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SHARP:

SPACECRAFT HEALTH AUTOMATED REASONING PROTOTYPE

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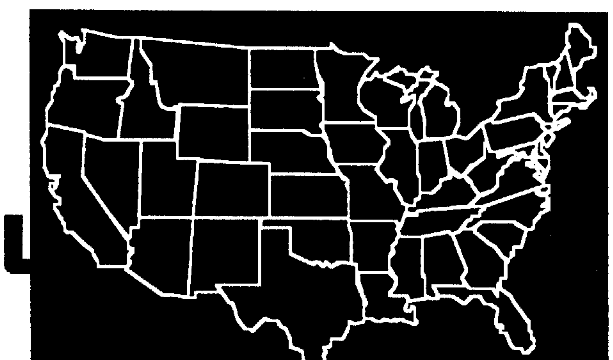

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OUTLINE

- BACKGROUND
- SHARP DESCRIPTION
- APPLICATIONS
- FUTURE DIRECTIONS
- BENEFITS, LESSONS LEARNED, CONCLUSIONS

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BACKGROUND

- PLANETARY SPACECRAFT MISSION OPS
- KNOWLEDGE SYSTEMS
- SHARP DEVELOPMENT TASK
- VOYAGER TELECOM LINK ANALYSIS

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PLANETARY SPACECRAFT MISSION OPS

- AGGRESSIVE PLANETARY EXPLORATION IN 1990's
  - MAGELLAN, GALILEO, ULYSSES, MARS OBSERVER, VOYAGER, CRAF, CASSINI
  - POSSIBLE LUNAR AND MARS SPACECRAFT
  - ALL WILL BE FLYING AT THE SAME TIME
  - VOYAGER ALONE REQUIRED ABOUT 40 REAL-TIME OPERATORS AT ALL TIMES

- LARGE GROWTH IN MISSION OPERATIONS WORKFORCE, OPERATIONS COMPLEXITY... COSTS FORESEEN

- PROGRAM TO UPGRADE OPERATIONS INFORMATION SYSTEMS UNDERTAKEN: SPACE FLIGHT OPERATIONS CENTER, ONE MULTI-MISSION SPACE FLIGHT OPS TEAM

- GOALS: SUBSTANTIAL AUTOMATION, REDUCE WORKFORCE AND COST TO OPERATE, IMPROVE SAFETY, RELIABILITY, AND PRODUCTIVITY

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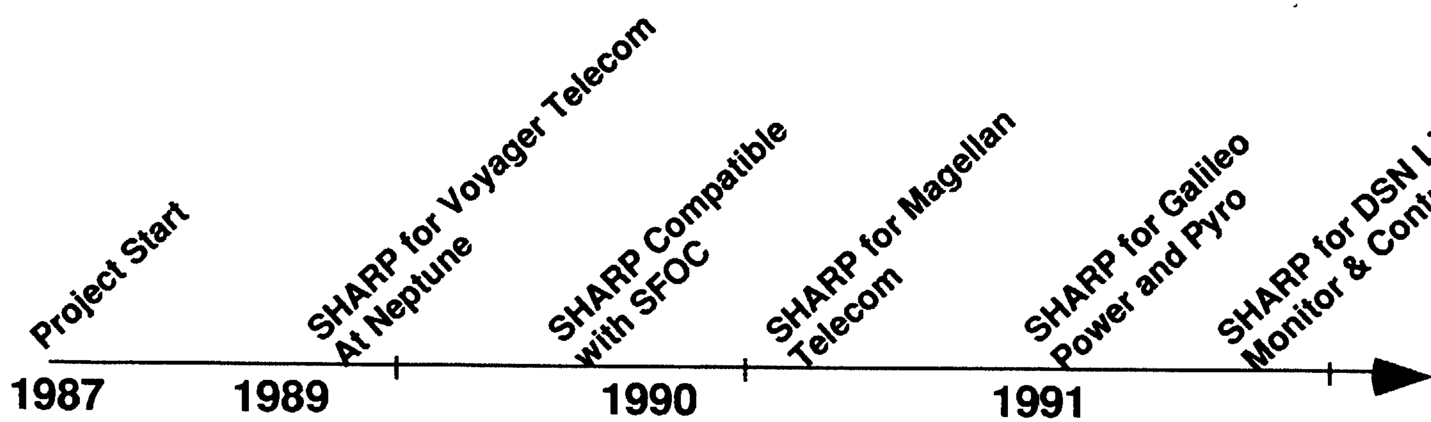
SHARP TASK BACKGROUND

