ANOMALOUS EVENT DIAGNOSIS FOR ENVIRONMENTAL SATELLITE SYSTEMS

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ABSTRACT

The National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) is responsible for the operation of the NOAA geostationary and polar orbiting satellites. NESDIS provides a wide array of operational meteorological and oceanographic products and services and operates various computer and communication systems on a 24-hour, seven days per week schedule.

The Anomaly Reporting System contains a database of anomalous events regarding the operations of the Geostationary Operational Environmental Satellite (GOES), communication, or computer systems that have degraded or caused the loss of GOES imagery. Data is currently entered manually via an automated query user interface. There are 21 possible symptoms (e.g., No Data), and 73 possible causes (e.g., Sectorizer - World Weather Building) of an anomalous event. The determination of an event's cause(s) is made by the on-duty computer operator, who enters the event in a paper-based daily log, and by the analyst entering the data into the reporting system. The determination of the event's cause(s) impacts both the operational status of these systems, and the performance evaluation of the on-site computer and communication operations contractor.

The Anomaly Reporting Expert Assistant System (AREAS) is an interactive, rule-based demonstration prototype using backward chaining goal-directed inference. Upon input of a new event's symptom, AREAS queries a database of prior events with associated symptoms and causes, and then suggests possible causes to the analyst. AREAS reasons with the archived events, a rule-based representation of the satellite, communication, and computer subsystem's physical relationships, heuristics acquired from resident domain experts, and a mean best fit of prior events with the new event. Whether the analyst confirms AREAS' suggested cause or enters a new one, the event, with its related attributes, is entered into the database and thus provides an up-to-date environment in which AREAS can operate. AREAS includes a help system designed to assist new users and it provides technical information, with graphical representation, on the GOES, communication and computer subsystems.

Key Words: Knowledge-Based System, Rule-Based, Backward Chaining, Goal-Directed Inference, Environmental Satellite Systems, Anomalous Event Diagnosis, Intelligent Database

INTRODUCTION

The National Environmental Satellite, Data, and Information Service (NESDIS) oversees the operation of civilian satellite systems used for Earth-observation, and the creation and maintenance of global databases in the physical and life sciences. NESDIS provides products and services derived from environmental data that are applied to the protection of people and property, national economic systems, and the development and distribution of food, energy and other natural resources on a national and international level.

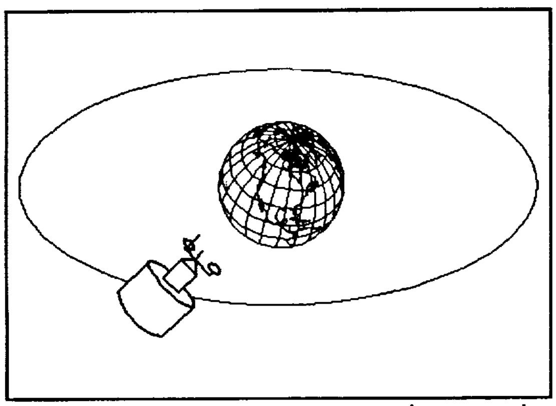

Figure 1 - GOES East in Orbit

NESDIS is responsible for the operation and maintenance of the Geostationary Operational Environmental Satellite (GOES), located at 112° West as shown in Figure 1 above, and the GOES Data Distribution System (GDDS). It is staffed with experienced meteorologists, oceanographers, computer specialists, and administrative personnel, as well as employees new to the environmental satellite domain. A contractor, PRC, Inc., provides communications and computer operations support for the GDDS.

Why Artificial Intelligence?

NESDIS determined to evaluate the potential of Artificial Intelligence (AI) tools and techniques in response to the challenge of sensing, communicating, processing, analyzing and distributing ever-increasing volumes of environmental data and products. This increase is due to the larger number of ground-based data collection systems, satellites in orbit with improved sensors, and additional data shared by other organizations, both public and private, in the United States and foreign nations.

