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PI-in-a-box : Intelligent Onboard Assistance for Spaceborne Experiments in Vestibular Physiology.

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Abstract

We are constructing a knowledge-based system that will aid astronauts in the performance of vestibular experiments in two ways: it will provide real-time monitoring and control of signals and it will optimize the quality of the data obtained, by helping the mission specialists and payload specialists make decisions that are normally the province solely of a principal investigator, hence the name PI-in-a-box. An important and desirable side-effect of this tool will be to make the astronauts more productive and better integrated members of the scientific team.

The vestibular experiments are being planned by Prof. Larry Young of MIT, whose team has already performed similar experiments in Spacelab missions SL-1 and D-1, and has experiments planned for SLS-1 and SLS-2. The knowledge-based system development work, performed in collaboration with MIT, Stanford University and the NASA-Ames Research Center, addresses six major related functions: a) signal quality monitoring; b) fault diagnosis; c) signal analysis; d) interesting-case detection; e) experiment replanning; and f) integration of all of these functions within a real-time data acquisition environment. Initial prototyping work has been done in functions a) through d).

Introduction

The conduct of experimental science in existing spaceborne laboratories such as Spacelab or future ones such as the Space Station is severely constrained in several respects. The principal investigator (PI) is normally not on the spacecraft and communication with the ground is either limited in bandwidth or availability. In any event, because of the open nature of the air-to-ground voice links, free discussion of experimental alternatives is inhibited. Furthermore, the experiment-specific decision-making ability of the astronauts is limited by the training they have been able to receive before the flight and by the time they have available in flight. Longer mission durations make it more likely that contingencies will arise for which the astronaut will have had inadequate preparation.

Considering the limited opportunities that exist for flight experiments, and the scarcity of both space and crew time, an intelligent system to assist in the conduct of spaceborne science seems like a potentially useful tool, especially if it contains much of the experiment specific knowledge known to the PI. At a minimum it would save crew time, but what we are especially targeting is the kind of improvement in the quality of the experiment that comes from a deeper understanding of the processes involved, and from the ability to make timely decisions that can change the course of the experiment on the basis of "interesting" data. In some sense, the present necessity of having the entire experiment pre-planned is likely to lessen the possibility of surprising discoveries, and the PI on the ground is often left with the frustration of not having had a chance to look again at some unusual event, or of mistakenly recording meaningless data, and of having to wait for years for a second chance.

The work we have initiated addresses the following major functions: signal quality monitoring, fault diagnosis, signal analysis, interesting-case detection, experiment replanning and, finally, coordination of these functions by a protocol management subsystem. Our initial prototyping effort has concentrated mainly on the areas of signal quality monitoring, fault detection and interesting-case detection.

In this paper we discuss the operational environment, how artificial intelligence technology can contribute to the attainment of better scientific data, and the experience we have gained during our initial prototyping effort.

The Operational Environment - How a Typical Experiment is Performed -

PI-in-a-box (symbolically [PI]) is initially designed to be used in the context of a series of experiments planned to test theories on adaptation to weightlessness and space motion sickness. The hypothesis tested and confirmed so far by Young et al. [3] is that, during adaptation to weightlessness and readaptation to one-g, signals from the inner ear are reinterpreted by the brain. In brief, on earth the presence of gravity is constantly sensed in the inner ear, and signals from the inner ear sensors (utricular otolith afferent signals) are combined in the brain with motor, visual and tactile clues to provide us with a sense of orientation within our environment. In the absence of gravity the inner ear signals are still sent, but, after some adaptation, they are reinterpreted and combined with other environmental clues in ways that are different from those observed in a normal one-g environment. An analogous process of readaptation occurs after returning to one-g.

In order to test the sensory reinterpretation hypothesis it is necessary to perform the same experiments under three different sets of environmental conditions: on the ground before flight, in flight with microgravity and, again, on the ground after the end of the mission. The first ground experiments provide a baseline, the flight experiments show the adaptation that occurs in the microgravity environment and, finally, post-flight ground experiments show the re-adaptation that must take place after gravity returns to play its usual role in the vestibular system.

