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AUTOMATION FOR DEEP SPACE VEHICLE MONITORING

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FLIGHT COMMAND AND DATA MANAGEMENT SYSTEMS SECTION
JET PROPULSION LABORATORY

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AUTOMATION GOALS

- SIGNIFICANT IMPROVEMENT IN PRODUCTIVITY AND RELIABILITY
- APPLICATION OF ARTIFICIAL INTELLIGENCE METHODS TO GROUND-BASED MONITORING
- ADVANCEMENT OF ARTIFICIAL INTELLIGENCE TECHNOLOGY

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AUTOMATION STRATEGY

- ACTIVE INVOLVEMENT OF THE END USER
- INCREMENTAL DEVELOPMENT WITH REGULAR DELIVERIES TO THE END USER
- EMPHASIS ON USABLE, REAL-WORLD PRODUCTS RATHER THAN PROTOTYPE DEMONSTRATIONS

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RESEARCH & DEVELOPMENT ACTIVITIES

- AUTOMATED MISSION MONITORING AND ANALYSIS
- INTELLIGENT INPUT DATA MANAGEMENT
- SYSTEM-LEVEL ANALYSIS USING COOPERATING EXPERT SYSTEMS

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AUTOMATED MISSION MONITORING AND ANALYSIS

- REAL-TIME MONITORING OF SPACECRAFT AND TELEMETRY
- KNOWLEDGE-BASED ANOMALY ANALYSIS
- COMBINATION OF CONVENTIONAL AUTOMATION AND ARTIFICIAL INTELLIGENCE
- MULTI-MISSION APPLICABILITY
- TWO-YEAR HISTORY OF CONTINUOUS ON-LINE OPERATION

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MONITOR/
ANALYZER OF
REAL-TIME
VOYAGER
ENGINEERING
LINK

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MARVEL

- FUNCTIONS
  - REAL-TIME MONITORING
  - REAL-TIME KNOWLEDGE-BASED ANALYSIS
  - GENERAL PRODUCTIVITY ENHANCEMENT
- FEATURES
  - DATA DISPLAY AND ARCHIVING
  - AUTOMATED ALARM MESSAGES
  - HIERARCHICAL ORGANIZATION
  - WINDOW ENVIRONMENT
  - MOUSE- AND MENU-DRIVEN OPERATION
  - ON-LINE USER DOCUMENTATION

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MARVEL

IMPLEMENTATION

- DISTRIBUTED MULTI-WORKSTATION ENVIRONMENT
  - MESSAGE PASSING FOR INTERPROCESS COMMUNICATION
  - VARIABLE NUMBER OF NODES
- MULTIPLE C PROCESSES PROVIDE STANDARD AUTOMATION
  - PROCEDURAL AND ALGORITHMIC FUNCTIONS
  - USER-INTERFACE FUNCTIONS
  - REAL-TIME SPEED AND PORTABILITY
- EMBEDDED KNOWLEDGE BASES PROVIDE EXPERT REASONING
  - ANOMALY ANALYSIS
  - CORRECTIVE ACTION RECOMMENDATIONS
  - COMPATIBILITY WITH C
- GOAL- AND DATA-DRIVEN REASONING ARE COMBINED IN KNOWLEDGE-BASED ANALYSIS MODULES
- LOWER-LEVEL C ALGORITHMS PROVIDE CALCULATIONS NEEDED BY THE KNOWLEDGE BASES

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ACHIEVEMENTS

- SIMULTANEOUS AUTOMATED MONITORING OF THREE VOYAGER SUBSYSTEMS
  - COMPUTER COMMAND SUBSYSTEM
  - FLIGHT DATA SUBSYSTEM
  - ATTITUDE AND ARTICULATION CONTROL SUBSYSTEM
- KNOWLEDGE-BASED ANOMALY ANALYSIS AND CORRECTIVE RECOMMENDATIONS FOR TWO VOYAGER SUBSYSTEMS
  - COMPUTER COMMAND SUBSYSTEM
  - ATTITUDE AND ARTICULATION CONTROL SUBSYSTEM
- CONTINUOUS ON-LINE OPERATION FOR BOTH VOYAGER SPACECRAFT SINCE AUGUST 1989
- SUCCESSFUL DETECTION OF ALL ANOMALIES
  - IMPROVED ACCURACY
  - IMPROVED TIMLINESS
- SMOOTH TRANSITION FOR POST-ENCOUNTER WORKFORCE REDUCTIONS AND CROSS-TRAINING OF PERSONNEL
- TRANSITION TO TOPEX, GALILEO, AND CRAF/CASSINI

