Distributed Planning and Monitoring in a Dynamic Environment: Trade-Offs of Information Access and Privacy*

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Abstract - *Distributed planning and monitoring relies on wide, lateral information access that may promote anticipatory behaviour, opportunistic planning and redundant checking and monitoring. The reliability of the resulting system performance is thus enhanced. However, information access control is often critical given the wide adoption of information technology. After presenting findings of several field studies related to the strategies used by distributed team members in managing information access control, we highlight how inefficiencies in information flows are exploited to achieve information access control. We then present implementation strategies for a video-based coordination platform to resolve the trade-off between information access and privacy. In particular, a role-based assignment of information access, along with mechanisms of controlling levels of information access was used to balance the potential loss of privacy with the gain in coordination efficiency.*

Keywords: Distributed planning, autonomy, information access, video based coordination.

1 Introduction

In collaborative work settings, planning is often used as a way to allow coordination of activities, despite the transient nature of plan validity in the face of constant and rapid changes [1]. High levels of uncertainty and rapid changes of events and status often lead to integration of planning, execution, monitoring of activities, and re-planning [4]. Recent studies on planning have highlighted the fact that in many domains planning activities are distributed among a number of people, often at different locations [2, 5, 8, 9].

Distributed planning and monitoring relies on wide, lateral information access that may promote anticipatory behaviour, opportunistic planning and redundant checking and monitoring. In a system described in [2] in the context of air traffic control, for example, close circuit televisions were used to transmit real-time images of the workspaces of neighbouring workers. The intention was to increase awareness among collaborating workers and support implicit communication. With such ability to cross monitor, anticipatory behaviour is supported and systems reliability is likely to be enhanced.

Although there are clear benefits to increased awareness of activities of others, there are costs in terms of individual privacy and perceived loss of autonomy. Nardi et al. [7] described a project in which video cameras and microphones were installed in surgical operating rooms to relay audio and video to remotely situated neurophysiologists. Prior to the project neurophysiologists could access remotely patient monitoring data. With the addition of audio and video, the neurophysiologists could monitor the patient better by the supplemental audio and video information about the progress of a surgery. Additionally, neurophysiologists could schedule their tasks better by utilizing low-workload periods better. However, transmitting video and audio was found to raise serious privacy issues, such as casual conversations in operating rooms being overheard by those remotely situated. In particular, "study participants were concerned about the possibility of their work activities being broadcast to unseen and unknown observers" (p. 514).

In reporting a calendar system, Palen [6] illustrated several types of issues associated with privacy in implementing computerized groupware systems. When calendar is publicly accessible, users may be concerned about judgments made about one's use or allocation of time. Users may be further concerned about the perceived relinquishing of control of one's schedules to others. Technology that brings these concerns can also provide potential solutions, such as access control mechanisms to differentiate access rights by different people to different calendar entries. Users may adapt to the potential threat to privacy through cryptic entries, or simply by omitting appointments in the calendar systems.

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Although information access control is frequently framed under the consideration of privacy, more generally, inherent tensions in the workplace (e.g., differences in opinion, judgments of priorities, and scarcity of key resources) may create resistance to increased levels of awareness. Implementation of information system often fails because of the lack of understanding of a wide range of issues in providing information access.

In this article, we first highlight the findings from several field studies related to the strategies used by distributed team members in managing information access control. In particular, we highlight how inefficiencies in information flows are exploited to achieve information access control. We then present implementation strategies for a video-based coordination platform to resolve the trade-off between information access and privacy. In particular, a role-based assignment of information access was used to justify the loss of privacy with the gain in efficient coordination methods.

2 Field Studies of Distributed Planning

To gain an understanding of distributed planning, several field studies were carried out in the context of operating room management. These studies examined how collaborators work together in managing highly fluctuating schedules and how artefacts are used.

2.1 Setting

The field studies were carried out in a six operating room (OR) suite, which was part of a busy, urban trauma center with over 6,000 patient admissions per year. A list of surgical cases was scheduled ("posted") the day before surgery and distributed to the OR suite by an on-line database. The list of cases posted was almost never the list of cases performed the next day. Often more cases were added on to the list on the day of surgery ("Add-on" cases). Emergency surgery might be performed in the OR suite for those patients who needed immediate life-saving surgery within a few hours of their admission to the trauma center.

As with many other highly complex and dynamic work environments, uncertainty arise from various sources when changes are frequently introduced. In the study setting, change was constant and unpredictable. Examples of changes affecting the planned surgery schedule include cancelled surgeries, unexpected additional surgeries (which result from both newly admitted patients as well as deterioration of previously admitted patients necessitating re-visits to an OR), multi-patient trauma situations in which demand exceeded resource supply, and any external variables impacting OR operational status (unavailable or malfunctioning equipment, lack of supplies, and changes in staffing patterns).

