N91-20708

OFMspert: An Architecture for an Operator's Associate that Evolves to an Intelligent Tutor

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Introduction

With the emergence of new technology for both human-computer interaction and knowledge-based systems, a range of opportunities exist to enhance the effectiveness and efficiency of controllers of high-risk engineering systems. This paper describes the design of an architecture for an operator's associate--a stand-alone model-based system, designed to interact with operators of complex dynamic systems, such as airplanes, manned space systems, and satellite ground control systems, in ways comparable to that of a human assistant. The presentation will have several sections. The first describes the OFMspert architecture. The second describes the design and empirical validation of OFMspert's understanding component. The third describes the design and validation of OFMspert's interactive and control components. The paper concludes with a description of current work in which OFMspert provides the foundation in the development of an intelligent tutor that evolves to an assistant as operator expertise evolves from novice to expert.

OFMspert Architecture

OFMspert--Operator Function Model (OFM) expert system--is a stand-alone knowledge-based system that is intended to function as an assistant to a human expert. This philosophy is different than many knowledge-based systems in which the computer system replaces or operates suggestions. OFMspert is intended to be a subordinate to an experienced operator, possibly replacing a less skilled assistant. As a result, OFMspert includes features such as dynamic allocation of functions between the human and computer controllers, interruption of OFMspert by the human user, and 'repair' of misunderstandings.

OFMspert (Figure 1) has two primary components that enable it to 'understand' operator activity in the control of a complex dynamic system. The first is the operator function model (OFM). The OFM is a representation of operator activity in dynamic systems that represents the interrelations between dynamic system states and operator functions. Each function is hierarchically decomposed down to the level of individual operator actions. The OFM defines the knowledge base that OFMspert uses to hypothesize expectations of operator activities and to infer why a given action was undertaken. Figure 2 depicts a generic OFM

The second major OFMspert component is a blackboard on which OFMspert dynamically constructs expectations of current operator function, subfunctions, tasks and actions. The blackboard, called ACTIN (actions interpreter), keeps track of model-derived expectations and data-derived interpretation of operator actions. ACTIN's hierarchy is a dynamic representation of the operator function model (Figure 3).

ACTIN and the OFM define OFMspert's understanding component. OFMspert's utility and effectiveness depend on its ability to 'understand' accurately.

The Validation of OFMspert's Intent Inferencing (Understanding) Component

In order to evaluate OFMspert's intent inferencing effectiveness two experiments were conducted in the domain of satellite ground control. The first experiment compared OFMspert interpretations of operator activity with a domain expert's interpretations. The second experiment involved verbal protocols in which subjects controlling the system stated the reasons for what they were doing; their reasons were then compared to OFMspert's interpretations. In both cases, OFMspert's understanding was quite impressive. Figure 4a and 4b summarize the empirical results. Areas of mismatch were due primarily to model errors in the OFM (correctable) or long-term planning and browsing--operator functions that the OFM had not represented.

We were very pleased with the intent understanding component. Based on its understanding capabilities, OFMspert was augmented with control properties in order to function as an assistant.

OFMspert as an Assistant

Based on the OFM and Rasmussen's abstraction hierarchy, a user interface to OFMspert was designed. The human operator could request a range of assistance from OFMspert. The types of assistance were identified based on the operator functions and subfunctions defined in the OFM. Each OFMspert function was further decomposed into levels of available assistance so that the user could dynamically choose how much or how little assistance was desired.

An extensive evaluation of OFMspert as an assistant (Figure 5) was conducted, again in the domain of satellite ground control. Trained subjects controlled a simulated satellite ground system using both OFMspert and a well-trained human assistant. Results showed that though the style of use varied, controllers with OFMspert as an assistant controlled the system as effectively as controllers with a human assistant (Figure 6).

This experiment provided strong evidence for the possibility of using knowledge-based technology to augment operator control capabilities. Subject responses indicated that they liked the highly interactive and flexible user interface to OFMspert--and, in fact, would prefer even more capabilities for dialogue and repair of miscommunication. Indeed, for the design of knowledge-based systems for complex domains, the human-human metaphor is an intriguing avenue for further research.

OFMspert as a Tutor that Evolves to an Assistant

Current research at Georgia Tech examines the use of OFMspert as an intelligent tutoring system (ITS) that can evolve to an assistant as the user's skills evolve from novice to expert (Figure 7). With the OFM, OFMspert provides the domain knowledge (static, dynamic, and operational) needed in an ITS. In addition, OFMspert's blackboard, ACTIN, represents expected operator activity, interprets actual activity, and is able to assess the differences. As such it provides the initial definition of the teaching component of an ITS.

Finally, as a tool that is designed to function both as a teacher and as an assistant, OFMspert may be a very viable architecture. With two applications, the assistance function being long term, it is easier to justify the development costs that such systems inevitably incur. From an operations standpoint, novice users may be more likely to spend the time interacting and using a training system that they know will eventually become a tool that they use operationally.