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INTELLIGENT INPUT DATA MANAGEMENT

- MANAGEMENT OF INPUT DATA VOLUMES THAT EXCEED PROCESSING CAPACITY
- COMBINATION OF DECISION THEORY AND KNOWLEDGE-BASED METHODS
- AUTOMATION OF AN IMPORTANT REAL-TIME TRADE-OFF BETWEEN

  AMOUNT OF INPUT PROCESSED

  VS

  TIMELINESS OF OUTPUT

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DECISION THEORY FOR MAKING TRADE-OFFS

- UTILITY THEORY AND PROBABILITY ARE USED TO SELECT THE MAXIMUM-VALUE ACTION FROM A SET OF POSSIBLE ACTIONS.
- THE VALUE (V) OF AN ACTION (X) IS DETERMINED WITH A SET OF EVALUATION CRITERIA (i = 1 TO n) AND WEIGHTING FACTORS (W)

$$V = \sum_{i=1}^{n} W_i V_i (X_i)$$

- DECISION THEORY HAS A HISTORY OF SUCCESSFUL APPLICATION TO MAKING TRADE-OFF DECISIONS IN STATIC ENVIRONMENTS.

DYNAMIC TRADE-OFF EVALUATION

- EXTENDS STATIC TECHNIQUES FOR USE IN REAL-TIME ENVIRONMENTS
- USES DOMAIN KNOWLEDGE TO
  - DYNAMICALLY RE-WEIGHT THE EVALUATION CRITERIA TO REFLECT THE DYNAMICS OF THE EXTERNAL ENVIRONMENT.
  - REDEFINE COURSES OF ACTION AS DICTATED BY THE EXTERNAL ENVIRONMENT.
- HAS BEEN APPLIED TO EVALUATING THE TRADE-OFF BETWEEN THE AMOUNT OF INPUT DATA AND THE TIMELINESS OF THE OUTPUT.

