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INTELLIGENT TUTORING AND AIDING IN SATELLITE GROUND CONTROL

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ABSTRACT

In supervisory control system such as satellite ground control, there is a need for *human-centered automation* where the focus is to understand and enhance the human-system interaction experience in the complex task environment. Operator support in the form of offline intelligent tutoring and online intelligent aiding is one approach towards this effort. The tutor/aid paradigm is proposed here as an desing approach that integrates the two aspect of operator support in one system for technically oriented adults in complex domains. This paper also presents GT-VITA, a proof-of-concept graphical, interactive intelligent tutoring system that is a first attempt to illustrate the tutoring aspect of the tutor/aid paradigm in the domain of satellite ground control. Evaluation on GT-VITA was conducted with NASA personnel with very positive results. GT-VITA is presented being fielded as it is at Goddard Space Flight Center.

Keyword: Intelligent tutoring systems, operator support, technical training, supervisory control.

1. INTRODUCTION

In very highly automated systems such as satellite ground control and process control, the human operator is involved in supervisory control task -- monitoring system states and compensating for system failures (Ref. 10, Ref. 13). On one hand, advances in computer technology over the years had contributed to the efficiency and productivity of automated systems in terms of high-performance equipment and innovative automation control strategies/algorithms. On the other hand, it is clear that the operator's changing role in

automation has also resulted in a new set of problems with prevailing issues in reliability and safety. This is evident in tragedies such as the three-mile island accident. Consequently, there is a need for *human-centered automation* where the focus is to explore technology not just for better automation, but for understanding and enhancing the human-system interaction experience in the complex task environment resulted from automation.

To reduce task complexity, Leplat (Ref. 8) suggests either changing the operator through training or changing the task through redesign. At NASA Goddard Space Flight Center, existing training methods to prepare novice for satellite ground control at the Mission Operations Division include classroom instruction, quizzes, volumes of reading materials, and on-the-job training. Unfortunately these methods are inadequate by themselves in meeting new training requirements imposed by the nature of supervisory control task and the complexity of the task domain. Operators require high-level skills beyond rote memory of procedures and rules to manage trouble when trouble arises, and to copy with unanticipated variabilities in system behavior. In addition, for on-the-job training, there is the problem of knowledge attrition that results as new generations of operators are being trained over time.

Hence the primary motivation for the research work reported in this paper is to explore the design of an intelligent tutoring system (ITS) for training novice operators in satellite ground control.

For the next generation of mission control systems, researchers and engineers at Goddard are involved in changing aspects of the satellite

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control task through redesign of existing systems, capitalizing on recent technological advances. While some existing problems may be come obsolete in the new systems, others may still arise because of the complexity of the application in an even more high-tech environment. Thus, there is still a need to address the issue of online operator support such as intelligent aiding systems that may potentially facilitate an operator in performing supervisory control activities. More importantly, many existing systems that have been in place for many years are often not amenable to redesign except potentially through distributed operator support tools and aiding systems.

Hence, the research presented here also suggests a design paradigm that considers intelligent training and aiding as two ends in the spectrum of operator support.

2. THE TUTOR/AID PARADIGM

Conventionally, research in training has been fielded separately from research in aiding. We propose the tutor/aid paradigm in which an intelligent tutoring system (ITS) evolves from a tutor to an operator's assistant as the novice operator's expertise increases. The tutor/aid paradigm integrates the issues of computer-based training and real-time aiding in complex dynamic systems. We believe that a system developed to function both as a tutor and an aid is more cost-effective over time, and is more motivating for operators to learn, to use and to trust. The goal is to design a tutor that not only compensates for a novice operator's deficiencies in knowledge and skills, but also prepares the operator to use the tutor as an assistant after training.

The tutor/aid paradigm proposes characteristics of an integrated intelligent tutoring and aiding system. The heart of which is a pedagogy structure that address "how and when and what" to teach to the novice operator of complex systems that eventually uses the tutor as an aid. Before the theory of the tutor/aid paradigm was defined, we investigated the recent developments in the field of intelligent tutoring systems. While research in intelligent aiding in complex domains has been emerging

with existing and successful methodologies, it is not the case with intelligent tutoring systems.

2.1 Academic vs. Technical Tutors

A survey of most of the ITS projects shows that the application domains prevalent in the field have been academic subjects matters such as geography, mathematics and computer programming. The application of ITS for training in engineering domains such as electronics and power plants has begun only in recent years. The distinction between academic ITSs and technical training ITSs is crucial because methods and concepts that work in academic tutors may or may not work in technical tutors because of the nature of the target domain and the target student that each class of tutors is generally designed for.

