop a translation between symbolic representation of information and representation by icons. This work will be done on a Symbolics, and will make use of Easy Graph, a Lisp tool developed in-house to draw polygons and various other geometric figures.

34.

Project: Knowledge Representation of an Executive Expert System Controller

Participants: Wun Chiou, SI
Bruce G. Buchanan, Stanford University

Status: Planning stage
Grant, in-house

Project Description:

This project will undertake an in-depth look at the knowledge representation involved in the control of the space station expert sub-systems.

STATE OF THE TECHNOLOGY FOR INTELLIGENT AIDING IN THE COCKPIT (CONTINUED)

TECHNICAL AREA	DESIRED/REQUIRED CAPABILITIES	CURRENT CAPABILITIES
O ARTIFICIAL INTELLIGENCE		
– PROBLEM SOLVING/ PLANNING	DYNAMICALLY CHANGING GOALS, CONDITIONS, OBJECTS, AND PROPERTIES	WELL–DEFINED, FIXED GOALS, CONDITIONS, OBJECTS, AND PROPERTIES
	MULTIPLE AGENTS	SINGLE AGENT
	SIMULTANEOUS AND OVERLAPPING EVENTS	NON–OVERLAPPING EVENTS
	TEMPORAL RELATIONS	
	PLAN EXECUTION MONITORS	
	INCREMENTAL PLANNERS	

STATE OF THE TECHNOLOGY FOR INTELLIGENT AIDING IN THE COCKPIT (CONTINUED)

TECHNICAL AREA	DESIRED/REQUIRED CAPABILITIES	CURRENT CAPABILITIES
O ARTIFICIAL INTELLIGENCE		
– KNOWLEDGE REPRESENTATION	REPRESENTATIONS FOR TEMPORAL, SPATIAL, QUALITATIVE, DEFAULT, FUNCTIONAL, STRUCTURAL, AND ANALOGICAL KNOWLEDGE	LIMITED EXPRESSIBILITY

STATE OF THE TECHNOLOGY FOR INTELLIGENT AIDING IN THE COCKPIT

Reference: LaRC, 4/16/85

TECHNICAL AREA	DESIRED/REQUIRED CAPABILITIES	CURRENT CAPABILITIES
O ARTIFICIAL INTELLIGENCE		
– EXPERT SYSTEMS	REAL TIME REASONING ABOUT DYNAMICALLY CHANGING ENVIRONMENT AND TIME–BASED INFORMATION	NON–REAL TIME REASONING ABOUT STATIC SITUATION
	RIGOROUS METHODS FOR DEALING WITH UNCERTAINTY	LIMITED CAPABILITY FOR DEALING WITH UNCERTAIN, INCOMPLETE, OR INCONSISTENT INFORMATION
	MODEL–BASED SYSTEM +	RULE–BASED SYSTEMS
	EFFICIENT CONTROL STRUCTURES FOR DEALING WITH MULTIPLE REPRESENTATIONS	LIMITED CONTROL STRUCTURES
	EXTENSIVE EXPLANATION CAPABILITY AS NEEDED	LIMITED EXPLANATION CAPABILITY
	HYBRID REASONING ABOUT SYMBOLIC AND NUMERIC INFORMATION	SYMBOLIC COMPUTATION
	MULTIPLE COOPERATING INTELLIGENT SYSTEMS	SINGLE EXPERT

STATE OF THE TECHNOLOGY FOR INTELLIGENT AIDING IN THE COCKPIT (CONCLUDED)

TECHNICAL AREA	DESIRED/REQUIRED CAPABILITIES	CURRENT CAPABILITIES
O SPEECH UNDERSTANDING	1000 WORD VOCABULARY, CONNECTED SPEECH, NATURAL LANGUAGE	100 WORDS, RESTRICTED SPEECH
O COMPUTER HARDWARE	PARALLEL OPERATIONS	SEQUENTIAL OPERATIONS
O CREW INTERFACE	CREW INFORMATION REQUIREMENTS BY FUNCTION ADAPTIVE AIDING MULTIPLE INTERFACE MEDIA NATURAL HUMAN-LIKE COMMUNICATION	NON-FLEXIBLE & LIMITED CAPABILITY