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KNOWLEDGE REPRESENTATION IN SPACE FLIGHT OPERATIONS

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In space flight operations rapid understanding of the state of the space vehicle is essential. Representation of knowledge depicting space vehicle status in a dynamic environment presents a difficult challenge. Space flight operations personnel must work rapidly integrating personal experience with knowledge representation provided by real-time data driven displays. Traditional methods have presented only an incomplete summation of limited system and subsystem information.

New avenues of graphics technology have provided a means for rapid display of complex knowledge and detailed parametric interrelationships. The use of large high resolution displays coupled with fast display update rates, on-screen command menu selection, as well as the inclusion of computer graphics and color oriented knowledge representation and intelligent screen formatting have allowed a rapid transition from information representation to human response.

The NASA Jet Propulsion Laboratory has pursued areas of technology associated with the advancement of spacecraft operations environment. This has led to the development of several advanced mission systems which incorporate enhanced graphics capabilities.
These systems include:

1) Spacecraft Health Automated Reasoning Prototype (SHARP),
2) Spacecraft Monitoring Environment (SME),
3) Electrical Power Data Monitor (EPDM),
4) Generic Payload Operations Control Center (GPOCC), and
5) Telemetry System Monitor Prototype (TSM).

Knowledge representation in these systems provides a direct representation of the intrinsic images associated with the instrument and satellite telemetry and telecommunications systems. The man-machine interface includes easily interpreted contextual graphic displays. These interactive video displays contain multiple display screens with pop-up windows and intelligent, high resolution graphics linked through context and mouse-sensitive icons and text.

INTRODUCTION

The Jet Propulsion Laboratory is a lead center for NASA's planetary exploration and earth science program. In support of this role JPL has pursued areas of technology associated with the advancement of the spacecraft operations environment.

The space flight operations environment presents large volumes of rapidly changing and complex information to flight control personnel. Rapid comprehension of spacecraft and ground support systems conditions are essential in flight operations. Representing complex knowledge is a difficult challenge because it requires operations personnel to integrate on-screen representation with past cognitive experience to often make demanding instantaneous decisions.

The Institutional Computing and Mission Operations Division (37) of the JPL provides the flight control and data management teams, which have supported NASA space mission from Explorer 1, to the Viking spacecraft landing on Mars and the Voyager mission to the outer rim of the solar system and beyond.

The Division's concentration of on technology in the mission operations domain has centered on the use of enhanced graphics in support of spacecraft and related ground system command and control functions. Enhanced graphics capability in the mission environment is significant for three reasons. First, carefully presented high level knowledge representation reduces the workload of operations personnel. Second, computer-based graphics tools [Schneiderman 1987] improve accuracy of data processing and assist space flight control personnel in monitoring spacecraft and mission sensors where operating data rates may greatly exceed the ability of individuals to monitor successfully. And third, as the number of missions increases, the number of trained and experienced flight support personnel cannot keep up with the extreme demands caused by information overload. Graphic aids and on-screen operator assistance allow for productivity enhancement and maintaining the required level of flight support. [Hansen 1988]

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Systems knowledge can be represented be via easily visualized contextual graphic displays [Park 1985]. These interactive video displays provide a direct representation of the intrinsic images associated with instrument and satellite telemetry and telecommunications systems. Multiple display screens with pop-up windows and high resolution graphics are linked throughgh context and mouse-sensitive icons and text.

In order to optimize JPL's mission operations environment, the Space Flight Operations Section (371) and the Project Test and Operations Section (374) have developed unique methods of knowledge