OBJECTIVES

Four objectives were established for the development and demonstration of the Anomaly Reporting Expert Assistant System (AREAS) prototype. They were:

1. Develop a help system for anomaly reporting.
2. Increase personal knowledge of GDDS.
3. Retain valuable GDDS expertise.
4. Demonstrate the ability of AI to improve administrative and operational tasks.

CURRENT ANOMALY REPORTING SYSTEM

As a result of a computer generated error message or other indicator, a computer operator documents the problem in the paper-based Environmental Satellite Distribution/Interactive Processing Center (ESD/IPC)

Daily Log. At the conclusion of a shift, the shift supervisor synopsizes the Daily Log entries into multiple summary reports including the Operational Problem report. A combined hardcopy daily report, including the Daily Log and Operational Problem report, among others, is then distributed to management and staff. Each morning, contractor and NESDIS personnel meet for a short discussion of the most critical issues encountered in the previous 24 hours. On a daily basis a NESDIS staff member evaluates the Daily Log and Operational Problem report and enters appropriate information into the Anomaly Reporting System (ARS). The staff shares this task on a weekly, rotating basis.

The ARS queries the user for the following information:

Julian Date
Satellite
Zulu Time
Symptom(s)
Number Products Affected
Probable Cause(s)
Responsible Division
Number Expected
Number Actuals
Number External Lost

The 21 possible symptoms and 73 possible causes are available to the staff in hardcopy or in an on-line text file. For example:

```
SYMPTOM CODES
CODE #    ENTRY

01 ...... DATA EARLY
.
.
.
14 ...... NO DATA
.
.
.
21 ...... WRONG DATA
```

```
CAUSE CODES
CODE #    ENTRY

01 ...... AIR COND/HEATING
.
.
.
53 ...... SECTORIZER-WWB
.
.
.
73 ...... VIRGS
```

Accompanying the hardcopy symptom and cause list is a GDDS Diagram, part of which is shown in Figure 2. This diagram is not available on-line in the ARS.

The complete diagram (not shown here) outlines the flow and processing of data for the major communications and computer systems from the GOES spacecraft to NOAA's facilities at Wallops Island, Virginia, and Suitland and Camp Springs, Maryland. With this information, along with other available documents, assigned staff must evaluate the Daily Log and Operational Problem report and determine the cause of the anomalous event. After determination of the problem's cause and input of the data, a daily report is produced for dissemination.

ANOMALY REPORTING EXPERT ASSISTANT SYSTEM

1.0 Problem Identification

A loss of expertise was recently suffered due to the retirement and promotion of several employees. New employees needed access to the lost expertise in order to accurately determine the cause of anomalous events and prevent future occurrences, if possible. The current ARS has