Consider the world of algebra and the world of steam propulsion plants. A tutor preparing a student for the former is very different from one for the latter due to the difference in knowledge and skills requirements imposed by the domain. From the vantage point of an individual performing some tasks in a world, a steam propulsion plant is more complex than algebra in dimensions of dynamism, the number and extensiveness of interacting parts, uncertainty and risk (Ref. 14).

Academic tutors differ from training tutors not only in "what to teach", but also in "who" they are teaching. In industry, novice operators who are mature and technically oriented adults are highly motivated to learn and be trained specifically because of their vested interest in job performance, and in most cases, because their job mandates them to do so. In contrast, whether the students are first-graders or college freshmen, in an academic environment, students often learn for the sake of learning and in preparation for future vocations. Thus, at the time, they usually do not have a job at stake.

2.2 Dimensions of an ITS

From a design perspective, an ITS can be addressed from three aspects: communication, instruction and knowledge (Ref. 1). The communication dimension concerns the "interactivity" between the student and the tutor via the interface. The interactivity of recent

learning environments has been greatly facilitated by the advancement in computer graphics and interaction techniques.

The instructional dimension concerns the representation of teaching knowledge and of the student so that individualized instruction can be imparted. Of the three, the instructional dimension is the most difficult and least developed. Most ITSs to date embody some pedagogical philosophy but lack a structure that explicitly encodes the teaching knowledge. In addition, many student models to date are simply good recordkeeping of student actions.

The knowledge dimension concerns the representation and presentation of the target domain. This dimension is probably the most developed, benefiting from the research and experiences in artificial intelligence.

The representation issue is especially critical in *knowledge-rich* domains, where the tutor teaches the conscious and accurate use of knowledge in a high-level problem solving task such as electronic troubleshooting (Ref. 4). Whereas in *high-performance* domains such as air intercept control, the focus is on speed and automaticity: the tutor trains a student to perform some skills as effortlessly and reliably as possible (Ref. 4, Ref. 11). Most ITS research to date has emphasized knowledge-rich domains or knowledge-rich components of the domain such as troubleshooting and fault diagnosis.

2.3 Scope of the Tutor/Aid Paradigm

In summary, based on the survey and analysis on current developments in ITS, the tutor/aid paradigm is an attempt to address some research needs in the field. First, the current work emphasizes the design of an ITS for technically-oriented adults in a complex and dynamic environment. Second, the focus is not just on training some knowledge component aspect of the task, but on training for the successful operations of supervisory control activities in realistic, time-constraint scenarios. Third, the tutor/aid paradigm proposes a pedagogy structure that explicitly defines the training process of the integrated tutor and aid.

Fourth, instead of designing an ITS from scratch, the tutor/aid paradigm capitalizes on the

emerging research in operator associates. Specifically, the current research enhances a validated operator's associate architecture that is based on a prescriptive model of human performance for supervisory control to include tutoring capabilities. The Operator Function Model (OFM, Ref. 9), in effect, provides the intelligence for the ITS by defining the target training state towards which a novice operator should be trained.

The remaining of the paper briefly discusses GT-VITA (Georgia Tech-Visual Inspectable Tutor and Assistant), a proof-of-concept ITS that is an initial attempt to illustrate and validate the tutoring aspect of the tutor/aid paradigm. Details of the tutor/aid paradigm can be found in Ref. 3. The aiding aspect of the paradigm is beyond the scope of this research but is addressed and complimented by a companion project on cooperative problem solving (Ref. 6).

3. FROM GT-POCC TO GT-VITA

The GT-VITA project can be viewed as a direct response to the training needs and problems of existing systems at the Mission Operations Division of GSFC.

A necessary first step of the project is to conduct extensive analysis on the NASA data-information system and the operator's knowledge and task requirements within the Payload Operations Control Center (POCC). Based on this analysis, we developed an interactive, real time simulation system called GT-POCC (Georgia Tech-POCC, Ref. 2).

3.1 GT-VITA Interface

GT-POCC provides the simulated task environment upon which GT-VITA is built up. GT-VITA is a graphical, interactive, real-time intelligent tutoring system. GT-VITA provides a graphical and animated representation of the NASA data-information system that allows a student to visualize system components, behavior and their relations at a various level of details. The graphical interface was developed in direct response to some concerns that were identified in our knowledge analysis. Operators at the POCC do not have a broad, top-down perspective of the NASA system (Ref. 7). Such a perspective has been argued to be crucial for

appropriate learning of and reasoning about a system's normal behavior and its reactions to different types of failures (Ref. 5).

