Automated Behavior-Based Interaction Customization for Military Command and Control

Scott D. Wood
Soar Technology, Inc.
3600 Green Court, Suite 600
Ann Arbor, MI 48105 USA
+1 734 327 8000
swood@soartech.com

ABSTRACT

In this paper, we describe a proposed architecture for behavior-based customization of user interaction with an adjustably autonomous system. Our approach will use a GOMS-based task representation and Bayesian plan recognition to determine the user's active tasks. The active task set will be modeled using a cognitive architecture to assess cognitive, perceptual, and manual workload. The resulting user assessment will then be used to determine what, where, when, why, and how the autonomous system can assist the user, adjust its level of autonomy, or perform other customizations to improve the user's overall performance. The system will be developed in the context of military command and control. The design of this architecture raises a number of scientific and engineering challenges, which we will also discuss.

Keywords

Intelligent user interface, plan recognition, GOMS, cognitive modeling, command and control.

INTRODUCTION

The Army's vision of the future for armored and mechanized military structure includes the use of mixed teams of human and robotic forces on a dynamic and rapidly changing battlefield. Successful implementation of this vision will require autonomous and semi-autonomous robotic forces and a command and control infrastructure that will allow human, robotic, and mixed teams to be controlled quickly and easily. For maximum effectiveness this infrastructure should allow human commanders to control the robot teams in a manner similar to how they command human teams, that is, in the language of the military, not the language of robotic control theory. Furthermore, the human interface for robotic command and control must simplify the controller's tasks and automate processes in such a way that the cognitive workload is reduced, situational awareness is enhanced, and situational control is preserved.

ICF: AN INTELLIGENT CONTROL FRAMEWORK

To reduce the inherent complexities of future warfare, we are researching and developing an intelligent control framework (ICF) from which to create warfighter interfaces that will automate and assist with warfighter tasks, and to augment warfighter abilities. This framework is based loosely on the reference architecture presented in [1], but organized in abstraction layers from which specific interfaces and applications would be created. Collectively the applications, agents, and services implemented for a specific domain might represent a cooperative technology that could integrate and apply various forms of user assistance in a holistic manner. We have initiated this research with the development of two separate systems for intelligent human-system interaction: one for task automation and one for enhanced information delivery. Each of these systems represents core technology in for the ICF, but neither will be fully functional without some form of behavior-based adaptation or customization.

Task Automation

The first ICF component, the CIANC^3 (Cooperative Interface Agents for Networked Command, Control and Communications, [2]) project, is aimed at assisting with complex, coordinated sequences of battle commands. It incorporates a cooperative interface agent system to act as an intelligent control layer between the user and the underlying command and control subsystems. The agents are being developed using the Soar Cognitive Architecture and are organized in a way similar to that of military command staffs. The system uses three core agent types corresponding to the roles of command, control, and communications, which perform general organizational functions for every mission type. There is also a larger set of more specialized agents that correspond to tactical functions including maneuver, effects, sensing, and others. When employed at the level of a company commander, the system might coordinate multiple units (such as sensing and shooting platforms) for a single mission. When used at a lower echelon, the system might instead coordinate the subsystems of a single vehicle or attached robotic assets. While this system focuses on user actions, a similar project focuses on user perception.

Information Delivery

Our second system, from the Information Configuration for Augmented Warfighter Readiness [3] uses a similar set of cooperative agents to customize the delivery of information to assist in the assimilation and understanding of knowledge as it relates to specific user tasks. It uses the same core set of command, control, and communication agents for high-level agent organization as before, but with a different set of task-specific agents. Here the specialized agent types correspond to technical functions regarding information interaction, such as acquisition, filtering, fusion, transformation, etc. With this system the domain is intelligence analysis for time-sensitive targeting, but the rapid situational understanding is critical in many time-, mission-, and safety-critical domains where events can often overwhelm users.

Common Need: Behavior-Based Customization

While either of these systems could be useful as statically-configured interaction tools, their full benefit will only be realized when their behavior can be adapted to the user's immediate task needs. As such, there must be a means for determining in which tasks the user is actively engaged (we are assuming that users in inherently complex domains are rarely engaged in only one task at a time). This includes the ability to reason about the relative importance of user task types, environmental events, and the user's cognitive abilities. The goals should be to automate those tasks that are mundane or tedious, provide information only when it is useful and in a form where it is most usable, and be able to control tasks of which the user may not be aware or which the user is unable to accomplish. If successful, such a system would result in a symbiotic relationship between the user and the system. In other domains, and from earlier IUI work, we know that there can be severe negative consequences from attempting to create fully automated systems that relegate users to merely a monitoring mode (e.g. see [4], [5]). Furthermore, the optimal level of automation is context dependent; for the same task a user may wish to have different levels of control over task execution in different situations. For example, the task, attention, and risk characteristics while maneuvering a vehicle on a highway are very different from those while conducting a peacekeeping mission in a hostile urban terrain. So, an additional, and important application for behavior-based modeling and customization is to support adjustable autonomy. To integrate the described ICF systems into a form that dynamically supports user needs, we must develop a suite of behavior recognition, modeling, and reasoning tools that support interaction customization in general, and adjustable autonomy specifically. We call this proposed ICF component an Adjustable Autonomy Module.