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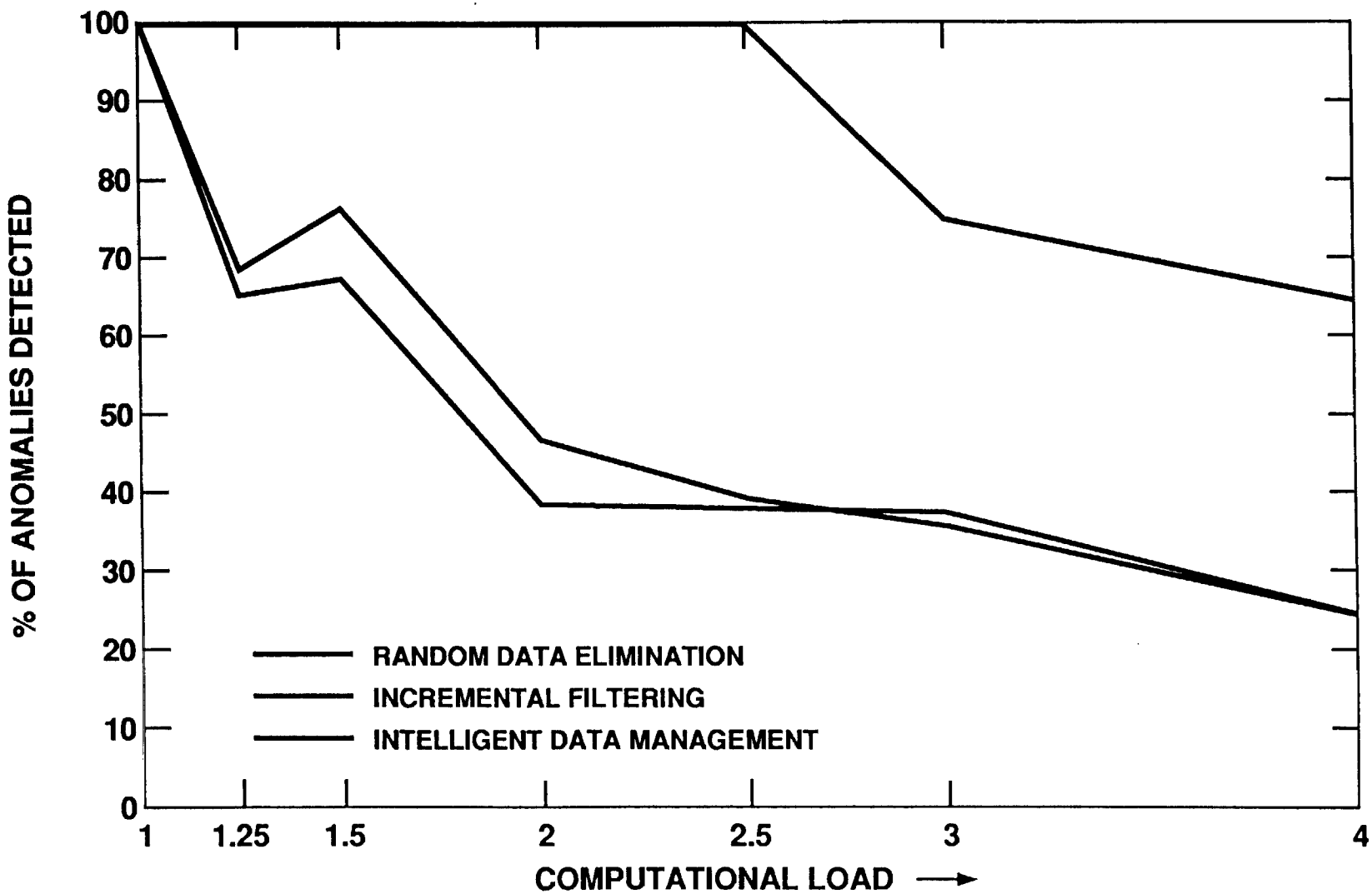
EVALUATION OF ANOMALY DETECTION RESULTS