The experiments are typically performed by teams of two people, who take turns being subject and experimenter. Examples of typical experimental setups are a rotating dome, a rotating chair and a sled on rails. The subjects might be asked to look into the dome, or sit in the rotating chair or on the sled while it is being moved. During the experiments, which typically lasts a few minutes, the subjects are asked to perform tasks that indicate their spatial orientation, for example, they may be directed to look at specific areas, describe sensations, or point to a perceived "up" or "down". Eye movements are a very important source of information in many of these experiments and can be recorded via electro-oculography (EOG). This technique is based on the fact that each eye acts as a dipole within the head, and its movements cause electrical field changes that can be detected by electrodes appropriately placed on the skin. Other types of movements, such as iris dilation, can be observed with video cameras and suitable image processing, but this type of observation has not yet been accomplished in flight.

Potential Role of Artificial Intelligence Technology

At present, in his/her mode as an experimenter, the on-board astronaut follows a protocol document in the form of a checklist. This checklist guides the specialist in preparing the instrumentation for the experiment and in instructing the subject on the actions required of him or her. The protocol document also provides a guide for evaluating the quality of the data produced by the experiment, and for what should be done when the quality achieved is not sufficient for meaningful results, or when there is some unexpected occurrence.

In spite of long and rigorous training imparted to mission specialists, the checklist system is inadequate in helping them keep track of events unanticipated in the protocol, and in helping them diagnose complex experimental problems. A consequence of the limitation of the checklist system is that problems can go unnoticed, or the PI on the ground must be summoned to help the specialist diagnose and correct the problem. The likelihood of timely and effective repair is higher when the expertise is available at the problem site - in the spacecraft.

An knowledge-based system can monitor several variables at once, and direct the mission specialist's focus of attention to problem areas. It can also aid the specialist in diagnosing problems of different levels of complexity, within the limits of the knowledge built into the system and the time available.

An additional, potentially extremely valuable contribution of this technology is in detecting opportunities, rather than just detecting problems. By this we mean the ability to detect that a particular data set reveals some unexpected behavior of the system under study and that this discovery may warrant a repetition of the experiment or a change in the set of experiments that is to follow. This is the type of insight that is normally the province solely of the PI. Can we build a system with enough knowledge and, perhaps, modeling ability, to achieve insights of this type? We are not yet ready to answer this question in the affirmative, but we report below on the experience we are beginning to accumulate.

The System Design

Our initial top level system design is illustrated in Figure 1. The hub of the system is the "protocol manager". This subsystem interacts with the astronaut and with the experiment, and serves as a controller for the remaining four major subsystem functions: a) data quality monitoring and fault diagnosis, b) interesting-data detection, c) suggesting new experiments and d) scheduling or rescheduling experiments and resources. Here we report on work done in a) and b).

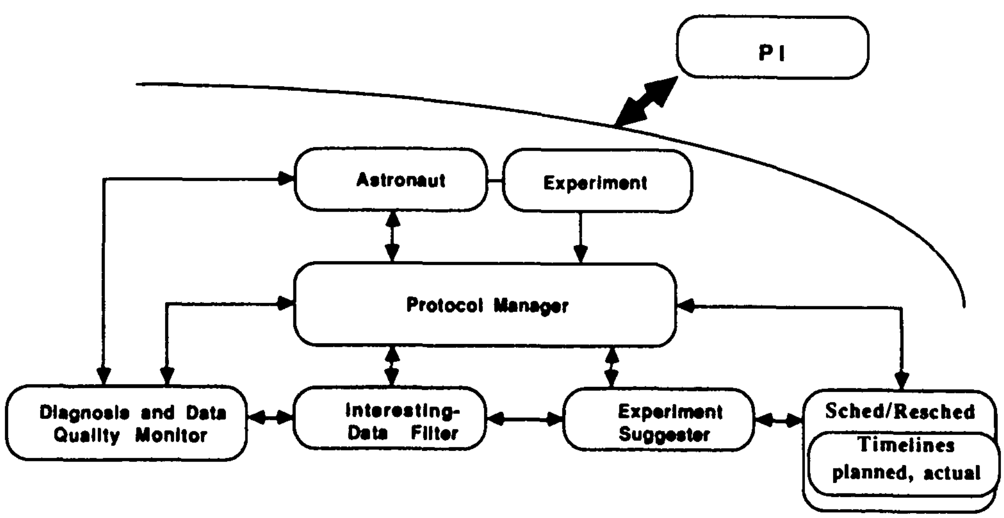

Figure 1: Top level system design of PI-in-a-Box

Signal quality monitoring and fault diagnosis

As a first prototype we built a small diagnostic knowledge based system for the EOG eye movement signal. Quality monitoring and diagnosis of this signal is representative of a type of monitoring and diagnostic activity useful for most experiments.