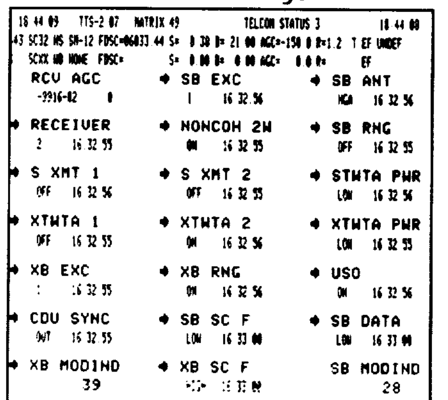

Figure 1 Typical Alphanumeric Spacecraft Telecommunications Display

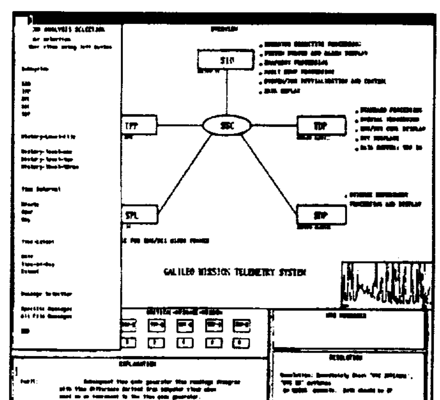

Figure 2 TSM GRAPHIC REPRESENTATION

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representation. Mission operations needs have included on-screen display of data since the days of Explorer I. These original capabilities have slowly evolved as have the machines driving them. These capabilities, evolved in the present realm of graphics capability, include primarily alphanumerical paged displays, such as seen in Figure 1, which have been standardized since the Viking Mars landing and the launch of the Voyager spacecraft. Arrows in the display indicate the latest telemetry data channels updated. These traditional displays have met needs of space flight operationss because of relatively large mission operations staffs and relatively low spacecraft data rates. As the number of Flight Operations personnel are reduced and mission operations are streamlined due to budgetary and other considerations, existing personnel and support systems must function at peak capacity. The Institutional Computing and Mission Operations Division (37) is attempting to satisfy mission operations requirements of the future by employing the latest available graphics technology to provide knowledge representation as an aid to flight operations. A display reflecting increased use of visualization techniques can be seen in Figure 2. A key element in flight operations is the need to adequately represent knowledge concerning states and events. The graphics requirements needed to satisfy these needs consist of unique representational goals.

Specifically included as the primary knowledge representation goals in the design of graphics tools shown in table I.

Table I.

1. Realtime display of large volumes of diverse information
2. Rapid presentation of complex interrelated information
3. Color categorization of interrelated and multiple related data fields
4. Instantaneous display and detection of changes
5. Promote visualization by decomposition of data into structures and control flows diagrams
6. Enhanced interpretation of information
7. Graphical representation of knowledge states

The Institutional Computing and Mission Operations Division has attempted to utilize advances in display technology to advance the spacecraft operations environment. This work has led to development of innovative mission systems which incorporate enhanced graphics capabilities to assist in flight operations visualization.

This effort has led to development of graphics systems which provide improved representation of system knowledge which improves the JPL spacecraft and instrument command and control process. Because of the large screen space graphic representations require these systems mix graphics with textual representation. The flight support system mentioned incorporate several factors in common which aid in knowledge representation and effective visualization of intelligence. Knowledge representation in flight control systems require, as a minimum, the capabilities shown in table II.

Table II.

1.	Large high resolution displays
2.	High level windowing capability
3.	On-screen pull-down command menu selection
4.	Color oriented knowledge representation
5.	Rapid transition from informational representation to user response

Five flight support systems have been developed which provide examples of knowledge representation through data visualization made possible by graphics technology. These systems are:

1) Spacecraft Health Automated Reasoning Prototype (SHARP),
2) Spacecraft Monitoring Environment (SME),
3) Electrical Power Data Monitor (EPDM), and
4) Generic Payload Operations Control Center (GPOCC), and
5) Telemetry System Monitor (TSM).

Spacecraft Health Automated Reasoning Prototype (SHARP)

The Spacecraft Health Automated Reasoning Prototype incorporates experience of the lead Voyager spacecraft telecommunications engineer into a usable knowledge base. The Space Flight Operations Section (371) has provided an independent standalone graphics capability for the prototype. These representational capabilities will be used in support of the Voyager spacecraft-'s upcoming Neptune Encounter. System know-ledge is represented in terms of annotated space and ground systems context diagrams. Displayed objects are icons and selectable via mouse or keyboard.

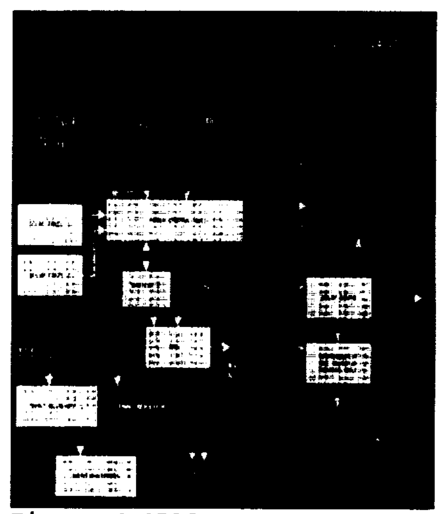

Figure 3 GRAPHICS DISPLAY FOR SHARP

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Spacecraft Monitoring Environment (SME)

The Spacecraft Monitoring Environment has been developed by the Project Test and Operations Section (374) and Aura Systems to aid in the Galileo spacecraft integration and test process. The SME provides a real time autonomous spacecraft test sequencing and data monitoring of integration and test activity. The SME provides high-level contextual graphic displays and windowing capability. Command success knowledge is presented by windowing of command issued with telemetry responses .