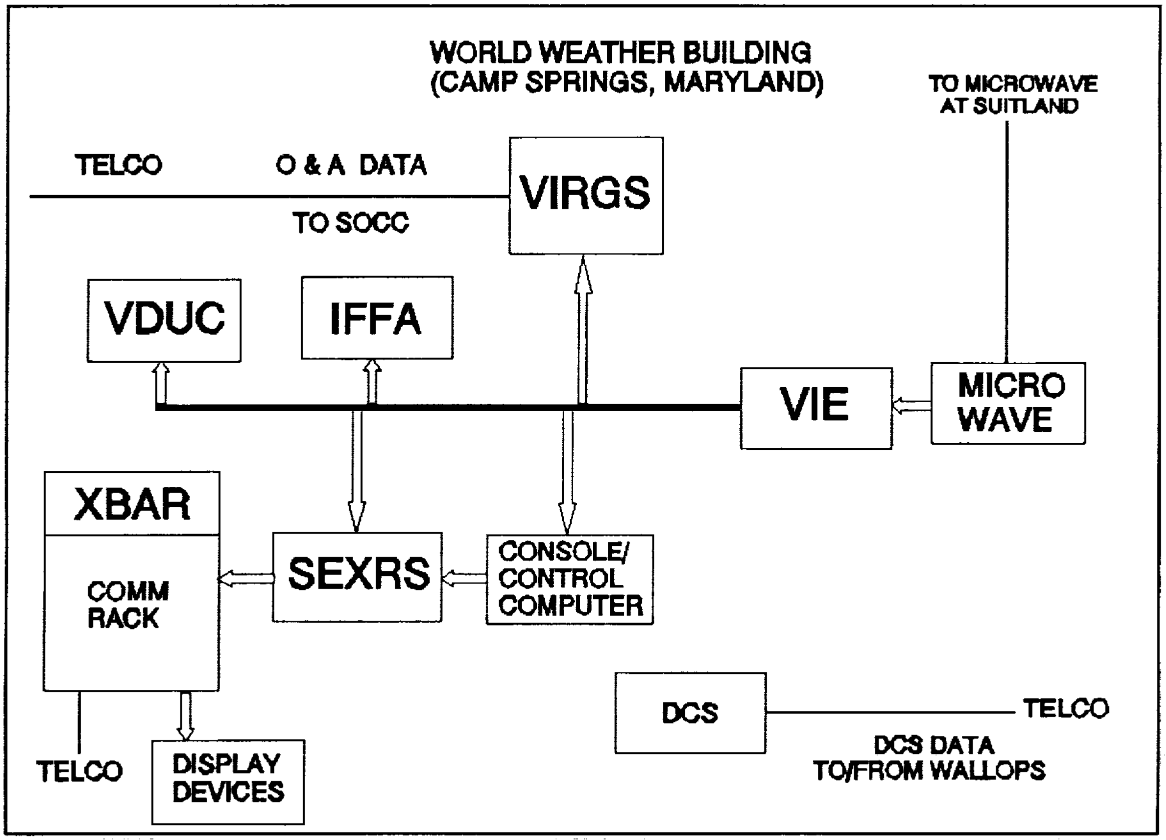

Figure 2 - GDDS Diagram: WWB

no help system and several of the new employees have limited knowledge of the GDDS.

2.0 Knowledge Acquisition

Domain knowledge was acquired through interviews with domain experts, one of whom has since retired. Extensive GDDS documentation, including the *GDDS Operations and Maintenance Contract*, was reviewed. In addition, the current Anomaly Reporting System, ESD/IPC Daily Logs and Operational Problem reports, Daily and Weekly ARS reports were also analyzed.

3.0 Analysis and Design

The analysis and selection of knowledge representation and the development tool along with the system design have been integrated within a single category. The intent is to emphasize the real world environment in which all three issues are frequently considered concurrently, especially during initial prototyping.

3.1 Knowledge Representation

Evaluation of the existing data indicated that an attribute/ value representation scheme combined with rule-based processing would be sufficient for initial prototype development. Since the current ARS uses a query/response interface it was decided to use backward chaining, goal directed inference to emulate the existing process.

3.2 Tool Selection

The criteria for tool selection, in addition to those identified above, were low cost, a simple development environment, and a short learning curve. The tool selected was Level5 Expert System Software (DOS Version 1.3) by Information Builders, Inc. This expert system shell fit the identified small system prototype requirements: a default query/response interface, symbolic representation used in an if/then rule-base environment, and the need to perform simple calculations.

3.3 System Design

The system design stressed modularity for ease of development, explanation, use, and maintenance. The shell's default user interface was employed for the selection of menu items and the input of numeric data. Individual knowledge base modules were used for each of the primary data items required for inferencing. The help system's customized graphic and narrative explanation screens were integrated through Level5's explanation function and separate knowledge base modules. The help system focused on the three major components of the GDDS: the satellite, data communications, and computer processing subsystems. A simple mean statistical analysis was provided through symptom specific knowledge base modules. This architecture is demonstrated in Figure 3., below.

4.0 Prototyping

Modularity was a key issue during the rapid prototyping of AREAS since the knowledge engineering process was being used as a learning tool for the GDDS environment. A large number of small, easily modified knowledge bases were initially prototyped to establish the relationship among various data elements, particularly between symptoms and causes, and to model the physical subsystems.