The system uses a simple backward chaining of rules where an attempt is made to establish that the signal received is "good". In order to establish this hypothesis, the system looks at a number of properties related to signal gain, noise and stability. If any of the values of these properties is not what would be expected for a good signal the system attempts to diagnose the problem and to suggest a solution. When the system detects an unexpected value, but cannot find an explanation and suggest a course of action, it recommends that the PI be contacted. However, the purpose of the system is neither to keep the PI out of the loop, nor to require less of the specialist in terms of understanding and skill. On the contrary we hope that this tool will help make both the PI and the mission specialist more productive and better decision makers by acting as an "intelligent partner".

The current knowledge base used to monitor and diagnose the EOG signal is embodied in about 60 rules at this time. This size has been sufficient to produce a meaningful demonstration, although the user is still required to input data that will be input automatically in the operational system, . Two typical interaction screens and a tree of the types of problems detected so far are shown in Figures 2, 3 and 4 respectively.

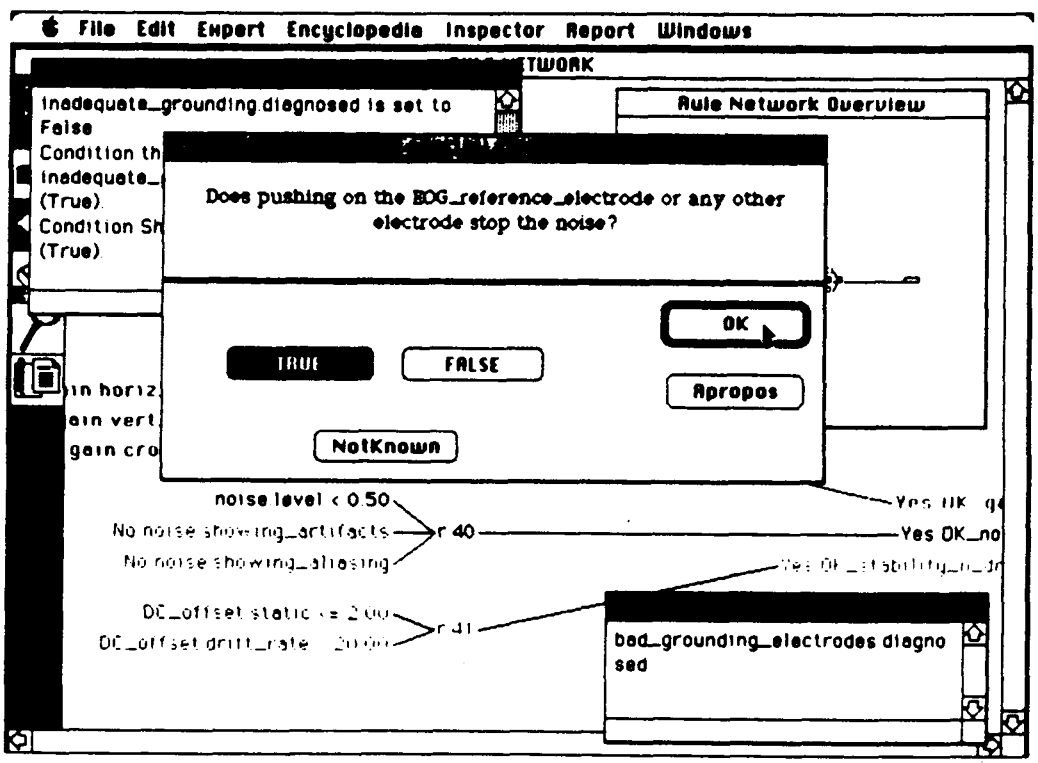

Figure 2: A prototype screen requesting input from the astronaut

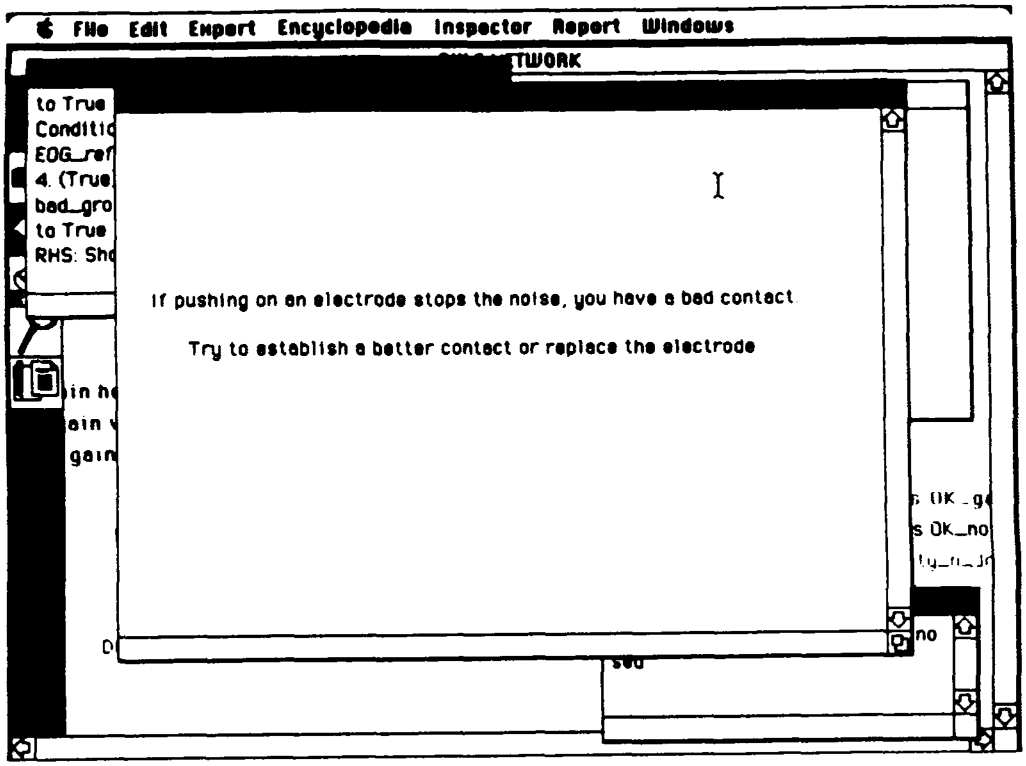

Figure 3: A prototype screen suggesting a course of action

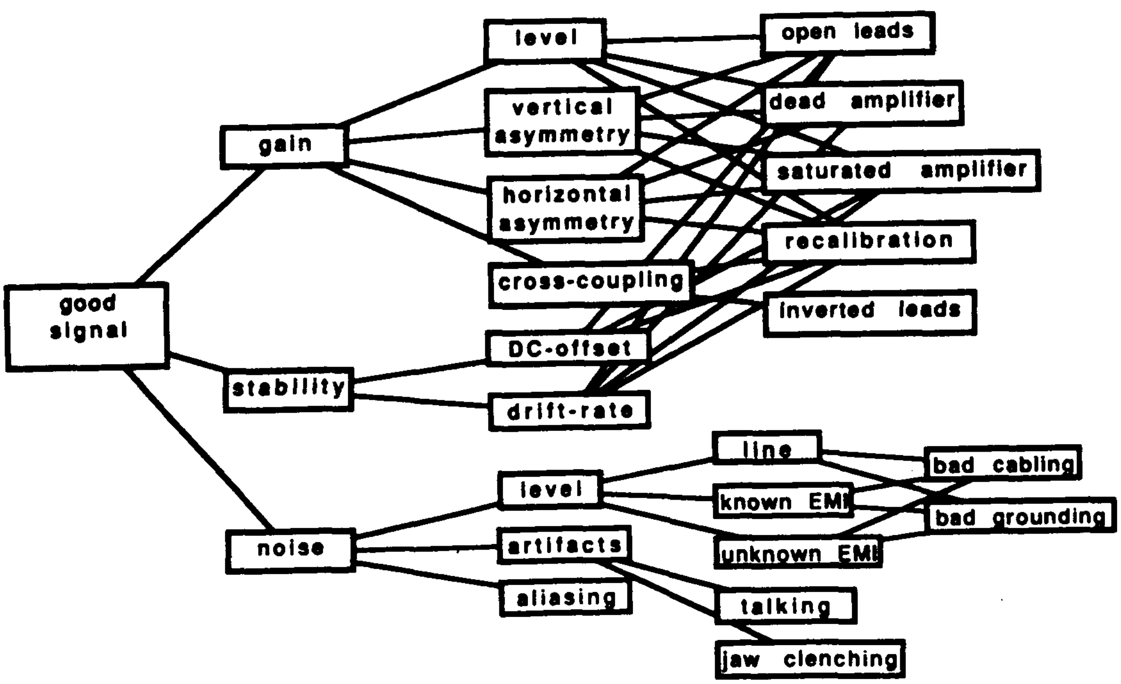

Figure 4: An overview of problems considered by the EOG signal quality monitor prototype.