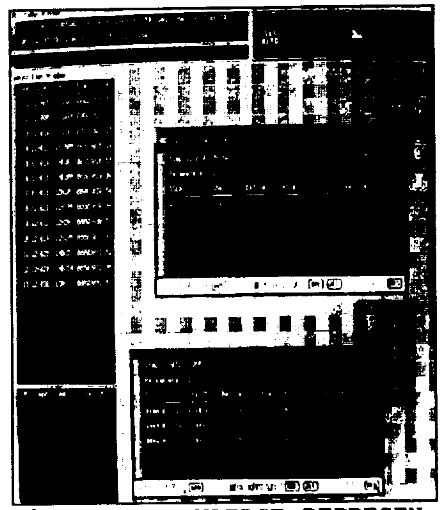

Figure 4 KNOWLEDGE REPRESENTATION IN AN SME TEXTUAL DISPLAY

Electrical Power Data Monitor (EPDM)

The Electrical Power Data Monitor is being developed by the Electrical Power Systems Section (342) and Aura Systems. The EPDM provides power system engineers with automated context diagrams representing power system knowledge [Bahrami 1987]. The EPDM will support the Voyager spacecraft during the up-coming Neptune Encounter. EPDM contextual representation power system knowledge is should in figure 5.

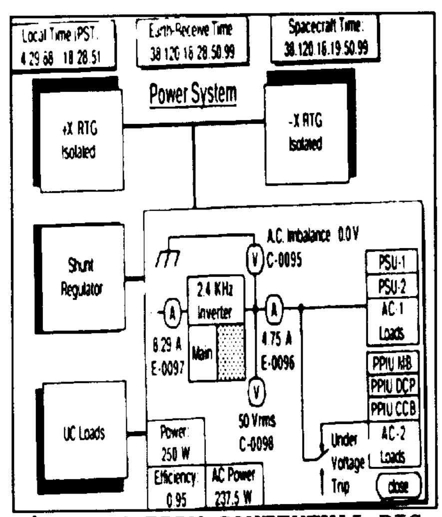

Figure 5 EPDM CONTEXTUAL DISPLAY

Generic Payload Operations Control Center (GPOCC)

The Generic Payload Operations Control Center is a conceptual prototype developed by the Project Test and Operations Section (374) and Aura Systems to apply automation and high level graphics capability to a mission operations environment. The GPOCC goal is to couple expert systems with high level contextual graphics to display to increase user comprehension [D-5435 1987]. A prototype was developed on an Apple MacIntosh II to demonstrate user interfaces and functionality of the GPOCC concept. An example of GPOCC contextual display representation is shown in figure 6.

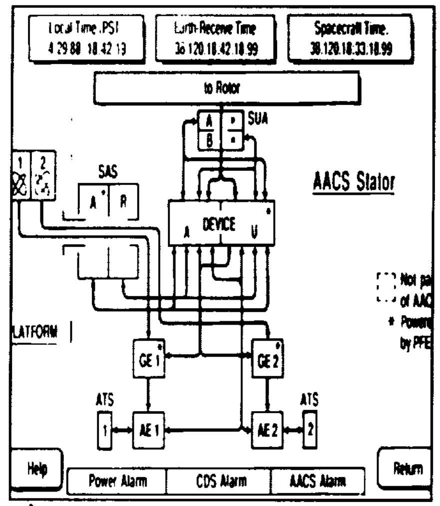

Figure 6 GPOCC CONTEXT DISPLAY

Telemetry System Monitor (TSM)

The Telemetry System Monitor (TMS) expert system, was developed by the Divisions Instrumentation Section (375). This system, using ART as expert system shell was developed on a Sun workstation. The TSM uses graphics capability to aid in rapid visualization of the health and display status of the Galileo Mission Ground processing system and display system fault cues [Mouneimne 1989-]. Knowledge relating the well-being of the telemetry system is contained in expert systems text messages. The graphic display pin-points faults area. An example of TSM representation is shown in fig--ure 2.

Knowledge Representation in Future Mission Operations

As spacecraft data rates increase (the Earth Observing System project 300 Mbps), and are support by extremely large and distributed ground data system the need to provide interpretive knowledge of systems status and configuration increases. Graphics visualization will continue to provide a significant means to accomplish knowledge representnation. Future considerations in knowledge representation are shown in table III.

Table III.

1.	Visual man-machine communication to replace alphanumeric communication.
2.	Inclusion of hyper-media (including voice synthesis in knowledge representation.
3.	Highly interactive display devices

SUMMARY

Knowledge representation in these systems provides a direct representation of the intrinsic images associated with satellite and ground support telecommunications systems. The man-machine interface includes easily interpreted contextual graphic displays. These interactive video displays contain multiple display screens with pop-up windows and intelligent, high resolution graphics linked through context and mouse-sensitive icons and text.

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