ADJUSTABLE AUTONOMY MODULE

The Adjustable Autonomy Module (AAM) is a component within the ICF that provides intelligent and autonomous ICF components with the knowledge of when, where, and how to assist the user. It will do this by understanding the user's situation in terms of tasks, mental workload, vehicle or system status, subordinate status, external events, commands from higher echelons, and other critical factors. This automated situation understanding will be a process that includes:

1) Sensing external and user stimuli,
2) Recognizing new user and system tasks or progression through existing tasks,
3) Simulating user actions to determine information and other task needs
4) Updating user and situation models,
5) Reasoning over model information to determine automation levels, and
6) Updating control instructions for automated processes.

Figure 2 shows a conceptual architecture for the AAM. It takes as input actions from the user, system status information, and external events related to the warfighter's mission, function, and current tasks. As output, the system produces a model that reflects the understanding of the user's current situation, and a table of adjustably autonomous sub-systems and current tasks with associated autonomy levels. The autonomy levels indicate to these sub-systems which tasks they should be engaged in at any time, to what degree they should be performing or monitoring those tasks, and links back to information in the user model. The following sections describe the operation of the AAM with regard to the six processes listed previously.

Sensing

In the sensing process, input is collected from three main sources: user actions, such as keystrokes, spoken commands, and other forms of human-system interaction; world and environmental events, such as new threats, targets, or commands from higher echelons; and system actions, such as changes in system status, completion of system or user-requested functions, and other information updates from the system that may affect the user. This new information is then used as input to the Task Recognition process.

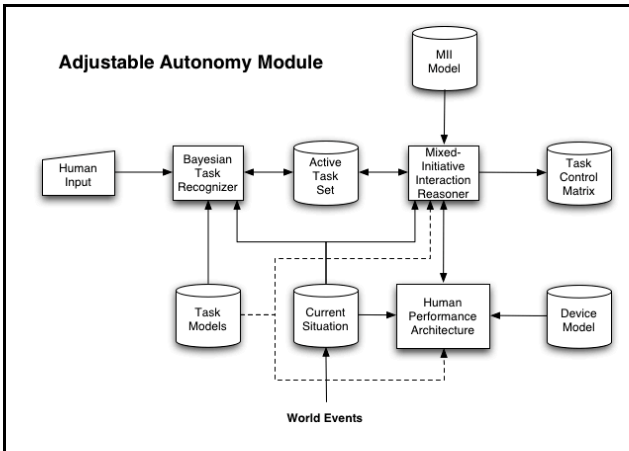

Figure 1. Flow diagram for an Adjustable Autonomy Module built around user behavior recognition, modeling, and reasoning components.

Modeling

Models necessary for the AAM include task, user, discourse and situation models. Task models are comprised of a machine-executable form of hierarchical task decomposition that can account for all user functions. This includes high-level tasks such as completing specific types of missions, low-level tasks such as launching a weapon, mid-level and operational-level tasks where low-level tasks are composed to accomplish high-level goals, and even cognitive-level tasks where users collect information in support of high-level decisions. User models are used by the system to collect information about the current user state and are used to determine how and when to help the user given current task constraints, current and past performance, and user preferences and styles. Discourse models (possibly an augmentation of the task models) specify how and when to communicate with the user. Situation models are used by the system (and the user) to understand how current world events are affecting survivability, mission success, and other factors of interest (e.g. Commander's Critical Information Requirements). Ultimately, situation models provide the information that allows the system to reason about how the user is contributing (or failing to contribute) to various success criteria, in which tasks the user is attending or should be attending, and where and how the system should assist. Each type of model will typically consist of a static component that represents doctrinal information, dynamic model instances that represent the current situation, and executable components that can be simulated for value judgments on future courses of action. Newly sensed information is used to update existing instances of dynamic models and create new dynamic models as necessary. The current dynamic model set, with other information not specifically modeled, is used for other reasoning processes in the AAM.

Task Recognition

A key reasoning process is task recognition: using newly sensed information to determine which tasks in which the user is currently engaged, including new tasks that the user has added to the current task list and progress made on ongoing tasks. Additionally, this form of reasoning will also be able to identify events of which the user may not yet be aware, that would or should precipitate the creation of new tasks. Task recognition will be accomplished by combining the various modeling techniques described previously with a Bayesian form of statistical reasoning on event and activity patterns. The resulting understanding of the user's current task load is fed back into appropriate models at the end of the task recognition process for each cycle. It is also fed forward to the Simulation Process to better understand and predict the user's needs in the near future.

Simulation

Simulation is used in the AAM as a planning tool to determine possible futures regarding the current mission and tasks, and the user's cognitive state under the current situation. A human performance engine based on the GLEAN human performance architecture will be used to assess the user's cognitive workload for each task independently and for the entire set of active tasks collectively. The goals of this assessment are to understand the effect of the current situation, as driven by the situation model and the current task set, on the cognitive and performance abilities of the user. Specifically, metrics that will be derived are working memory load, resource bottlenecks, potential errors, necessary information elements and key decision points.