4.1 Knowledge Sources

4.1.1 Heuristic Knowledge

Heuristic knowledge was obtained from the domain experts through their explanation of Daily Log and Operational Problem report entries and GDDS processing. For example, the hardware element designation "RTIR" (i.e., RealTime InfraRed) is not specified in the sectorizer subsystem node of the Wallops version of the GDDS Diagram, but it was identified by one of the domain experts as important in distinguishing between sectorizers at the World Weather Building (WWB) and those at Wallops Island. This knowledge was then incorporated into the rule base of AREAS.

4.1.2 Documentation

A number of different documents were used as primary knowledge sources. *NESDIS Programs - NOAA Satellite Operations* identified the organization's mission and major systems used in carrying out that mission. The *GDDS Operations and Maintenance Contract* was indispensable in identifying subsystems and

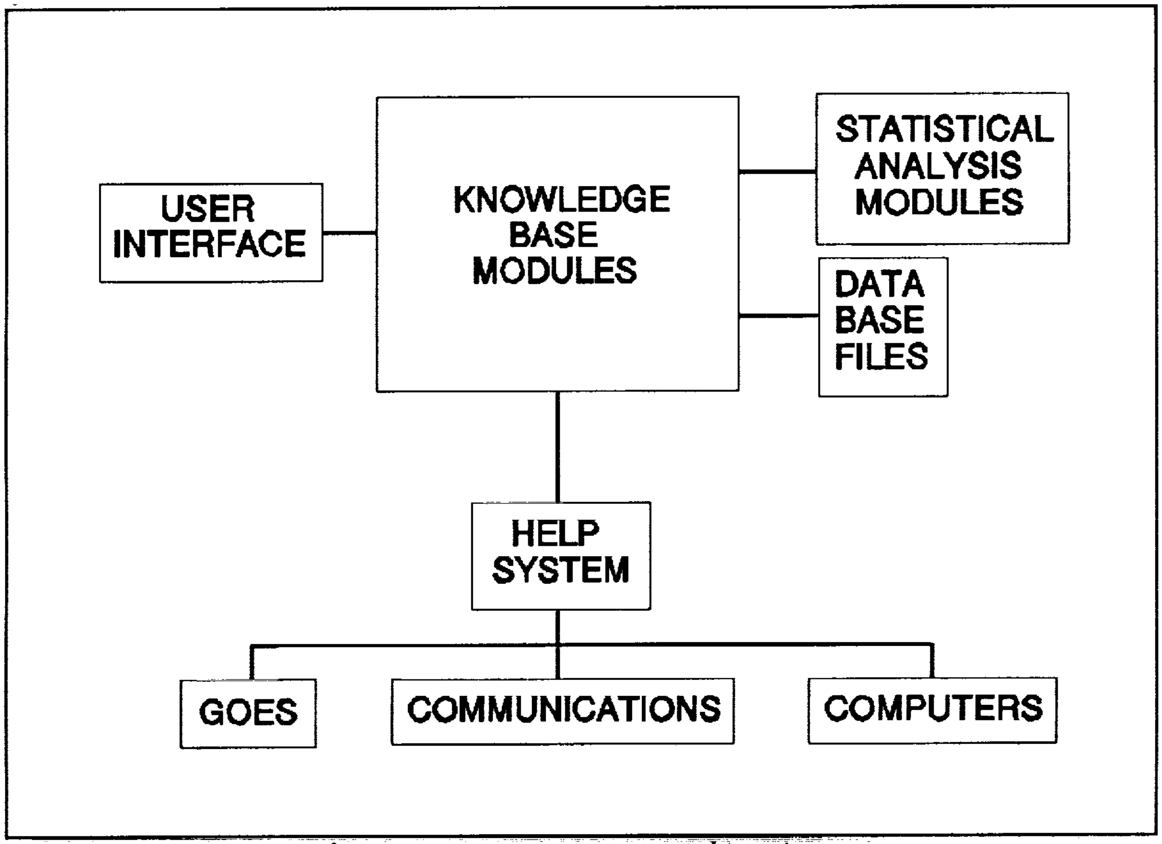

Figure 3 - AREAS Architecture

their constituent components. A memorandum to all the organizations responsible for the GDDS operation explained the use of ARS as, in part, an instructional tool. It included the GDDS Diagram, of which the WWB segment at Camp Springs, Maryland is shown in Figure 2, and the lists of possible symptoms and causes. The memorandum's express purpose was to establish a common framework in which to identify and respond to anomalous events.