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Many people participated in and contributed to this research. They include T. Govindaraj, Richard Robison, Kenny Rubin, Patty Jones, Jim Bushman, and Rose Chu. The research was supported in part by a NASA Ames grant "Operator Function Modeling: An Approach to Cognitive Task Analysis in Supervisory Control Systems," NASA Ames Grant NAG 2-413, Dr. Everett Palmer, Technical Monitor, and NASA Goddard Space Flight Center grant, "Human-Computer Interaction in Distributed Supervisory Control Tasks," NAG 5-1044,Walt Truszkowski, Technical Monitor.

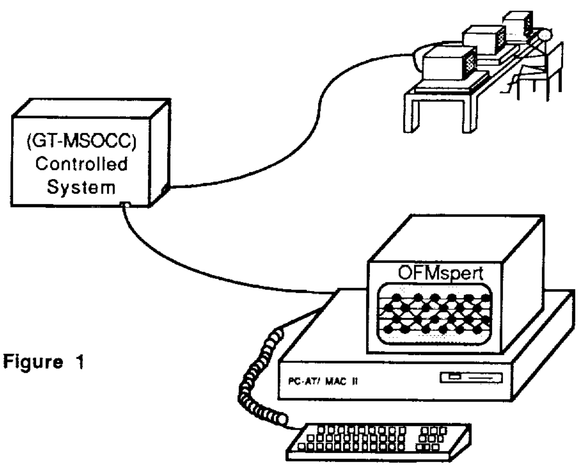
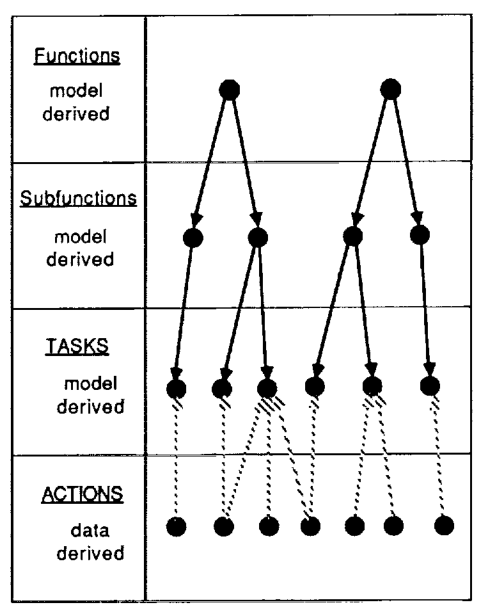
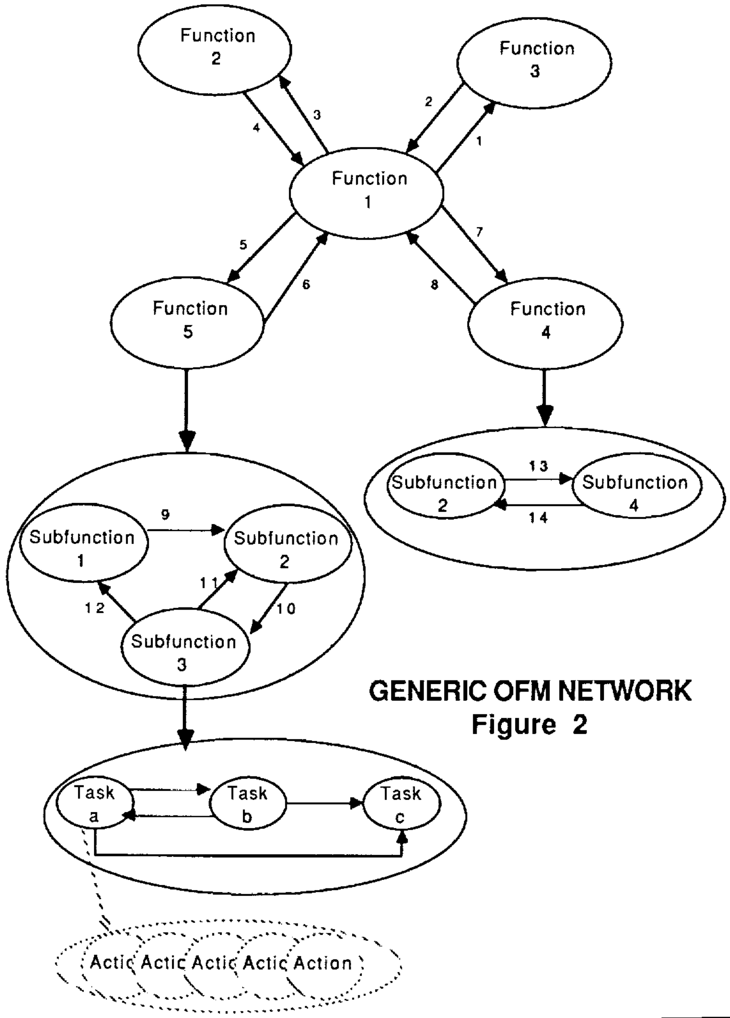