Reasoning

The Mixed-Initiative Reasoner takes information from the sensing, modeling, and simulation steps and considers each task in the active task set along several dimensions to determine for which tasks it should assist, which must be under user control, and which can be safely delayed or shifted to system control. It must consider which tasks are most critical, which most timely, which are most contributing to the user's cognitive workload, which task the user is currently attending to, and to which tasks need to be attended. It must also consider which portions of each task are best suited to human control and which to computer control, based on task and human performance characteristics, user preference and proficiencies, doctrine, rules of engagement, and policy (e.g. legal issues). While there will be some tasks that will always be human- or machine-driven, a great many will vary according to the task type and situation. For those tasks where mixed-initiative interaction is appropriate, the reasoning system will help determine who has control and, in the case of the system, the level of autonomy for that task.

Updating

At the end of each cycle of the AAM, control tables, and system models are each updated with the results of the reasoning and other processes. In addition, the user is informed of any planning, autonomy or initiative changes, and other critical information determined by the AAM.

ISSUES RAISED

Design of the adjustable autonomy module architecture has raised several scientific and engineering issues that must be addressed. These issues would seem to be critical within any application of behavior-based customization.

How does behavior-based customization fit within a larger control hierarchy/system?

In any complex system the user interface cannot operate in isolation. If the interface is customizing the user interaction and experience, how best can the behavior reasoning system control and interact with underlying system functions?

How well can it deal with multi-tasking?

Given that users rarely do one thing at a time, how best can individual user actions be interpreted and assessed with regard to current or new tasks? How can task progress be accurately measured? How can we deal with canceled, intermittent, or suspended tasks?

How will the task models need to be augmented?

Traditional task models such as GOMS work well for describing many types of human-computer tasks, but they do not necessarily capture adequate information for customizing interaction. How must these traditional modeling techniques be augmented to adequately deal with expected world events, task priorities, user information needs, etc., and use that additional information to more accurately recognize user action plans?

What sort of reasoning will be required?

Most early and existing behavior-based customization systems utilize relatively straightforward value judgments regarding the utility of the system taking action versus the cost of not doing something (e.g. [6]). Is this level of reasoning adequate for military and other complex domains or must more knowledge be applied to the valuations?

How will the autonomous systems need to be redefined to work with adjustable autonomy?

Most agent-based and other automated systems are designed to be either fully automated or semi-automated in a predefined way. How must these underlying technologies be redesigned to enable smooth transition from user control to system control without creating an undue mental context-switching cost on the user?

How will users interact with the system for maximal benefit?

In which domains, contexts, and task-types can behavior-based customization systems truly change the user experience for the better? Where should they never be used? How does long-term use of such systems affect user learning, problem solving, performance, and expertise?

CONCLUSIONS

While we believe behavior-based adaptive systems offer much promise for reducing the complexities of using inherently complex systems, there remain many critical and pervasive problems that must be addressed before such systems are truly useful.

AUTHOR BACKGROUND

Scott D. Wood, Ph.D., is a Senior Scientist and Vice-President, Strategy with Soar Technology. Dr. Wood has over ten years of research and industry experience in the areas of software development, e-business consulting, cognitive modeling, and human-computer interaction. This work included optimizing workflows and interface usability through task analysis, and in designing web solutions for e-business applications. His research areas include human error modeling, error-tolerant design, and applying intelligent systems techniques to simplifying human-system interaction. In addition, he spent four years in the U.S. Army attached to 5th Special Forces Group and other special operations units. He earned a B.S. in Computer Science (1990) from Tulane University, and M.S. (1994) and Ph.D. (2000) degrees in Computer Science and Engineering from the University of Michigan, Ann Arbor.

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REFERENCES

1. Maybury, M.T., Wahlster, Wolfgang, *Readings in Intelligent User Interfaces*. 1998, San Francisco, California: Morgan Kaufmann Publishers, Inc. 648.

2. Wood, S.D., *Cooperative Interface Agents for Networked Command, Control, and Communications (CIANC^3): Phase I Final Report*. 2003, United States Army Research Institute for the Behavioral and Social Sciences.

3. Zaientz, J., *Information Configuration for Augmented Warfighter Readiness, Phase I Final Report*. 2003, Soar Technology: Ann Arbor.

4. Sheridan, T.B., *Telerobotics, Automation and Human Supervisory Control*. 1992, Cambridge, MA: MIT Press.

5. Roth, E.M., J.T. Malin, and D.L. Schreckenghost, *Paradigms for Intelligent Interface Design*, in *Handbook of Human-Computer Interaction*, M.G. Helander, Landauer, Thomas K., Prabhu, Prasad V., Editor. 1997, Elsevier: Amsterdam.

6. Horvitz, E. *Principles of Mixed-Initiative User Interfaces*. In *ACM Conference of Human Factors in Computing Systems*. 1999. Pittsburgh, Pennsylvania.