4.1.3 ARS Database

Evaluation of the ARS data base provided input to the data type classifications used in AREAS, as provided by the expert system shell: numeric, attribute/value, and string.

4.2 Process of Discovery

Since one of the objectives of building AREAS was to gain additional insights into GDDS, AREAS had to be able to represent GDDS physical relationships among its subsystems and components. For example, the following "identify symptom" rule represents the interpretation of, and the relationship between, the shift supervisor's comment in the remarks column of the Operational Problem Log and the identified symptom.

```
RULE identify symptom
IF remark IS Short-SZ Halted in RCV
THEN symptom identified
AND symptom IS Degraded Data
```

The remark, "Short - SZ Halted in RCV," means the sectorizer's processing of the imagery product's data set during transmission was terminated while in receive mode. The symptom is thus classified as degraded data (i.e., by definition 50 percent or more of the complete image was produced and was of animation quality). The next rule, "identify responsible organization," establishes the relationship between the identification of the satellite and a specific sectorizer and the organization responsible for its operation.

```
RULE identify responsible
     organization
IF symptom identified
AND satellite IS GOES East
AND hardware element IS Sectorizer
    6A11
THEN responsible division
     identified
AND responsible division IS SSD
```

4.3 Help System

The help system provides query specific information in narrative and graphical formats of crucial areas of the GDDS. If the user doesn't understand a particular query, such as "What was the responsible division?" a help screen is available with additional information explaining the physical system relationships and the organizations responsible for their oversight. Mutually supportive information from different documents is merged as well in help screens. For example, a glossary of terms such as the one shown below was merged with the GDDS Diagram in Figure 2, above.

COMM RACK	Communications Rack
DCS	Data Collection System
IFFA	Interactive Flash Flood Analyzer
O & A	Orbit and Attitude
SEXRS	Sectorizers
SOCC	Satellite Operations Control Center
TELCO	Telephone Data Lines
VAS	VISSR Atmospheric Sounder
VDUC	VAS Data Utilization Center
VIE	VAS Interface Electronics
VIRGS	VISSR Image Registration and Gridding System
VISSR	Visible and Infrared Spin - Scan Radiometer
XBAR	Crossbar Switch

4.4 Statistical Analysis

The initial objective of a statistical analysis of the ARS data base was to provide the user with background information as to the apparent relationships between symptoms and causes. This was accomplished through a simple mean analysis of the type and number of causes attributed to each symptom. This analysis, coupled with the rule output reviewed above, produces a diagnosis as shown below in Figure 4. The user is then at liberty to accept or reject the diagnosis.

4.5 Introduction of Knowledge-Based Systems

The focus on simplicity of the prototype's development, architecture, purpose, and operation was important. These issues had to be easily explainable to use AREAS as an introduction of knowledge engineering concepts. A basic approach was taken in knowledge acquisition, representation, search, and inference for this purpose.

Based on the following information:

Julian Date:	310
Satellite:	GOES East
Zulu Time:	0200
Symptom:	No Data
Number of Products Affected:	1
Hardware Element:	SZ6A11

Do you agree with the diagnosis below?

Probable Cause:	Sectorizer-WWB
Responsible Division:	SSD

⇨ Yes

No

Figure 4 - Diagnosis Screen

5.0 Verification and Validation

Verification was performed through analysis of shell-produced knowledge trees linking all the goals, rules and attributes in a given knowledge base in a logical order of precedence starting with the top-level goal. Each logical path through a knowledge base was also manually derived and tested.

Initial validation was performed by comparing archived results of domain experts' analyses to system generated conclusions. Subsequent validation was conducted by domain experts through the evaluation of results from test data sets processed by AREAS.