3% ANOMALY DENSITY



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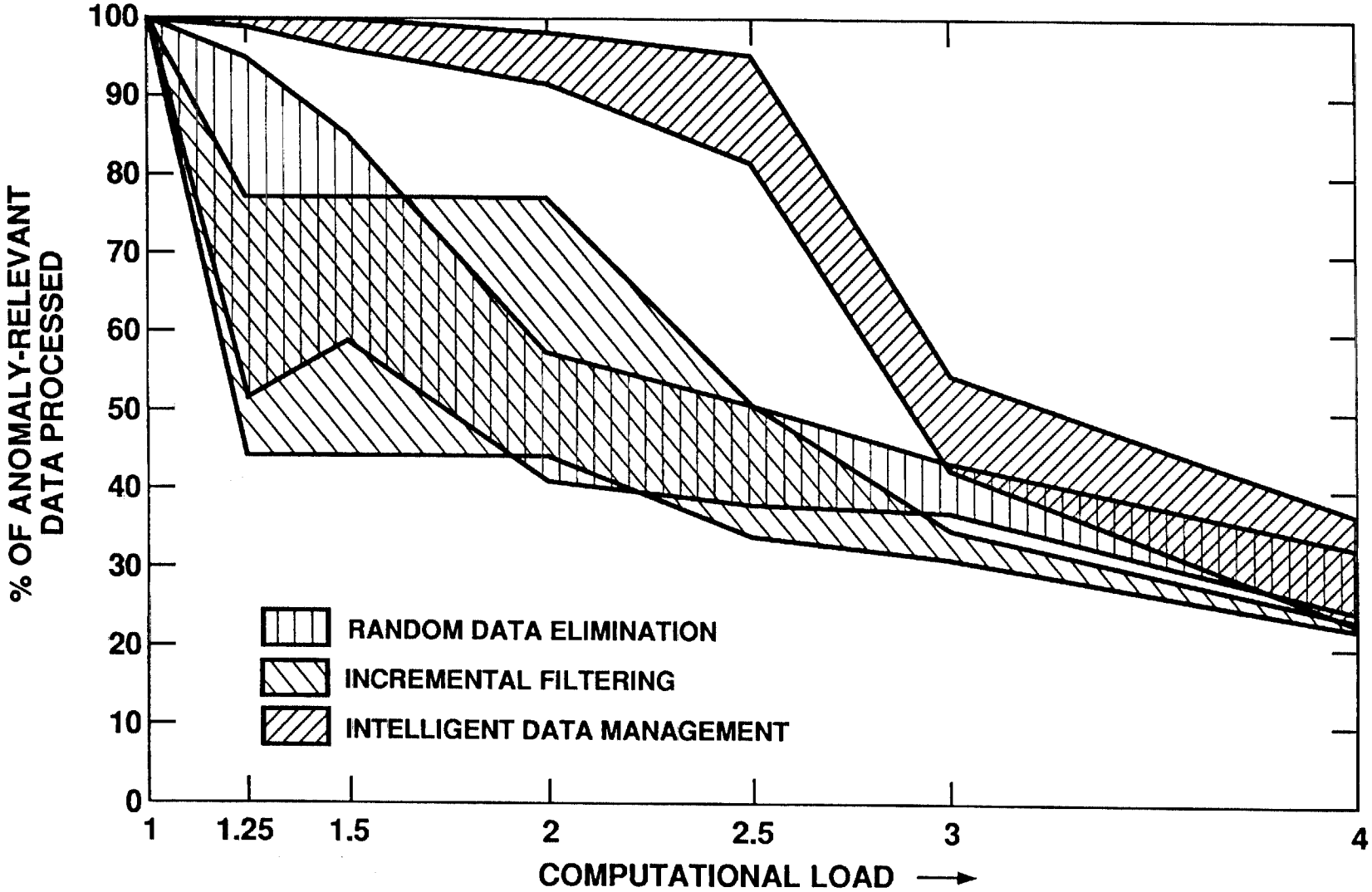
EVALUATION OF DATA MANAGEMENT METHODS