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Prof. Laurence Young, an internationally recognized expert in vestibular physiology, has served as domain expert in our initial work. We chose the commercial tool Nexpert Object [2] as the system building tool. Our main reason for selecting Nexpert was that it appeared to be the most powerful knowledge based shell that could run on a range of mini-computers and microcomputers, including the IBM PC and the MacIntosh. Its price was within our initial budget, and it provided a powerful user interface that made it suitable for demonstration purposes.

Interesting-case Detection

We think of Interesting-case Detection as the ability to distinguish among normal expected good data , experiment artifacts, and unexpected data that is interesting enough to lead to a recommendation for changes in the original experiment plan, either for a second look or for the exploration of previously unexpected possibilities. This capability, which we hope to achieve, is what would set this system apart from normal diagnostic and planning systems, and truly earn it the name PI-in-a-Box.

This portion of our research focused on a vestibular sled experiment. In this experiment the subject sits on a sled which rides back and forth on a track. The subject's eye movement is measured by EOG. Comparison of pre-in- and postflight values of these parameters provides a test of the orientation model. For this phase of the work, the signals were assumed to be of good quality. The decision-making behavior we tried to reproduce was that of a scientist who looks at the data for a pre- and an inflight experiment, compares the two sets, and decides in a manner of minutes, during the experiment, whether the results are interesting enough to warrant further exploration. A consequence of this assessment might be to repeat the experiment, modify the same or subsequent experiments, or simply note the finding and proceed as planned.

