Information for Successful Interaction with Autonomous Systems

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Abstract

Interaction in heterogeneous mission operations teams is not well matched to classical models of coordination with autonomous systems. We describe methods of loose coordination and information management in mission operations. We describe an information agent and information management tool suite for managing information from many sources, including autonomous agents. We present an integrated model of levels of complexity of agent and human behavior, which shows types of information processing and points of potential error in agent activities. We discuss the types of information needed for diagnosing problems and planning interactions with an autonomous system. We discuss types of coordination for which designs are needed for autonomous system functions.

We are developing design concepts for collaborative intelligent systems to support future mission operations teams. Teams of distributed computer and human agents will collaborate, in multi-agent mixed-initiative operations. Software tools, including software agents, are needed to support work processes and interaction in teams that include autonomous agents. In mission operations teams, the level of involvement of intelligent agents and human team members will vary significantly. Software agents will be continuously engaged in focused autonomous tasks, while human agents will periodically manage multiple tasks, including occasional interaction with autonomous systems. Human activities include managing information, understanding past, ongoing and planned operations and situations, solving problems, and negotiating and participating in carrying out solutions.

There are several ways in which interaction in such teams is not well suited for classical models of coordination with autonomous systems (Nodine, Chandrasekara, and Unruh 2001). Human shift work and on-call work makes role-agent relationships unstable. Agents can vary in complexity and sophistication of reasoning and representation. There are potential delays in information and communication. Tasks may be interrupted and discontinuous, and may not be tightly coordinated. "Plans" with multiple tasks and fluctuating resources are likely to be ill-structured and flexible. We will consider design of software agents for loose coordination and information management.

Loose Coordination

To shift between autonomy and interdependence, autonomous agents need to provide information to support loose coordination, and to orient team members as they pass in and out of team activities. Orientation during handover is not merely a matter of information access or retrieval, since context can be stale or missing (Reddy, Dourish and Pratt 2001; Chalmers 2002). Work is required to organize, understand and analyze histories of information and actions from multiple sources (Danzitch et al. 2002). There is significant risk of misunderstanding, being distracted and forgetting information, which can lead to inappropriate actions and surprises (Malin et al. 1991; Christoffersen and Woods 2002; McFarlane and Latorella 2002).

Several means of loose coordination among human teams are used in control room domains. Loose coordination is supported by voice loops (Patterson, Watts-Perotti, and Woods 1999), by review of console logs or diaries (Jones 1995; Robinson, Kovalainen, and Auramaki 2000), and by handover meetings, briefings and reports between shifts (Patterson and Woods 2001). Anomaly response teams are formed to handle problems that come up during missions (Watts, Woods, and Patterson 1996). During quiet phases of operation of the International Space Station in the early unmanned phase, a single Station Duty Officer covered the longest shift. System experts developed anomaly response instructions for these graveyard shift operators. These instructions specified how to analyze, log, report on events and to notify other team members when data indicated that a problem might be occurring. Loose coordination promotes team awareness of important achievements and failures, significant changes, and problems and issues that may influence upcoming activities. Information is provided not only on events but also on the stance of team members: assessments, priorities and plans. Systems designed to promote awareness provide the following benefits: better management of team movement between loose and tight coordination, reduced and simplified communication, better predictive coordination of actions and more appropriate help and assistance (Gutwin and Greenburg 1999). This awareness can prepare team members for three types of coordination: assuming some or all duties of another agent (handover), participating in coordinated activity with another agent, or controlling another agent (assessing, directing, correcting).

Information Management

As the complexity of tasks, controlled processes and agents increases, the complexity of information management tasks increases. We have analyzed information management by International Space Station control center personnel during shifts and handovers. Figure 1 shows types of information sources and information handling. Chronological console logs are used to keep a stable record of selected material from streams of rapidly changing distributed information. The information is further refined and combined with diverse interim and semi-permanent information sources, to produce summary reports, action lists and formal request packages. These products are used to orient other team members as they prepare to come on shift and take over responsibilities. Other participants also use and review these products from various remote locations as they work cooperatively on issues and plans, and they may respond as needed in person, or by phone or email.