As one of the tools to help manage the fluid situation, a large, dry-erase board (whiteboard) was used. The board measured 365x122cm (12 feet by 4 feet) and held magnetic materials which themselves could serve as surfaces for writing. The board was referred to as the OR board (Figure 1).

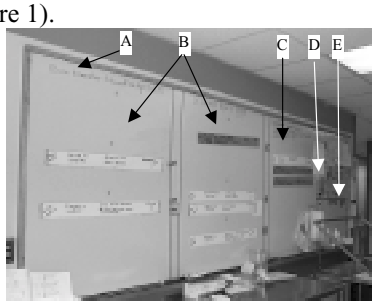

Figure 1. *The OR board. Various areas of the board were used for different purposes. A: General staff information and announcements; B: magnetic case strips for all six ORs in the suite; C: Holding area for case strips, especially unscheduled add-on cases; D: Magnetic staff name tags for off-duty staff; E: Magnetic staff name tags for on-duty staff).*

2.2 An observational study of artifact use

Through observation it was apparent that the OR board was used frequently by many people to collaboratively manage the ORs in terms of the case sequence, staffing requirements, equipment, and supplies. An observational study was initiated to understand how public displays were exploited to support collaborative work [9]. It was found that the OR board was exploited in a number of ways. The location of the OR board afforded the collaborating workers to share the display, often serendipitously. By sharing the board both synchronously and asynchronously, the collaborators used the board as a way to "remember" things, to visually display current status and plans, and to refer to items relevant to collaborative work. These functions of the board were found to support a number of collaborative activities, such as schedule negotiating, jointly planning for staffing and work arrangement, communicating significant changes, and calling attention to disturbances.

The findings from the observational study demonstrated the importance of widely disseminating schedule and staffing information. Collaborators, such as those working in the "upstream" section (i.e. where patients stayed before going to the OR) and "downstream" section (i.e. where patients stayed after leaving the OR), frequently visited the OR board area to get an update of what was on the OR board.

2.3 An observational study of distributed planning and monitoring

To better understand coordination processes in distributed work settings with rapidly changing resource supplies and demands, a second field study was conducted to descriptively capture the efforts by and challenges to collaborators in the management of ORs [4]. The management of ORs is an example of distributed planning, since different stakeholders have access to different information. For example, the nursing manager would know best the staff availability of nurses; the surgeon would know the planned surgery best. Although the schedule of the cases to be carried out was determined one day before, it was found that much effort was necessary to coordinate timing of events and to coordinate changes to the schedules. Since a number of stakeholders were typically involved, planning and changes to plans (re-planning) were carried out in collaborative manners.

Through observation, it was found that the planning and monitoring of ORs was distributed in several aspects. First, management tasks were distributed among different stakeholders. The generation of plans and re-planning was distributed because different care groups provided their input to the process in terms of supplies and demands. A safe and efficient surgical operation requires the contribution from several care groups to ensure adequate human and material resources. Secondly, the planning and monitoring of ORs was distributed at different locations. A successful surgical operation requires the execution and monitoring of several processes, such as preparation of the patient, the equipment, and the OR. These processes occur in different physical locations. Thirdly, the information needed for planning and monitoring of OR was distributed among different people. At any point in time, different collaborators may have access to different information. For example, a nurse may have happened to walk by a patient scheduled to go to the OR but saw that the patient was not ready for the surgery. Last but not least, the task of monitoring and ensuring the dynamic processes associated with ORs was distributed among people. To ensure the smooth flow of events in ORs, several people were found to share the task of monitoring progression of cases, and to anticipate potential obstacles to planned schedules.

Because of the distributed nature of planning in the OR management, information sharing was often cited by the study participants as the most important aspect for a safe and efficient OR suite. De Visser et al. [4] suggested two ways to support distributed planning. One was to provide mobile workers ubiquitous information access (e.g. through wireless personal digital assistants). The other was to provide electronic planning boards so that schedule information could be distributed widely.

The findings of this study highlight a key aspect of collaborative work in a dynamic environment: plans and schedules are constructed in distributed manners, continuously maintained by collective efforts, and constant monitoring efforts are needed.

2.4 An interview study of coordination in a high velocity environment

If information sharing is so critical, then why is not consistently carried out to everyone's satisfaction? One could hypothesize a number of possible reasons why information sharing is inadequate. To answer this question, we interviewed a number of stakeholders to understand the barriers to information sharing [3]. Through interview, it was found that in the studied setting, it was not unusual for staff to misinform others about their schedules and about preparatory status to obtain certain advantages. Cited examples included a situation when a surgeon might say that he is ready to operate when an OR becomes available, even if he is not yet finished with another task. Such "misinformation" is used to ensure that the room is held for the surgeon's case. Another cited example was a situation when a charge nurse might say that an OR needs disinfecting, even though the OR is ready. This "misinformation" is employed to give her staff time for a break without letting others know the real reasons.