Usually a scientist uses a graphical representation of data suited to the necessary interpretation, some examples being graphs of distributions or of derivatives. The scientist identifies attributes of interest by describing qualities of the graphical representation, such as "beats", "phases", or the shape of a curve. Translating raw data into the kinds of attributes a scientist actually thinks about is, in general, a difficult task. For this prototype, we identified the relevant attributes that would have to be extracted from the data, and asked the user for these values. In the future, the values of these attributes will be obtained by traditional signal analysis techniques (e.g. [1]). For this experiment we identified the following parameters: degree of linear nystagmus, and gain, phase and correlation of eye movement in relation to sled motion (Table 1). The values of these parameters can be obtained by algorithmic means, such as Fast Fourier Transforms, peak to peak ratios, or cross correlation techniques. The screen shown in Figure 5. compares these parameters for a pre- and an inflight experiment, and suggests whether the discrepancies detected should be viewed as interesting or not.

Parameter	Obtaining the Value	Value We Use
correlation	Cross correlation technique	Number representing degree of correlation
lnystagmus	Fortran program and rule base	Number representing certainty of presence of nystagmus
gain	Peak to peak ratio of sled motion to eye movement	Number
phase	FFT	Number representing degree of phase shift

Table 1: Parameter values considered in the Interesting-case Detection prototype for the sled experiment.