Information management in a control center is challenging. It is difficult keep up with the volatile information sources, while preparing for the next relevant operation and participating in team work on plans and issues. Selecting and recording information from rapidly changing sources can be tedious and repetitious. Voluminous information from multiple sources makes it difficult to successfully find items and move them among tools and team members. It is an important and challenging task to combine and organize information from multiple sources and time scales to support coordination: to orient the next shift worker, or a new team member who will participate in work on a problem.

We are prototyping information agents and a suite of tools that can help address these information management challenges. Intelligent Briefing and Response Assistants (IBRAs) are triggered by data from autonomous agents that manage remote life support systems and handle anomalies. IBRAs select and organize information and enter it into information management tools. IBRAs make console log entries and assemble reports and briefings in issue workspaces. These agents can pass on information

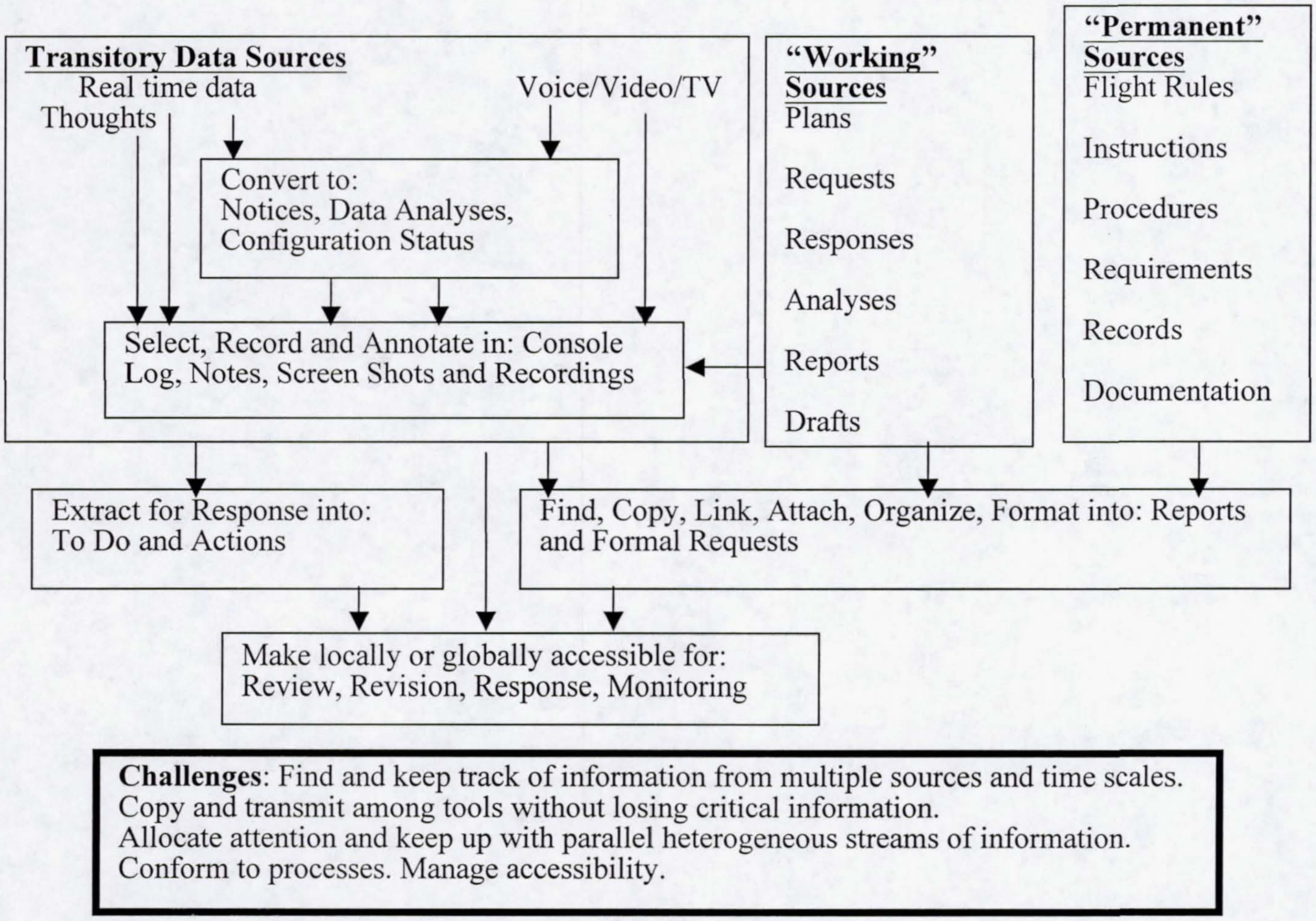

Figure 1. Information Management in a Control Center.