- "PROOF OF CAPABILITY" DEMONSTRATION TO EVALUATE BENEFITS OF AUTOMATION
  - PRODUCTIVITY OF MISSION OPERATIONS REAL-TIME ANALYSIS
  - SAFETY OF SPACECRAFT
  - RELIABILITY OF GROUND DATA SYSTEMS
- METHODOLOGY: ITERATIVE PROTOTYPING AND SPIRAL MODEL SOFTWARE DEVELOPMENT
- FIRST APPLICATION: VOYAGER TELECOMMUNICATIONS

SHARP PROGRESS



Evaluation Prototype	Reusable Kernel	Pilot Installation	*Underway*
Shallow Diagnosis	Constraint Based Diagnosis	Deeper Telecom Diagnosis	
30 Sec. to Diagnose	1.5 Sec. to Diagnose	"Anytime" Diagnosis	
Max ~ 100 RT Channels	Max ~ 10K RT Channels	Capacity to Spare	
LISP Machine	Sun and SFOC Compatible	Installed in Magellan Ops	

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TELECOMMUNICATIONS OPERATIONS

- TELECOMMUNICATIONS LINK ANALYSIS:
  - MONITORING THE HEALTH AND STATUS OF THE TELECOMMUNICATIONS LINK BETWEEN THE SPACECRAFT, DEEP SPACE NETWORK, AND GROUND DATA SYSTEM COMPUTERS AT JPL

- MAJOR FUNCTIONS:
  - NUMERICAL ESTIMATION OF SYSTEM PEFORMANCE
  - MONITORING OF REAL-TIME ACTIVITY AND DETECTION OF FAILURES
  - DIAGNOSIS, ISOLATION, AND RECOVERY FROM FAILURES

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TELECOMMUNICATIONS OPERATIONS

- CHARACTERISTICS:
  - MANUAL CALCULATIONS TO UPDATE & REVISE NUMERICAL PREDICTS
  - FREQUENTLY CHANGING HARDCOPY SEQUENCE OF EVENTS INFORMATION
  - MANUAL, LABORIOUS DETERMINATION OF ALARM LIMITS
  - VERY LIMITED COMPUTER DISPLAYS OF STATUS INFORMATION
  - ALL ALARM SITUATIONS ARE REFERRED TO EXPERT
  - TELECOM IS SUBJECT TO NUMEROUS ALARMS DAILY

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SHARP DESCRIPTION

- **FUNCTIONAL CAPABILITIES**
  - MONITORING
  - DIAGNOSIS AND RECOVERY
  - DISPLAY AND USER INTERFACE
  - OTHER
- **TECHNOLOGY**
  - ROLE OF ARTIFICIAL INTELLIGENCE
  - EXAMPLE: ANOMALY DETECTION AND DIAGNOSIS
- **APPLICATIONS PERFORMANCE**

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FUNCTIONAL CAPABILITIES

- FUNCTION OF THE SYSTEM: PROVIDE COMPUTER WORKSTATION SUPPORT FOR REAL-TIME SPACECRAFT SUBSYSTEM ANALYSTS

- CAPABILITIES INCLUDE:
  - REAL-TIME ANOMALY DETECTION, ANALYSIS AND DIAGNOSIS
  - DISPLAY MANAGEMENT, DATA VISUALIZATION AND SYSTEM STATUS
  - ACQUISITION AND CENTRALIZATION OF ENGINEERING DATA FOR ANALYSIS
  - INTEGRATION OF AI-BASED MONITORING AND DIAGNOSIS FUNCTIONS WITH CONVENTIONAL NUMERICAL ANALYSIS SOFTWARE

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MONITORING

- CHANNELIZED DATA ON SERIAL OR NETWORK CONNECTIONS
- REAL-TIME PERFORMANCE WITH UP TO 10,000 CHANNELS EACH UPDATING 1/SEC
- AUTOMATED, CONTEXT SENSITIVE, ALARM LIMIT SELECTION
- DYNAMIC, DERIVED CHANNEL MONITORING
- EVENT SIGNATURE AND TREND MONITORING