The graphic interface of GT-VITA is not only used during training, it is intended to function as support for real-time operations after training, as illustrated in the companion project GT-MOCA (Georgia Tech-Missions Operations Cooperative Assistant, Ref. 6). Figure 1 is the NASA system graphic display, one of many used both for GT-VITA and GT-MOCA.

GT-POCC and GT-VITA have been implemented in C++ on Sun SparcStation platforms. The user interface have been created with Transportable Applications Environment Plus (TAE Plus, Ref. 12), an interface builder developed at GSFC.

3.2 GT-VITA Tutoring Capabilities

The tutoring capabilities of GT-VITA are captured in a pedagogy module that defines the instructional goals and strategies of the tutor in the form of eight lesson types. Figures 2 shows the pedagogy network as proposed by the tutor/aid paradigm. At present, GT-VITA implements seven of the eight lessons in three phases: declarative, procedural and practice. Right now, GT-VITA is not yet capable of the dynamic transition between lessons that the paradigm ultimately proposes.

A typical training session in the GT-POCC domain is as follows: In the declarative phase of training, the student learns about the various NASA components such as spacecraft subsystems and ground computers, followed by the behavior of the NASA system in terms dynamic data flow between components. During this phase, the student also explores the NASA system both from the visual perspective as well as from the perspective of the tutor's internal hierarchical representation of the system.

In the procedural phase, a student learns about the various satellite ground control activities first via tutor's demonstrations, followed by tutor's instruction to perform the activities.

Finally, in the practice phase, a student has the opportunities to apply previous learned

declarative and procedural knowledge in real-time scenarios. The consensus among POCC operators is that all the concepts and tasks are not difficult by themselves. It is when they have to be applied and coordinated under limited time and dynamic conditions. In the first type of practice lesson, the tutor provides direct feedback for untimely or erroneous actions. In the second type of practice lesson, the tutor only intervenes during critical phases of the real-time scenario.

4. GT-VITA EVALUATION AND RESULTS

An evaluation of GT-VITA was conducted on site at GSFC, in June 1991. Sixteen NASA personnel volunteered six to nine hours of their time to participate in the evaluation. The subjects included software testing engineers, administrators, spacecraft specialists and computer operators. The subjects varied in their experience with computer technology (e.g., using the mouse). They also varied in their general knowledge of the NASA system and the duties of a POCC operator. However, none of the subjects had on-the-job experience as a POCC operator. All subjects were trained on GT-VITA with all seven lessons. The evaluation procedure consisted of subjective questionnaires, and objective performance measures.

In general, results show that GT-VITA was perceived favorably by all the subjects in terms of what they learned. All subjects agreed that GT-VITA would be useful for training novice POCC operators.

An analysis of the performance data collected for the practice lessons showed that regardless of the subjects' differing background, all subjects performed comparably and even committed consistent errors in the practice lessons. These results can be attributed to the flexibility and adaptability afforded by GT-VITA.

Overall, the response of other NASA training personnel and managers have been very positive. Some have commented that GT-VITA could save them several months of training time. GT-VITA is currently being fielded as it is at NASA, and also modified for the next generation T-POCC (Transportable POCC) applications. Eventually, the two different

versions will be integrated with the overall training program for novice satellite ground control operators.

In conclusion, the GT-VITA project represents a first attempt in understanding and addressing issues in computer support systems for operators of complex dynamic systems. Many research avenues need to be conducted further to validate the full impact of the tutor/aid paradigm. The tutor/aid transition is being investigated at Georgia Tech. Other enhancements to GT-VITA such as student modeling and curriculum transition are being explored at Honeywell.

5. ACKNOWLEDGMENTS

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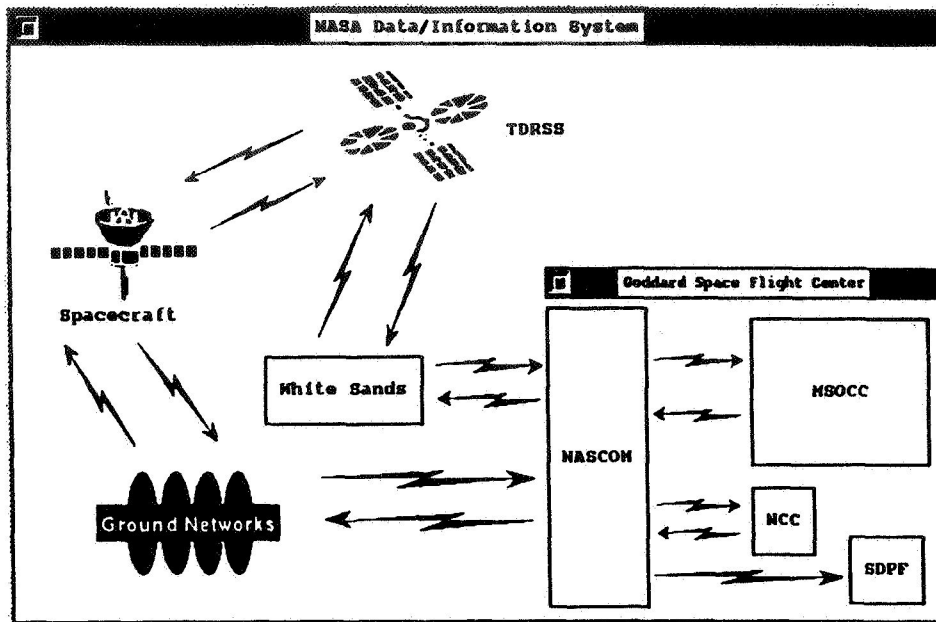