from intelligent system management agents (ISMAs) concerning goals, procedures, control regimes, configurations, states and status. The prototype tool suite has the following features:

- Team members and agents use the same tools, to facilitate incremental agent development and learning approaches that reuse techniques of users.
- Web-based and database-based tools facilitate global and tool-independent access and search.
- Explicit content links between tools enable finding things and keeping track of their locations, minimizing extra data entry effort or error.

The tools in the Team Work Center include:

- Agent Instructions and Procedures – specify Briefing and Response Instructions (BRIs) and team processes and procedures.
- Electronic Console Logger – create a database of log entries, to support review of large log files, automated logging, and generation of reports and custom logs.
- Workspace Manager – collect and share items related to an issue, anomaly or work topic in one accessible workspace, with capability to handle files, links, actions, logs, and paperwork.
- Report Maker – create report formats that collect information from multiple databases (log entries, data, data analyses, notices, actions, procedures, links to workspaces and references) and embed them in editable reports. Example reports include notices, handover reports, and anomaly reports.
- Notifier – manage notification of team members at varying locations in various roles.
- Portal – links to most recently changed data in the tools.

The Team Work Center prototype includes the Portal and three of the tools: Logger, Workspace Manager, and Report Maker. IBRAs use these tools to manage information from autonomous systems (ISMAs) and to increase team understanding of events, assessments, priorities and plans. We have demonstrated feasibility of our concepts and prototypes in a testbed where simulated advanced life support hardware is operated by an autonomous system management agent (Malin et al. 2002).

Avoiding Bad Outcomes

What can autonomous systems provide human team members in the way of orienting information and coordination support, so that unexpected and inappropriate outcomes can be avoided? Cognitive theories of human error (Norman 1981; Rasmussen 1982; Reason 1990) discuss the types of slips and mistakes that can occur at stages in automatic and conscious processing of information, intentions and actions. These theories indicate stages where faulty cognitive processing or faulty information can lead to bad outcomes. We have enhanced and integrated aspects of these theories to address stages of information processing in both human and software agents (Figure 2).