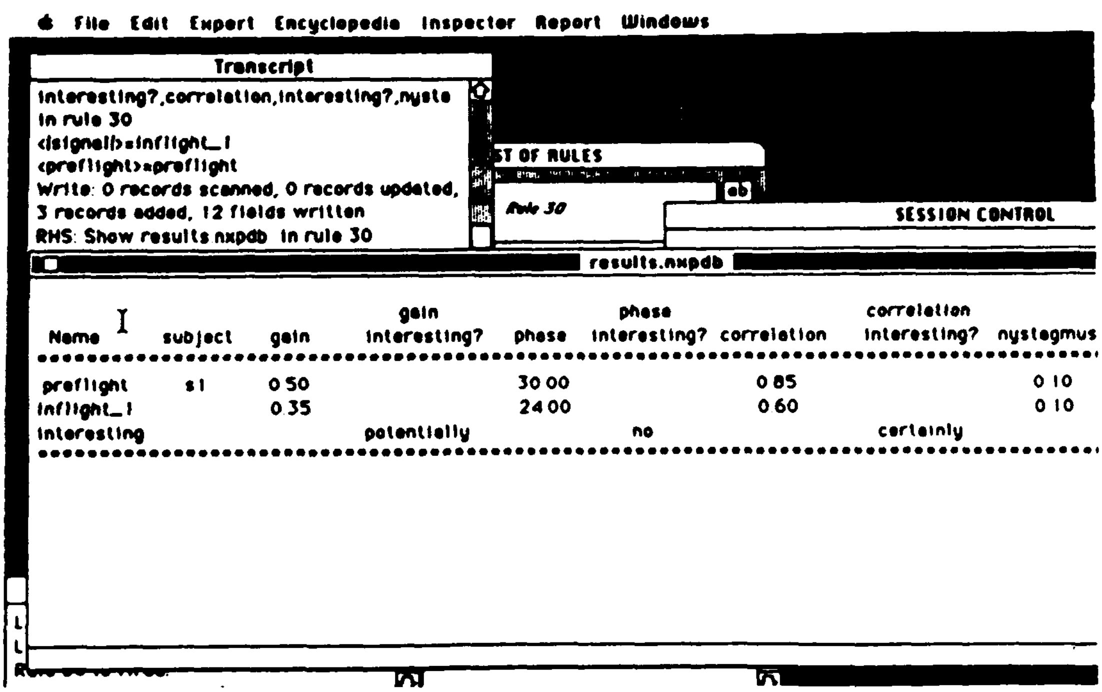

Figure 5: Parameter values for a pre- and an inflight experiment are compared. The system suggests which discrepancies should be viewed as interesting.

Currently, the system detects cases in which the values for attributes obtained inflight deviates significantly from those obtained through preflight trials. In the future, the system will combine this information with an underlying model of the scientific hypothesis being tested, and of the experimental process, in order to explain the deviations that are identified as being interesting.

Protocol Manager

The protocol manager will be the hub of the system. Under normal circumstances it will simply inform the astronaut on which experiment should be performed next and provide any necessary instructions. The real power of this subsystem will come into play in the very likely event that the experiments will not proceed quite as planned. These circumstances include cases when the experiments are taking more or less time than expected, problems are found that take a long time to diagnose, or interesting events are detected. In all of these cases some decision must be made as to the course of action. For example, do we continue to troubleshoot a problem or proceed with degraded data? Given that we have extra time or something interesting has been found what experiment do we perform next? Given that we are running late what experiment do we eliminate, or how do we modify subsequent experiments? The protocol manager will exchange information with the other subsystems, such as the diagnostician or the planner, and provide the mission specialist with alternative courses of action.

Future Development

Short range plans for development include further testing and refining of EOG signal interpretation rules, and extending signal quality monitoring, diagnostics and interesting-case detection to a new set of experiments involving the sled. A prototype of the protocol manager subsystem is also being developed. We do not yet have firm ideas on the planning/re-planning, and experiment suggestion subsystems, but we hope to demonstrate the utility of our work as early as 1990, in the pre- post- flight Baseline Data Collection Facility measurements, as part of Dr. Young's experiments on Spacelab SLS-1. At the earliest opportunity, mission specialists will also become actively involved in helping us design or modify the system.

Conclusions

A set of vestibular experiments planned for future Spacelab missions are providing a test of the applicability of AI technology for increasing the productivity of mission specialists and improving the quality of the data obtained. The functions of a knowledge-based system planned to assist with these experiments will include protocol management, signal quality monitoring, problem diagnosis, detection of interesting cases and planning. The intelligent aspects of these functions are normally considered the province of a principal investigator, hence the system name PI-in-a-Box. The initial prototyping effort has concentrated on signal quality monitoring, problem diagnosis and interesting case detection for a small subset of experiments. A level of system ability sufficient for meaningful demonstrations in these areas has been achieved to date. It appears that the most difficult problem is to extract from the raw instrument data the high level attributes a scientist is accustomed to thinking about. A careful analysis is required in order to distinguish between those attributes that are more easily obtained algorithmically, those that require heuristic knowledge and those that require a deeper underlying model of the scientific hypothesis and of the experimentation process.

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