the pilot tends to think of it as a person. If your computer on a CRT gives you wrong answers, you say, "Ah, the computer is mixed up." If the speech system gives you the wrong answer, the pilot says, "It lied to me." So, you have to be very careful about the use of that interface.

Question Is there interaction between your program and the FAA?

John P. Retelle, Jr. There is none, and that is really a hoped-for outcome of this meeting.

SHUTTLE AIR TRAFFIC CONTROL EXPERT SYSTEM

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This presentation will examine some of the work being done at the Johnson Space Center, particularly in the application of expert systems to a number of problems. Some 10 or 12 expert systems have either been developed or are in the process of being developed. A number of them probably apply to the subject of air traffic control appropriateness.

An expert system called a controller has been built and basically what it does is evaluate the status of the hardware and software at Mission Control Center in real time and then advise the computer supervisor as to the status. This replaces two people who had very tedious jobs but, also, very, very important jobs. In the process of implementation is what is called computer controllers; they will actually control all the antennae and do antenna management during real time in the space transportation system. It also includes an interactive graphics capability for the controller interface. Schedulers have been developed which schedule both people and resources in very specific narrow areas. These are now in operation and have proved to be much more capable than the people who were doing the job. In process of development is an automated rendezvous and docking expert system which would include three expert systems.

It has also been found that as some of these expert systems are built they are excellent trainers. There is also ongoing research with natural language and speech recognition, neither of which are very satisfactory at this time.

This presentation will now describe an application of expert system technology to a typical mission control center monitoring problem. The mission Planning and Analysis Division currently works for many shuttle support activities. One of these is high-speed ground navigation. Currently teams of three people work during the ascent and entry phases of missions from the space shuttle. These people work on a standard console consisting of five CRT devices, five digital display driver panels, one computer terminal or manned equipment device and one DRK panel, which is a pushbutton device.

These operators monitor and control the processors that work during the ascent and entry phases of the mission. The first one is the high-speed trajectory determinator or HSTD. The other is the Delta-State update processor, SUP. The configuration that is believed possible using expert system technology is to reduce the manpower from a three-person team to a single-person team aided by an expert system. Currently these people monitor and control the HSTD high-speed trajectory determinor. This processor uses data from one to three radar stations processed through a Kalman filtering technique to generate estimates of the shuttle's position and velocity. The state update processor is a program which monitors the on-board computer navigation performance and compares it to the ground navigation performance. Currently it requires two or more years to train a person to operate on this console. This is a very complex, highly detailed, monitoring problem, and there is a tremendous amount of data coming in. The operators work with a display which has over 110 parameters on it, and each of these numbers changes every 2 seconds. As such, a series of lights go on and off every 2 seconds. There are as many as 50 or 60 lights the operators must monitor. The operators will take three prime actions with regard to the filter. First, they can exclude or include data coming in from a particular radar station. They might include it if there is a good solution or good data to be incorporated into the solution or conversely, they may exclude a station to prevent bad data from being included in the filter solution. Also, they may restart the filter to prevent propagating ahead or finally if they have to, they can stop the filter to prevent a bad solution from being used by anybody else. These operators are responsible for doing whatever actions are required to maintain the health of a carbon filter and to provide the best possible estimate of the ground velocity and position of the shuttle.

The expert system was used to emulate or recreate the decision-making process of the units. The expert system was used or built using an ART, the automated reasoning tool developed by Inference Corporation. When describing an expert system the size is estimated by counting the number of rules. This expert system has about 100 rules. It was developed in less than two months using the automated reasoning tool. The performance of the expert system often called NAVEX is very impressive. It is able to monitor all the information coming in the computer's monitor at a rate that is four to eight times faster than the humans currently work at. That gives us the capability to add in more words to the expert system to make it more robust and more flexible and, also, potentially gives us the capability of increasing the rate at which we monitor information. The expert system will be improved to include the ascent case or ascent rules and bring those on line as well.

A more detailed description of the high speed ground navigation expert system which has been developed at Johnson Space Center is given in the attached appendix. In brief, the chief functions demonstrated by this project are as follows.

First, it demonstrated that expert system technology is feasible for use in NASA's console operations. This was a complex monitoring problem, requiring much expertise and human skill. The expert system was able to handle that. Also, the expert system was able to meet the real time needs of the system working at a very high data rate. Second, the expert system did not require a highly experienced or highly expensive knowledge engineer to develop it. It was developed in a very short time typically by the NASA personnel with help from the Inference Corporation.