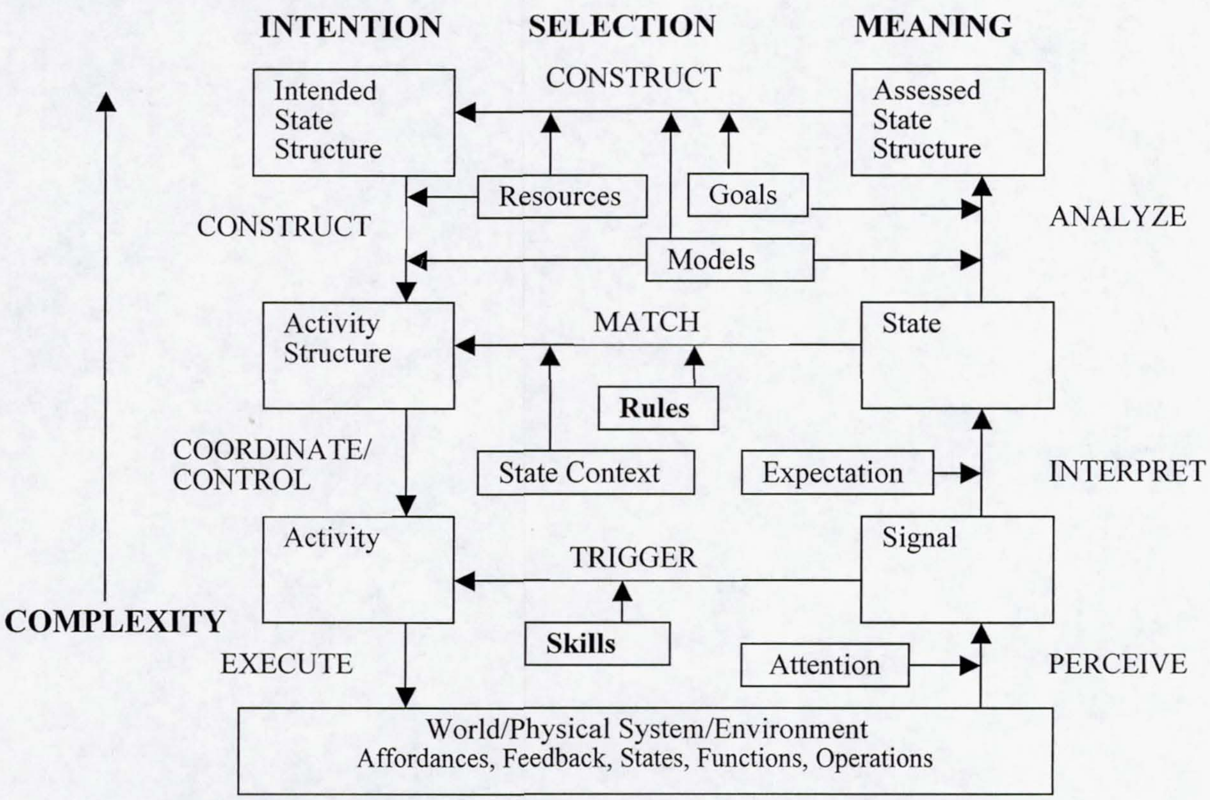

Figure 2. Model of stages of information processing in controlled agent behavior.

This model partitions controlled agent behavior into three levels of complexity and three types of stages of information processing. The three types of stages are processing meaning, making selections and processing intentions. In this theory, an activity is an intended action with associated agent(s) and resources, and standards for evaluating success. The explicit selection stages extend and integrate concepts from other theorists. The processing that depends on skills, rules and knowledge is located at multiple levels of complexity in selection. The three levels of complexity are also used to make distinctions in the scope and permanence of internal knowledge that is required for processing. Internal conscious knowledge includes rules, models, goals and resource knowledge. There are opportunities for error at each of nine stages in processing. There are additional causes of error in faulty skills, rules, beliefs, goals and knowledge that are applied in the stages of processing. Understanding the basis of an action or an error may involve understanding all these factors.

For successful coordination, human agents and autonomous systems need a variety of contextual information concerning agent skills, rules, knowledge, intentions and procedures. How can orientation and interaction be designed to support human agents who will intervene to help autonomous agents manage unexpected events, including agent errors? The amount and variety of information that is needed for understanding increases as agents become more complex. Likewise, information needs increase as agents need more help, from assessment to direction, to correction and then to handover. For coordination, information needs to be understandable in the context of the interaction and types of control that are supported by the agent. These include supported types of direction (opportunities for control) and correction (opportunities for changing skills, rules and knowledge). To assess the appropriateness and urgency of an action and to plan an intervention, it may be necessary to understand much more than action content and status. Other needed information may include the place of the action in an activity structure, how intentions were constructed, what assumptions and models were used in the reasoning, and what goals and standards were applied or constructed for evaluating success.

With increasing information demands, avoiding error in interaction with complex autonomous systems becomes more of an information management problem. Information agents such as IBRAs can perform some of this work. It will be important to build detailed scenarios of types of coordination that autonomous agents are required to support, to learn how to structure and present information that supports understanding and intervention.

Conclusion

In this paper, we have discussed several ways in which interaction in heterogeneous mission operations teams is not well matched to classical models of coordination with autonomous systems. We have presented methods of loose coordination and information management used in mission operations. We have briefly described an information agent and information management tool suite that we have prototyped and demonstrated. We are continuing to design and develop agent and tool capabilities, using the information agent to manage information from many sources including an autonomous agent. We have presented a new cognitive model of agent and human errors that shows types of information processing and points of error in agent activities. We have used this model to show the range of information that may be needed for diagnosing problems in an autonomous system and planning interactions. We call for building detailed scenarios to discover requirements for autonomous system functions to support various types of coordination.

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