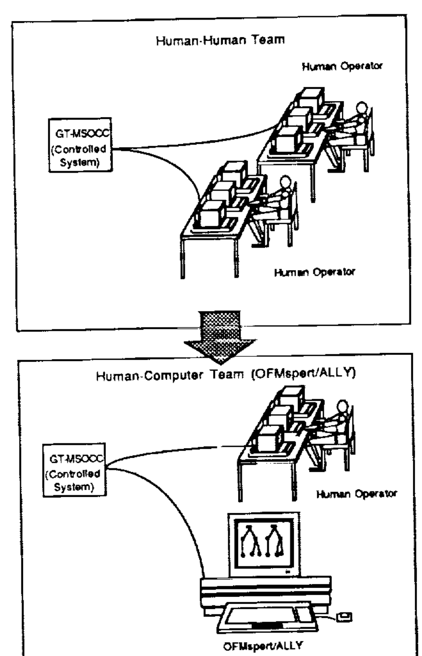
Figure 1



ACTIN's Intent Inferencing Structure
Figure 3



GENERIC OFM NETWORK
Figure 2



ALLY: An Operator's Associate
Figure 5

Experiment 1: Average Percentage of Equivalent Interpretations Between ACTIN and a Human Domain Expert. (Ordered by Rank).

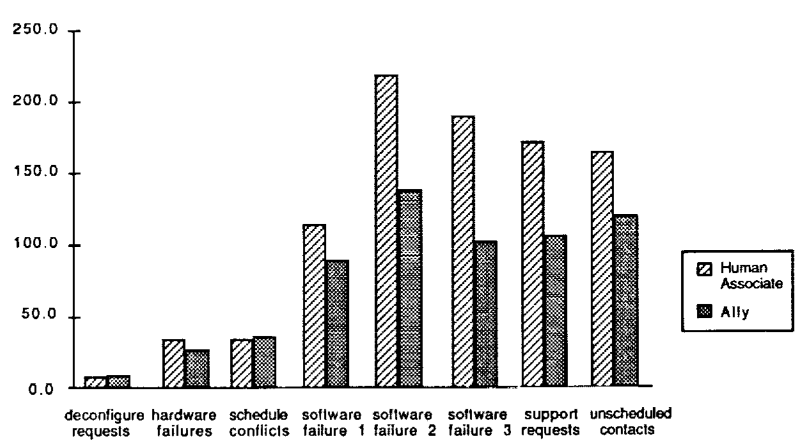
Configure	100 %
Deconfigure	100
Answer	96.2
Replace	94.8
Equipment schedule page requests	90.3
Mission schedule page requests	85.7
Interior telemetry page requests	84.3
Endpoint telemetry page requests	76.5
MSOCC schedule page requests	75.5
Telemetry page requests	70.2
Reconfigure	60.8
Events page request	53.9
Pending page request	33.3

Figure 4a

Experiment 2: Average Percentage Of Equivalent Interpretations Between ACTIN And Verbal Reports. (Ordered By Rank).

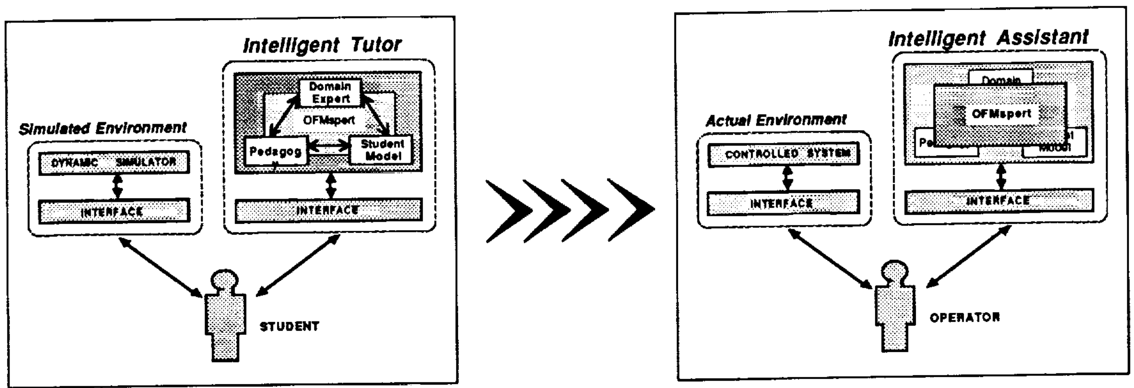
Configure	100 %
Endpoint telemetry page requests	100
Deconfigure	97.1
Telemetry page requests	96.3
Answer	91.4
Reconfigure	91.2
Interior telemetry page requests	87.1
Replace	75.3
Mission schedule page requests	66.7
MSOCC schedule page requests	50.3
Equipment schedule page requests	21.8
Events page request	17.7
Pending page request	16.7

Figure 4b



Comparison of Human Associate and Ally

Figure 6



During Training

During On-Line Operations

Architectural evolution of an intelligent tutor to an operator's assistant

Figure 7