In summary, the work had a number of objectives. One was to demonstrate the current state of the art in terms of the technology that is available now in hardware and software. The purpose was to demonstrate that this technology is being used and that expert systems can be developed rapidly at a reasonable cost. This project was done in a few months. Typically we run well under six months on any expert system application, with one or two people working on it. It has also been possible to develop the in-house capability to do the knowledge engineering kinds of jobs, but that may be peculiar to NASA applications since many systems analysts have done this.

One of the things that an expert system does is to keep track of all the potential problems; as a problem develops the human tends to get tunnel vision and be concerned with that emergency. The expert system, of course, does not do that. It watches for all the potential problems that may come up later which is a tremendous advantage, certainly in the problems that are being examined.

The need for three console operators is that three pair of eyes are needed to look at all the data that is coming in, and decisions are a general consensus. The method used was to take a consensus of eight experts to compare that consensus with the decisions made by the expert system. In every case the expert system made the appropriate decision and in general, being conservative, made it earlier. It was also found that most of the time the expert system was idle, waiting for more information which means that basically four to eight times as much data can be added.

DISCUSSION

Question What machine was that running on?

Robert M. Brown Symbolics. But we are using every major expert system builder that is available.

If you are going to build expert systems, you are going to do it rapidly. The best thing to do is get the most power that is available to do that. As we get into developing an expert system, the experts are asked how many rules they use in making their decisions. For example, in this case one said, "Oh, 1000." Another said, "Two thousand", and one said "Several thousand." This was reduced to 110 rules, and it was found that in most cases there is a tremendous reduction in what an individual or an expert thinks he uses in making decisions and how you can implement those in terms of rules.

Today's technology can build kernel expert systems very rapidly and at a very low cost. In today's environment, there are a tremendous number of companies selling hardware and software expertise which looks good and sounds good. When you really get down to trying to do a lot of different things with it, it is just really not very powerful at all.

Another problem is verification and validation. Expert systems normally do not degrade gracefully. When you get out to the edge of the knowledge domain, they will start giving you very, very idiotic answers. So, you have to be extremely careful how you build them.

We do not know much about verification and validation. The way I am doing that is I have a fiberoptics line to the mission control center in my area, and we run in parallel with the control center until we are satisfied.

One of the things you have to be careful about is that expert systems do not exhibit imagination, originality or common sense. You know it is bad for airplanes to crash. An expert system does not. You know if you drop something it will fall, and an expert system does not know that. You know if a pilot is making a decision based on incoming information, and he sees some obstruction, he knows he needs to fly around it. Unless you tell the expert system, it does not know. So, there are some things that we have to be extremely careful about in terms of building expert systems. Our expectations are using them in consultant modes, developing them in kernel form on well-understood, well-defined problems. The technology is here today to do that.

Questions Do you have any mission-critical applications in expert systems operations?

Robert H. Brown No, this of course is the NAVEX and it will go in as a consultant. It is still in the evaluation phase.

One of the big problems is target machines. If you want to rapidly develop an expert system, the best thing to do is use a symbolic machine or LISP-type machines that are available and being developed rapidly, but then when you get ready to deploy them, it is very, very expensive.

APPENDIX

HIGH SPEED GROUND NAVIGATION EXPERT SYSTEM (NAVEX)

C. J. Culbert
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Artificial Intelligence (AI) is flourishing outside the bounds of its traditional academic environment. Spurred by the success of a few key technologies, commercial development is placing more and more of the computer advances pioneered by the AI world into the applications environment. These technologies are beginning to reach maturity in a number of areas, and can make a significant controbution to all aspects of the space program.

The AI section of the Mission Planning and Analysis Division (MPAD), Johnson Space Center (JSC) is developing applications which apply AI technologies to NASA problems. In particular, the AI section is using expert systems to aid highly trained humans accomplish complex tasks. An example of this is the Navigation Expert project, NAVEX. NAVEX is an expert system built to aid in the operation of the high speed ground navigation console in the Mission Control Center (MCC) at the Johnson Space Center. This project was one of the first expert system development projects in MPAD. It was begun as a feasibility study to examine the potential for the use of state-of-the-art artificial intelligence hardware and software in typical JSC applications. The prototype expert system for NAVEX was developed by the Inference Corporation in conjunction with MPAD personnel in about three months. NAVEX was designed and built on a Symbolics computer (a specialized LISP machine) using the automated reasoning tool (ART), a product developed by Inference. ART is a sophisticated software tool used to develop an expert system. ART allows programmers to work in a very high level language with advanced programming constructs, and takes full advantage of the development environment of the Symbolics computer (1).