These findings suggest that in addition to the concerns associated with privacy and autonomy, organizations often have inherent tensions among different stakeholders. Controlling access to information would be one of the methods used in such organizations to manage tensions. A direct implication of these findings would be that the deployment of information systems that may put valued, existing information access control mechanisms in jeopardy. As a result, information systems may be rejected by users.

3 A platform for coordination supporting tools

The OR suite of a trauma center (the study setting described above) was outfitted with extensive telecommunication networks as a research platform in a real, dynamic environment. There are several significant characteristics of the environment that were exploited by the research associated with the platform: the setting is highly dynamic, the tasks require the collaboration from highly specialized personnel, a large number of people (over 100) working on multiple tasks simultaneously, and the consequences of lack of coordination are high in terms of human and economic costs.

Two general research goals were pursued with the platform: (1) to experiment with innovative tools

supporting coordination, and (2) to investigate psychological and social aspects in an information technology enhanced collaborative work environment. The trade-offs between information access and privacy was an example of one such research topic. The platform allowed addition of different functional modules to change the nature of computer support and information access.

3.1 Infrastructure

In each of the six ORs, two cameras were installed to acquire video images from two ceiling mount points. All video signals were routed to a central video hub. A video server was used to provide the interface between the video hub and a secure local area network (LAN). The video server digitized video signals for processing and dissemination within the secure LAN. As part of the data communication networks, all patient monitors were connected to a separate LAN. A separate interface was developed to extract significant patient status information.

Users were provided information access through various user interfaces. The basic principle in developing user interfaces was to emulate the "First Do No Harm" oath: to ensure minimal additional efforts to the care providers and minimal undesirable disturbances to the existing work process. This principle was translated to requirements of no user training, no need for active user data-input or maintenance of data, and co-existence of the new interfaces with current interfaces.

For this paper on the issue of information access and privacy, we focus on the public display interface: the VideoBoard. The other interfaces included those on portable wireless personal digital assistants and intranet desktops. The VideoBoard was a "hybrid" whiteboard (Figure 2): networked multi-media data objects were presented in an embedded manner with regular physical objects on a whiteboard. Multi-media data objects included graphics (such as progress bars), video (such as those from ORs), and text (e.g. messages).

Figure 2. *Sample layout for the embedded OR board (contrast with Figure 1). Note that video images from the cameras in the ORs are embedded with other regular OR board objects (magnets, handwritings, papers).*

3.2 Mechanisms for information access control

The VideoBoard interface was used in a series of field trials to determine the trade-offs between improved information flow and privacy. A number of mechanisms were developed to control the type and level of details of information access to OR status.

Through the studies highlighted earlier, it was learned that OR status was an important piece of information for decision making and collaboration. The VideoBoard provided a range of levels of information access to OR status, and correspondingly a range of potential threats to privacy (both that of the patients as well as the staff).

A user authentication system based on identification (ID) badges was used to control who could activate video images of a given level of details. The same authentication system was also used to track usage patterns. Since most users were familiar with the use of ID badges for accessing hospital areas, we did not anticipate any difficulties in such an interface of access control for the VideoBoard.

In terms of levels and types of information access to OR status, we provided three types of information on the VideoBoard: (1) Key OR events, as identified through an image analysis program. The key events identified included: the operating room cleaned, the patient brought in, the patient placed on the operating table, the patient covered with sterile drapes, the drapes taken down, and the patient taken out of the OR. (2) Patient monitoring status, as identified through an analysis program using patient vital signs. Two key events were automatically identified: when the patient was connected to and disconnected from patient monitors in the OR. (3) Video images. These images could be displayed at a number of levels of details with several strategies to degrade the quality of images. Details of such strategies are described in Figure 3.

Figure 3. *Image display options. Top left: original video image. Top right: corresponding pixelated image. Bottom : corresponding cartoon abstraction image. Note for the cartoon abstraction image, the people working in the OR were represented as blobs in different colors. When viewed overtime, cartoon images allow identification of some of the activities.*

Since video often poses significant privacy risks to both the patient and care providers, much efforts were devoted to how to exploit such a powerful information source while ensuring privacy. We anticipated great value of providing video images on the VideoBoard, which is a public display board, as many different users could potentially benefit from a better sense of situation awareness. A set of image display options were established to assist the evaluation of trade-offs between access and privacy (Figure 3). These image degrading strategies were used to provide needed information for coordination, while still providing some assurance of privacy. The options developed include:

(1) Pixelation. An algorithm was developed to reduce the resolution to a chosen level yet maintaining the projected image size. The resulting images are "blocky" in appearance.