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DIAGNOSIS AND RECOVERY

- EXPLICIT CAPTURE OF EXPERT DIAGNOSTIC AND RECOVERY RULES AND PROCEDURES
- DOMAIN INDEPENDENT DIAGNOSTIC SHELL WITH DOMAIN-SPECIFIC DIAGNOSTIC KNOWLEDGE
- "ANYTIME" DIAGNOSIS -- REAL-TIME ANALYSIS USING BEST, TIME-SYNCHRONIZED DATA AVAILABLE
- DYNAMICALLY GENERATED HEALTH AND DIAGNOSTIC SUMMARIES OF SPACECRAFT SUBSYSTEMS
- RANKING OF UNCERTAIN HYPOTHESES FOR OPERATOR

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DISPLAY AND USER INTERFACE

- SYSTEM STATUS DISPLAYS FROM MULTIPLE DATA SOURCES
  - REAL-TIME STATUS
  - PERFORMANCE OVER TIME
- GRAPHICAL VISUALIZATION AND DATA PLOTTING
- MIXED-INITIATIVE -- SYSTEM AND USER BOTH CONTROL THE DISPLAY
  - DISPLAY MANAGEMENT USING CONTEXT SENSITIVE MODELING OF FORMAT, CONTENT, SOURCE, AND RATIONALE
- DYNAMICALLY GENERATED USER HELP AND INPUT ERROR TOLERANCE

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OTHER CAPABILITIES

- REAL TIME DATA CACHE AND ON-LINE HISTORICAL DATABASE
- EDITABLE ALARM PARAMETER AND EVENT DATABASES
- MONITORING AND DIAGNOSTIC CAPABILITIES EASILY INTEGRATED WITH CONVENTIONAL ANALYSIS ROUTINES (E.G., FAST FOURIER TRANSFORM)
- INTEGRATED WITH SPACE FLIGHT OPERATIONS CENTER (SFOC) DATA SERVICES

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ROLE OF AI

- ARTIFICIAL INTELLIGENCE USED THROUGHOUT SHARP

- EXAMPLES:

  ARCHITECTURE: MULTI-PROCESS BLACKBOARD WITH OPPORTUNISTIC, DATA-DRIVEN CONTROL STRUCTURE

  DATA HANDLING: HEURISTIC ADAPTIVE PARSING, TEMPORAL REASONING DECLARATIVE DATA REPRESENTATIONS

  MONITORING: STATE MODELLING, DISCRIMINATION NETWORKS, TRUTH MAINTENANCE

  DIAGNOSIS: HIERARCHICAL COMMUNICATING EXPERTS, REASONING IN MULTIPLE CONTEXTS

  USER INTERFACE: RULE-BASED EXPERT SYSTEM TO MANAGE DISPLAYS, RULE-BASED DIAGNOSIS AND RECOVERY FROM INPUT ERRORS

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ANOMALY DETECTION & DIAGNOSIS

- HIERARCHICAL SYSTEM BASED ON CLASSIFICATION PROCESS

- ALARM EXECUTIVE DETERMINES EXISTENCE OF ANOMALY BY COMPARING EXPECTED AND ACTUAL SPACECRAFT STATES
  - USE OF COMPILED DISCRIMINATION NETWORK TECHNIQUES
  - SOME FAILURES ARE UNIQUELY DETERMINED AT THIS STAGE

- FAULT CLASSIFICATION SUBSYSTEM
  - MAKES INITIAL CHARACTERIZATION OF THE PROBLEM
  - IDENTIFIES RELEVANT SOURCES OF DATA FOR USE IN DIAGNOSIS
  - APPROX. 60 RULES FOR VOYAGER TELECOM APPLICATION
  - POSTS INITIAL HYPOTHESES, DATA VALUES, SPACECRAFT STATE, OTHER INFO TO DIAGNOSTIC DATABASE

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ANOMALY DETECTION & DIAGNOSIS

- SPECIALIZED "MINI-EXPERTS" FOR FAULT CLASSES
  - TRIGGERED BY FAULT HYPOTHESES TO REACH DETAILED DIAGNOSIS AND RECOVERY RECOMMENDATIONS
  - PURSUE INDIVIDUAL CLASSES OF FAULTS (E.G., CONFIGURATION ERRORS) USING SPECIALIZED KNOWLEDGE IN THE FORM OF PROCEDURAL NETWORKS
  - OPERATE INDEPENDENTLY IN INDIVIDUAL CONTEXT TREES