Figure 1. The NASA System Graphic Display of GT-VITA

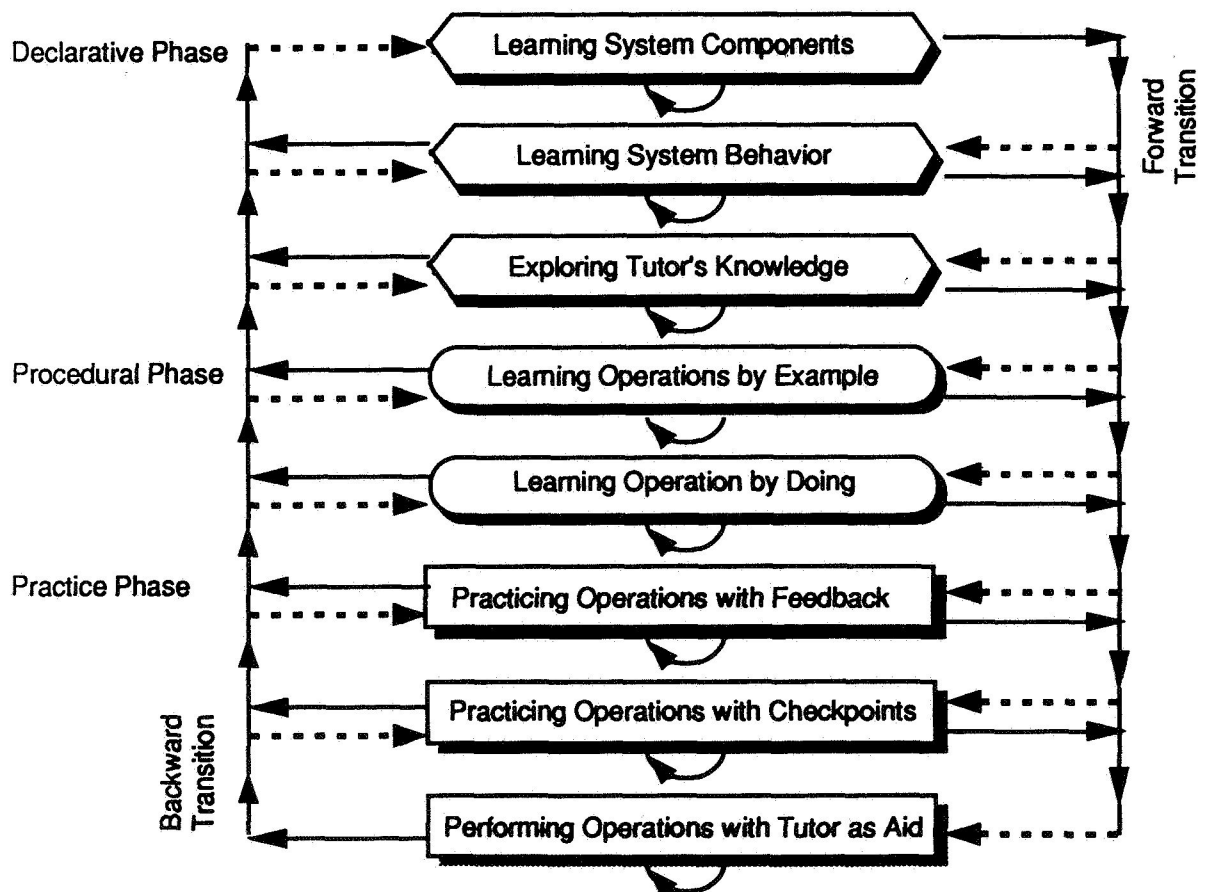


Figure 2. The Pedagogy Network of the Tutor/Aid Paradigm