(2) "Cartooning." Instead of displaying video images, we displayed abstraction of video images. Objects are displayed in filled outline forms with corresponding color. For example, the surgeons and scrub nurses are represented by dark green color, the color of their sterile overalls.

3.3 Field trials of the VideoBoard

The VideoBoard platform was used to understand the issues involved in the trade-offs between information access and privacy. A carefully planned staging process was implemented due to the sensitive nature of remote video display. The goal of the field trials was two-fold: to assess staff acceptance of remote video display, and to determine the trade offs between information access control and the amount of information transmitted. The staging process included the following elements:

(1) Demonstration of the VideoBoard's functionalities with key personnel to solicit opinions on potential objections by the OR personnel. A mock system was established in a laboratory setting and key personnel from different care groups was invited to comment on the potential impact of deploying the VideoBoard.

(2) A combination of group briefings and one-on-one interviews with opinion leaders. Presentations on the VideoBoard were made to the OR personnel with ample opportunities for questions and answers. Private one-on-one meetings were offered.

(3) Ensuring clear communication to the OR personnel on what would and would not occur. For example, much of the potential reservation about remotely monitored video display was on the unknown factors with regarding of who would have access to the video images, whether there would be transmission of audio, and whether there would be recording of images.

(4) A series of trial-and-errors implementations of different configurations to locate the "sweet" point of the trade-offs between information access and privacy. During the trials, the question of "are the images too clear for you and for the patient" was posed to different care groups (nursing, anesthesia, surgery, and ancillary staff). The initial image quality was deliberately set to be very low and the quality was raised gradually to remove the fear of unknowns. A detailed diary was kept to document the user responses during the field trial.

The location of VideoBoard was such that only people working in the OR suite had access to the VideoBoard. These people included OR nurses (when they were on a break or on an errand), coordinators, and surgeons when they passed the OR whiteboard before entering ORs and when they came to the OR whiteboard to discuss schedules and other matters with the OR coordinators. OR coordinators were given the rights (authenticated through the ID badge reader) to display video images in any level of details they chose. There was an automatic time-out mechanism to reset the image quality. Currently the VideoBoard was the only point of displaying video images. Future plans included disseminating the OR status information (in various levels of quality) to other locations and through other platforms.

A range of user reaction was heard during the field trial. Generally, the responses could be classified into the following three types:

(1) Totally against the idea of remote video monitoring. Although a small minority (out of about 100 OR personnel, two explicitly expressed reservations), the responses were best captured by the following quote: "I am totally against the idea [displaying video images on the OR board]. It does not matter what resolution or quality the images are. I mean, this is big brother watching." During the field trials, counter responses were voluntarily offered by other OR personnel. For example, during one trial session one member argued back, regarding image quality: "What could you identify here? Could you even tell me who is who?"

(2) Support but having no strong feelings either way. In this type of responses, the opinions were expressed in the form of supporting the general idea of improving information access. The view on the loss of privacy was not strong because of the nature of images displayed. However, when unaltered images were presented (i.e. in native 320x240 pixel resolution), several members of the OR personnel voiced reservation on the need for such high quality of images, if the goal of improving

information access is for coordination (as opposed to observe the surgical techniques).

(3) Strongly support. In this type of responses, the opinions were stressing the value of information access. When discussing the issue of privacy, one member said: "I never understood why you [the researcher] have to be so uptight. I mean when I go to a 7-Eleven store, the camera is there and recording is going on. No one asks me for permission."

To gage the acceptance of the VideoBoard system, we allowed the OR personnel to turn off the cameras inside the ORs. During the field trials of four weeks, the cameras were never turned off. When the VideoBoard system was turned off for maintenance or data capturing, OR personnel immediately demanded that it be turned on again.

Additionally, through interviews during the field trials, a change of attitude was detected in terms of the value of improved information access and removal of unknowns associated with the type of video images and who would be able to view what types of images. Formal evaluation through questionnaires was underway through analysis of access logs, timings of key OR events, and questionnaires.

4 Conclusions

With the advance of computing and communication technology, there is an increasing trend of deploying tools to facilitate information access. Such access can potentially improve system reliability and operational efficiency through information sharing and awareness support. If implemented properly, information technology should lower the burden of accessing information.

In some sense, remotely video access is often viewed as the most desirable form of awareness support yet at the same time the most severe intrusion of privacy. In the field trial of a coordination platform based on video, we implemented a number of options to experiment with the trade-offs between information access and privacy. The staging process was deliberate to avoid unnecessary rejection of the system. The four-week field trials had shown that it was possible to identify a satisfactory point between video-based information access and preservation of privacy.

A number of future steps were planned, including a wider range of information access to OR status to further explore the issue between information access and privacy/autonomy, which should provide further insights into the trade-offs between information access and privacy.

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