- BLACKBOARD USED TO COMMUNICATE AND SHARE RESULTS

- HYPOTHESIS COMBINATION SUBSYSTEM
  - GROUPS RELATED CONCLUSIONS AND RECOMMENDATIONS TO OPERATOR, LOGS DATA, AND SIGNALS MODIFICATIONS TO OPERATOR'S DISPLAYS

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APPLICATIONS PERFORMANCE

- ANOMALY DETECTION AND DIAGNOSIS
  - ABLE TO ANALYZE 39 CLASSES OF TELECOM PROBLEMS
  - 60 UNIQUE PROBLEM SOLVING DIAGNOSES
  - 20 ADDITIONAL DETECTABLE PROBLEMS
  - ABOUT 15 PROBLEMS ARE NOT COVERED
  - TOTAL FAULT COVERAGE IS ABOUT 80% AND IMPROVING AS KNOWLEDGE BASES ARE EXTENDED
- CONSCAN (ANTENNA POINTING) ERRORS DETECTED AND TRACKED BY SHARP UNTIL RESOLVED BY DSS OPERATORS
- (NON-CRITICAL) ANOMALIES DIAGNOSED BY SHARP
  - OPERATORS MANUALLY VERIFY THE DIAGNOSES
  - RCV AGC, S-BAND TWT BASE TEMP OCCURRED DURING VOYAGER ENCOUNTER

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VOYAGER ENCOUNTER SURPRISING EVENT

- RESOLVED VOYAGER SCIENCE DATA ERROR COMPLAINT PRIOR TO THE ENCOUNTER, AVOIDING A POTENTIAL CRITICAL SITUATION
  - SCIENCE PERSONNEL SAID CORRECTION COUNT WAS TOO HIGH
  - SHARP DETECTED AND REPORTED A POSSIBLE EXCESSIVE NOISE PROBLEM
- TELECOM PERSONNEL USED SHARP SCATTER PLOT OF BIT ERROR RATE VERSUS SYMBOL SIGNAL TO NOISE RATIO
  - CONFIRMED AN ANOMALOUS CONDITION WHICH WAS CORRUPTING THE SCIENCE DATA AT HIGH SSNR'S WHERE NO ERRORS ARE EXPECTED
  - DEFINED MAGNITUDE OF PROBLEM
  - PROVIDED ABILITY TO SHOW NO CORRELATION OF ERRORS WITH DSN STATIONS
- FURTHER INVESTIGATION TRACED PROBLEM TO A FAILED WIDE-BAND INTERFACE UNIT IN VGR DACS
  - SHARP USED TO CONFIRM PROBLEM RESOLUTION AFTER THE FAILED UNIT WAS REPLACED

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DSN EXTENSIBLE GROUND ANALYSIS SYSTEM

- BACKGROUND
  - PLANNED FOR THE DSN'S NETWORK OPERATIONS CONTROL CENTER, WHICH MONITORS QUALITY OF NETWORK DATA AND STATUS OF ALL DSN SYSTEMS
- DSN EXTENSIBLE GROUND ANALYSIS SYSTEM (DEGAS)
  - SHARP-BASED ENHANCEMENT TO THE NOCC OPERATOR WORKSTATION
- KEY CHARACTERISTICS
  - VISUALIZATION OF CENTRAL NETWORK STATUS
  - RAPID ANOMALY DETECTION, DIAGNOSIS, AND RECOVERY.
  - EXTENSIBLE WITH EXTERNALLY DEVELOPED ANALYSIS MODULES.
- BENEFITS EXPECTED BY DSN
  - REDUCTION OF LARGE AMOUNTS OF DATA FOR PRESENTATION TO NOCT
  - ENABLE TIME-CRITICAL RESPONSE TO ANOMALIES
  - ASSIST IN OFF-LINE DIAGNOSIS, CALIBRATION, AND SYSTEM READINESS

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DSN LINK MONITOR AND CONTROL OPERATOR ASSISTANT

- **BACKGROUND**
  - LMC OPERATORS AT DSN STATIONS CONFIGURE, CALIBRATE, AND CONTROL THE STATIONS ANTENNAS AND SUBSYSTEMS TO TRACK SPACECRAFT.
  - "PRE-CAL" OPERATIONS TAKE 45 MINUTES TO 4 HOURS TO COMPLETE