6.0 Test and Evaluation

The qualitative test and evaluation of the AREAS demonstration prototype focused on its potential use as a help system in identifying the symptoms and causes of anomalous events. Feedback from user surveys indicated:

- a positive reaction to the display of statistical data but a need to further highlight only the most prevalent symptom/cause ratios;

- a desire to have AREAS identify individual GDDS components and their output of specific products (i.e., products are currently assigned identification codes and are logically linked to specific hardware elements within GDDS);

- approval of the graphics used but a request for more detail in representing GDDS subsystems and components;

- the need to allow multiple symptom identifications for a single anomalous event (e.g., the symptoms Data Incomplete and Degraded Data can be specified for a single event in the current ARS), and the ability to generate multiple symptom/cause records per report; and

- support for the ability to easily review input prior to data base update and subsequent report generation.

CONCLUSION

Part, but not all, of each objective was accomplished in the development and demonstration of AREAS:

1. Develop a help system for anomaly reporting.

The current ARS has no help feature. One of the expressed purposes for users and new employees using the ARS is to train them in the nomenclature and processes of the GDDS. One of the primary objectives of AREAS was the linkage of relevant narrative and graphical information to specific user queries. Based on user feedback AREAS has made an important step in identifying user needs in the successful analysis of anomalous events in GDDS.

2. Increase personal knowledge of GDDS.

The author is a novice with satellite-based systems but experienced in knowledge-based systems development. Through the development of AREAS and preparation of this paper, he was able to take advantage of the process of discovery highlighted by the knowledge engineering process to gain a better understanding of the GDDS.

3. Retain valuable GDDS expertise.

The retirement and promotion of several employees who were very experienced in the GDDS created a potential problem for new employees assigned to anomalous event tracking and analysis. Part of their expertise, through the knowledge engineering process, was captured for use through AREAS.

4. Demonstrate the ability of AI to improve administrative and operational tasks.

The only automated tool available within ARS to search the database requires the user to possess a clear idea of what is being searched for and familiarity with the data types and structures employed. The purpose in providing the user with a simple mean analysis of the data represents the initial step in providing ready access to analytical tools and results. These tools, when augmented by heuristic rules to constrain the search space, provide a reasonable method of diagnosis to assist the user in making decisions. In the future these results may identify potential trends in specific GDDS subsystems and hardware elements, as well as processing methodologies.

AREAS, with its focus on simplicity, provides the opportunity to introduce knowledge-based systems concepts, development and use to employees in a direct, hands-on way. It highlights the value of knowledge engineering as a process of discovery. It also demonstrates the ability to harness the knowledge of disparate sources of information and provides a focus for that knowledge on problem-solving in the domain of anomalous event diagnosis for environmental satellite systems.

REFERENCES

Cote, D. "Planning Begins for Major Upgrade of NOAA's Data Management System." *Earth System Monitor* 3(1) (September 1992):1-2.

Harmon, H. & King, D. *Expert Systems*. New York: John Wiley & Sons, Inc., 1985.

Mairs, R. "Anomaly Reporting System." Memorandum (May 27, 1988), Satellite Services Division, National Environmental Satellite, Data, and Information Service, Camp Springs, Maryland.

Miller, D. & Hay, D. "Final Report of the Artificial Intelligence Techniques Study for Environmental Products and Computer System Operations." (September 1992). U.S. Department of Commerce Service Order Number 40AANE201402. Greenbelt, Maryland: COMSO, Inc.

Morelli, R. "Using Knowledge Engineering to Teach Science." *IEEE Expert* 5(4) (August 1990): 74-78.

National Environmental Satellite, Data, and Information Service. *NESDIS Programs: NOAA Satellite Operations*. Washington, DC: U.S. Government Printing Office: 1985-472-036, 1985.

PRC, Inc. *GDDS Operations and Maintenance Contract: Technical Management Proposal*. Department of Commerce Solicitation Number 52-DGNE-9-00067. McLean, Virginia: PRC, Inc., 1989.

Rao, K. & Holmes, H. & Anderson, R. & Winston, J. & Lehr, P. (Eds.). *Weather Satellites: Systems, Data, and Environmental Applications*. Boston, Massachusetts: American Meteorological Society, 1990.

Image/Data Classification/Interpretation