The console task currently requires teams of three people who monitor and control the high speed trajectory determinator (HSTD) during the ascent and entry phases of a shuttle mission. They also monitor the Delta-State Update processor (SUP). These teams work at a typical MCC console with 5 CRT displays, 5 digital display devices (colored status and warning lights), a computer terminal for data entry, and a set of push buttons for command entry. By using an expert system advisor, manpower requirements can be reduced from three people to one person while also reducing training effort and improving response.

The HSTD is a Kalman filter program which uses data from one to three radar stations to generate an estimate of the shuttle's position and velocity. This state vector is then used by numerous other flight controllers and/or programs in the MCC which need the shuttle's current state vector. The HSTD generates a state vector every two seconds, using the current radar measurement to propagate the previous state vector forward. The HSTD also estimates the error in the radar measurements. The SUP is used to help monitor performance of the onboard navigation systems and to compute state vector updates. The processor computes the differences between the onboard state vector and the HSTD state vector.

A tremendous amount of information is presented to the controllers. The prime display has over 100 parameters which change every 2 seconds. Typically there are two or three other displays available for additional information on the other CRT's and there are between 30 and 50 blinking lights on the digital display devices which need to be monitored.

The console operators are responsible for maintaining and improving the performance of the HSTD. The operators monitor the noise and bias statistics generated by the HSTD, looking for trends or data anomalies. They can specifically include or exclude the data from a particular radar station in the Kalman processing. They can also completely restart the filter, i.e., drop all previous state vector estimates from the current solution and start fresh with the next set of radar data. Deciding what actions to take and when to take them is a process which requires a high level of human expertise. Console operators require 2 or more years of training to become experts. They need to have knowledge of how a Kalman filter works, how radars work, how a particular radar has reacted in previous missions, the potential effects of their actions on other flight controllers, how to input data and commands, and of course, the flight rules. Other responsibilities of the high speed navigators include advising other flight controllers of the current reliability of the HSTD solution, and the validity of the state vector update. A more complete description of the duties of the console operators is available in reference (2).

The techniques used to develop NAVEX are applicable to numerous other monitoring type problems. A better description of this architecture is available in Reference (3). NAVEX uses a "synchronous data acquisition architecture", i.e., data is input to the expert system at regular intervals. The output from the HSTD is presented to NAVEX for reasoning every two seconds. NAVEX also makes use of the ART viewpoint architecture for temporal modeling. This modeling does not include a complete history of the past (although it could). Instead, information of importance in each cycle is saved as state information to a special viewpoint. At the beginning of each clock cycle a new viewpoint is created and the current HSTD information is asserted into it. NAVEX then reasons about this information, together with state information. The use of state information allows NAVEX to reason about trends in the data. In addition to making recommendations, NAVEX can note trends developing in the data and can both alert the users and set a watch in the state information.

NAVEX operates in four phases during each clock cycle. The first phase advances the clock, creates the new viewpoint and calls the LISP functions which gather the data. The second phase reasons about the current data to generate all possible actions. Multiple recommendations are allowed to coexist during this phase (within the current viewpoint). During the second phase, all recommendations are considered independently. Any previously noted trends or watches for possible problems are considered and updated in this phase. The third phase then considers interdependencies among all the independent recommendations and refines the set of possible recommendations. The fourth phase selects the best of the recommended actions for execution. Finally, a new clock cycle is begun. A complete description of the NAVEX system architecture is available in reference (4).

The high speed console was chosen for the NAVEX project because it was typical of shuttle monitoring type problems, it represented a good test of a complex operation, and also was a well defined problem. The expert system had to demonstrate not only expert level reasoning capability, but also had to meet the real-time data needs. It had to be capable of monitoring large amounts of data at high rates and make critical recommendations in real time. To date tests of the NAVEX system have shown it capable of meeting these stringent requirements while still functioning at an expert competence level.

The NAVEX project demonstrated two key points. First, that current AI technology was capable of handling typical JSC type problems, both in complexity and speed. Second, the prototype system was developed in a very short time without relying on specialized "knowledge engineers". These points open the door to numerous other uses within NASA, both for the space shuttle and the space station. The AI Section is developing other systems which further demonstrate the use of AI technology in NASA applications.

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