- **LMC OPERATOR ASSISTANT**
  - GOAL OF 30% REDUCTION IN TIME SPENT DURING PRE-CAL OPERATIONS
  - AUTOMATIC "DUAL CONTROL MODE", WHERE SINGLE OPERATOR CONFIGURES AND SYNCHRONIZES MULTIPLE ANTENNAS AND SUBSYSTEMS
  - AUTOMATIC PRE-CAL DIRECTIVE PLANNING AND PARAMETER SELECTION TO SHOW FEASIBILITY OF AUTOMATED CONTROL OF DSN STATION WITH OPERATOR ACKNOWLEDGEMENT.
    - => BUT NO REAL DIRECTIVES FROM PROTOTYPE TO ACTUAL DSN SUBSYSTEMS
  - LAB DEMO IN 1991 FOLLOWED BY INSTALLATION AT GOLDSTONE DSS-13 FACILITY IN 1992

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CONCLUSIONS

- BENEFITS PROJECTED BY TELECOMMUNICATIONS USERS
- LESSONS LEARNED
- CONCLUSION

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BENEFITS PROJECTED BY TELECOM USERS

• WORKFORCE SAVINGS	ULTIMATE REDUCTION IN REAL TIME LINK ANALYSIS STAFF BY A FACTOR OF FIVE. SIMILAR SAVINGS MAY BE POSSIBLE IN OTHER AREAS.
• SAFETY	REAL-TIME SYSTEM CAN DETECT AND ANALYZE PROBLEMS IN SECONDS THAT TAKE HUMANS HOURS, E.G., ANTENNA POINTING ERRORS
• RELIABILITY	SYSTEM WIDE STATUS MONITORING HELPS ASSURE CORRECT SYSTEM CONFIGURATION, REDUCES COMMANDING ERRORS, AND REDUCES LOSS OF DATA
• PRODUCTIVITY	REDUCED NUMBER OF OPERATIONS PERSONNEL CAN MONITOR A GREATER NUMBER OF SYSTEMS AND PERFORM REQUIRED ANALYSES MORE EFFICIENTLY

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LESSONS LEARNED

- ENTHUSIASTIC PARTICIPATION OF END-USERS AND EXPERTS IS REQUIRED.
  - ENSURES ACCESS TO DOMAIN KNOWLEDGE AND FUTURE OPERABILITY.
  - PROVING "VALUE-ADDED" BY AUTOMATION IS DIFFICULT FOR TECHNOLOGISTS.
- PRACTICAL AUTOMATION USING AI REQUIRES EVOLUTION AND INTEGRATION WITH EXISTING SYSTEMS.
  - CONSTRAINTS OF EXISTING SYSTEMS LIMIT THE SCOPE OF THE AI APPLICATION.
- AI CANNOT BE APPLIED INDEPENDENTLY FROM OTHER TECHNOLOGIES (E.G., NETWORKING, GRAPHICS)
  - GOOD SYSTEM ENGINEERING IS WHAT MAKES A KNOWLEDGE SYSTEM.
- MAKE PRAGMATIC SELECTION OF MATURE AI TECHNIQUES
  - SUFFICIENT TOOLS ARE AVAILABLE BUT SKILLED DEVELOPERS ARE REQUIRED

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CONCLUSIONS

- ARTIFICIAL INTELLIGENCE HAS A PROVEN CAPABILITY TO DELIVER USEFUL FUNCTIONS IN A REAL-TIME SPACE FLIGHT OPERATIONS ENVIRONMENT

- SHARP HAS PRECIPITATED MAJOR CHANGE IN ACCEPTANCE OF AUTOMATION AT JPL -- AI IS HERE TO STAY

- POTENTIAL PAYOFF FROM AUTOMATION USING AI IS SUBSTANTIAL

- SHARP, AND OTHER ARTIFICIAL INTELLIGENCE TECHNOLOGY IS BEING TRANSFERRED INTO SYSTEMS IN DEVELOPMENT
  - MISSION OPERATIONS AUTOMATION
  - SCIENCE DATA SYSTEMS
  - INFRASTRUCTURE APPLICATIONS

INTENTIONALLY