3% ANOMALY DENSITY



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SYSTEM-LEVEL ANALYSIS WITH COOPERATING EXPERT SYSTEMS

- CO-ORDINATION OF HIERARCHICAL EXPERT SYSTEMS
- COMBINATION OF DISTRIBUTED COMPUTING AND MULTIPLE USER-INTERFACES

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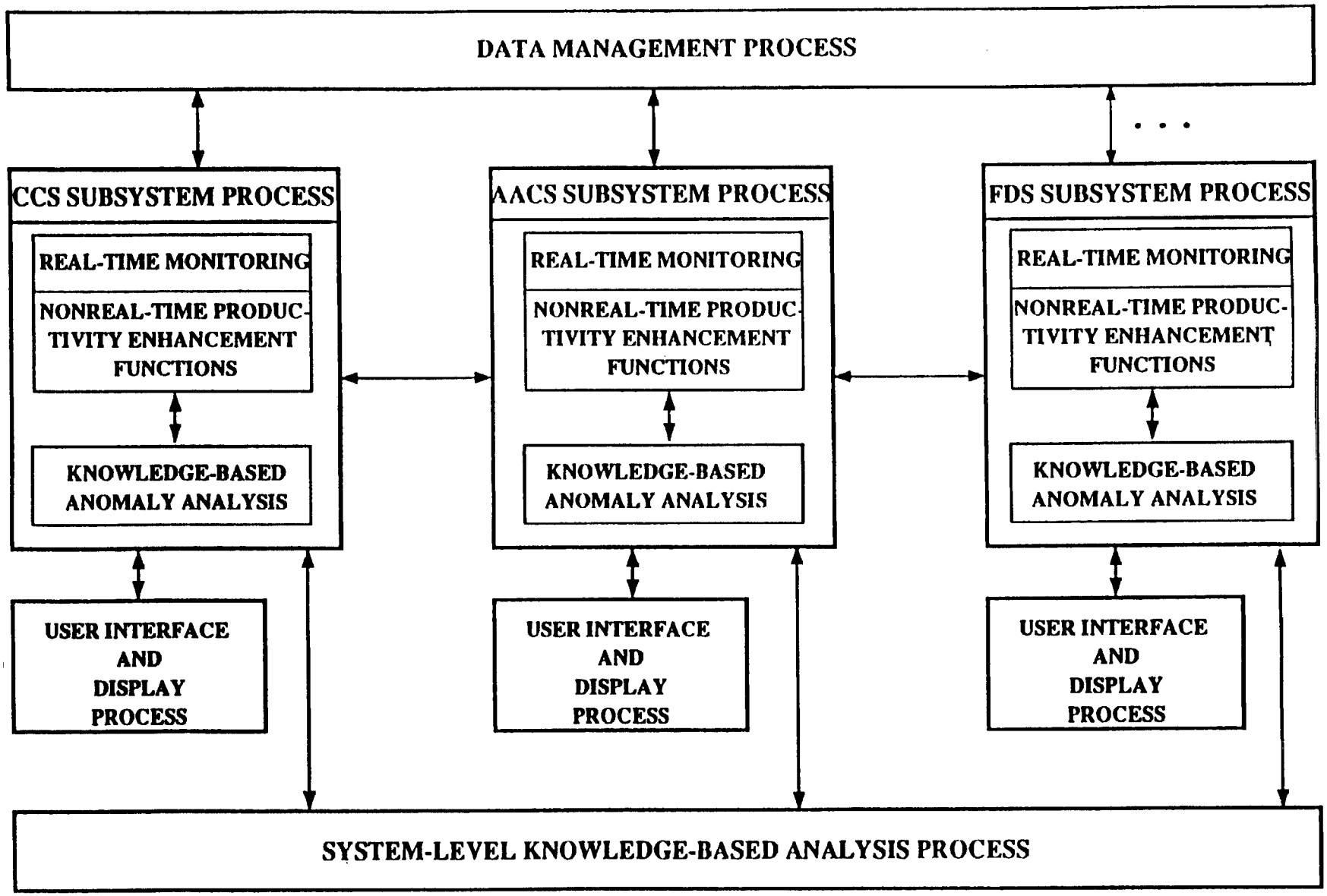
COOPERATING EXPERT SYSTEMS

- EVENT-DRIVEN INFORMATION EXCHANGE
- DEMONS AT SUBSYSTEM LEVEL RESPOND TO SUBSYSTEM ANOMALIES
- DOMAIN KNOWLEDGE AT SUBSYSTEM LEVEL IS USED TO DETERMINE WHICH SUBSYSTEM ANOMALIES HAVE POTENTIAL SYSTEM-LEVEL IMPACT
- SUBSYSTEM DEMONS SEND MESSAGES TO SYSTEM-LEVEL KNOWLEDGE BASE
- SYSTEM-LEVEL DEMONS COORDINATE SYSTEM-LEVEL ANALYSIS

MULTIPLE EXPERT SYSTEMS

DISTRIBUTED ARCHITECTURE



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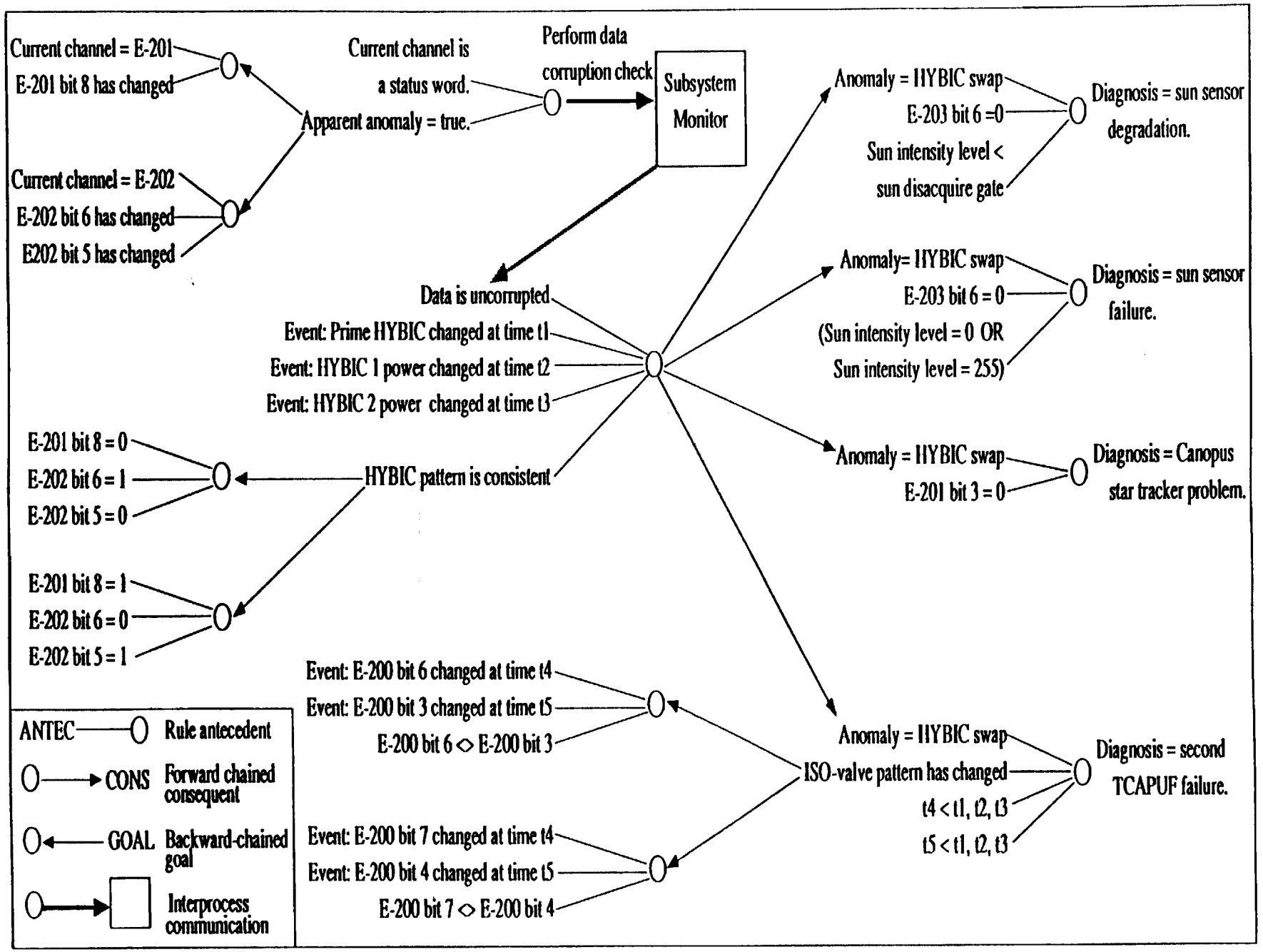
EVENT-DRIVEN RESPONSE

- DEMONS IN THE KNOWLEDGE BASE CONTROL REASONING
  - EVENT-DRIVEN RESPONSE TO ANOMALY CONDITIONS
  - INSTANTIATION OF APPROPRIATE RESPONSE PLANS
- DEMONS ARE ACTIVATED BY THE APPEARANCE OF ANOMALOUS DATA
  - TELEMETRY
  - INFERRED KNOWLEDGE FROM BACKWARD CHAINING
  - OTHER DEMONS
- BACKWARD-CHAINED PRODUCTION RULES PERFORM DIAGNOSIS
  - ANOMALY ANALYSIS
  - RECOMMENDATIONS FOR CORRECTIVE ACTION
- RULES ARE ACTIVATED BY DEMONS

EVENT-DRIVEN RESPONSE



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SUMMARY

- REAL-TIME, REAL-WORLD DEMONSTRATION OF SIGNIFICANT ARTIFICIAL INTELLIGENCE CAPABILITIES
  - INTELLIGENT DATA MANAGEMENT
  - EVENT-DRIVEN COORDINATION OF KNOWLEDGE-BASED DIAGNOSTICS
  - APPROPRIATE RESPONSE TO UNCERTAIN DATA
  - MULTIPLE EXPERT SYSTEMS
- SUCCESSFUL INTEGRATION OF ARTIFICIAL INTELLIGENCE AND CONVENTIONAL AUTOMATION HAS ACHIEVED
  - FULLY-AUTOMATED, REAL-TIME MONITORING AND DIAGNOSIS
  - RECOMMENDATIONS FOR CORRECTIVE ACTION
  - PRODUCTIVITY ENHANCEMENT TOOLS
- DEMONSTRATION OF WORKFORCE REDUCTIONS AND IMPROVED PERFORMANCE

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