Distributed Monitoring and a Video-Based Toolset*

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Abstract - *Healthcare environment is a prime example of collaborative work, in which work is organized both at the macro-level over days and weeks as well as micro-level over hours and minutes. Coordination is carried out jointly by those who often share the ultimate goal of providing best care to the patient while at the same time have different perspectives. Additionally, uncertainty and contingencies often arise to disrupt the best plans. Based on the phenomenology observed in coordination for day of surgery management, we illustrate strategies employed by healthcare workers to enhance operational robustness and reliability. Based on the insight learned, a video-based toolset was developed and deployed in a Level-I trauma center to enhance distributed monitoring. Initial trials showed that the toolset was highly received.*

Keywords: Distributed planning, distributed monitoring, information access, video based coordination.

1 Introduction

Very rarely does one work alone in today's environment, where communication and coordination is the key to achieve productivity and safety. In healthcare environment, a patient is always taken care of by a number of people, with differing skills and expertise, over a period of days or longer. Equally, most of the care providers participate in the care of multiple patients during a given period of time. How to coordinate activities in such a setting? Although operations research is of relevance in design and facilitate workflow in such a setting, uncertainty and contingencies often arise to disrupt the best plans. The dynamic and uncertain nature of events often make it essential to mutually adjust among care providers, to each other's activities as well as to external events. Such mutual adjustment may occur in different timescale, ranging from macro-level over days and weeks as well as micro-level over hours and minutes. A centrally planning approach will likely fail while the needs of planning and mutually adjustment are satisfied in distributed manners, among different stakeholders, in different locations, and over different time horizons.

In particular, a key issue in collaborative work is articulation work: mesh of clusters of tasks and segments of the trajectory of tasks [1,19]. To quote Bannon and Schmidt [1]:

> "*In work environments characterized by task uncertainty, due to, e.g., an unstable or contradictory environment, task allocation and articulation cannot be planned in advance. In these work environments task allocation and articulation is negotiated and renegotiated more or less continuously*" (p. 9).

In fact in some work settings, articulation work is so massive and substantive that dedicated personnel are employed to facilitate the articulation work. Examples of such personnel include air traffic controller [5,13] and train dispatchers [17]. Studies of such personnel can provide us with insight on articulation work.

In this paper, we first present a phenomenology of distributed monitoring in a high-stake environment: surgical operating rooms. Surgical operating rooms (ORs) are often the biggest cost center in a hospital, with enormous impact on the well-being of patients and on the economics of any healthcare organization. Great efforts have been put in place to make the operation of ORs both safe and efficient. We wish to highlight the fact that in a distributed environment, the monitoring tasks are distributed across roles and carried out by purpose and opportunistically. Based on the observed behavior of distributed monitoring, we designed and implemented a set of video-based coordination tools to support and enhance distributed monitoring. Although the tool set at the moment was limited, it demonstrated the importance of providing context awareness information. Through research on the targeted tasks of day of surgery management, we hope the strategies and principles used in the development of the coordination tools are applicable to a wide range of tasks.

2 Awareness support : A review

Studies of co-locational team activities (e.g. [2,4,12]) have shown the value of dynamic knowledge about the activities of other team members. Fluid, effective coordination often depends on such knowledge [9]. The terms *workspace awareness* and *activity awareness* (e.g. [6]) have been used to denote this type of knowledge about collaborators. Recently there have been numerous attempts focusing on how to support awareness in computer-mediated collaborative work (e.g. [7,15,16]).

When working together, co-workers often need to monitor others continuously and actively. Such monitoring could, for example, allow one to detect "boundary" of others' activities so that interruption could be made in most opportune time. Coordination is simplified due to the fact that everyone in the group is aware of each other's activities. Bellotti and Bly [2] found that the members in a design team took the advantages of being co-locational by walking to colleagues' workstation. They concluded that co-presence and mutual awareness provided opportunity for implicit communication, whereas current technology tends to provide only explicit communication.

One advantage to being co-located is the sharing of physical space. Such advantage was found to be exploited in several studies. Bellotti & Rogers [3] found that news organizations used wall displays for representing personnel/work status and for discussing designs. Shared audio-space was used by workers in a control room for London Underground [12]. By verbalizing, information was updated to all workers in close proximity.

It seems that awareness is a mediating variable in explaining the difference in coordination processes between co-locational and distributed situations. Several technological explorations provided evidence to support this hypothesis. Issacs, Tang, & Morris [11] attempted to provide mechanisms for collaborators to gain awareness through unintended interactions, whereas Gutwin and colleagues [7,8] demonstrated that awareness support improved performance. In this case, awareness was defined as knowledge about other people's activities, work objects, and viewing perspectives. Tollmar et al [20] described the design of a system with the objective of providing distributed workers with the benefits of physical proximity.

Hudson and Smith [10] introduced the concept of awareness support and the tradeoff between awareness of surroundings with the issue of privacy and disturbance. The basic assumption is that the more information that is received about the activities of colleagues, the more potential awareness we have of them.

Dourish and Bellotti [6] examines mechanisms of achieving awareness. They defined awareness as an understanding of the activities of others, which provides a context for your own activity. Two approaches of provision of awareness information were summarized: explicit support, which users explicitly provide information about their own activities, and shared feedback, which provides information about activities through the work objects (shared workspace). Explicit support approach requires additional workload and would require information provider to know what the recipient wants to know. In shared feedback approach, the provision of awareness of information requires little overhead. Through shared workspace, Dourish and Bellotti [6] observed that users make use of opportunity to peripherally monitor others' activities.

3 Managing Surgical Operating Rooms (OR)

As a prime example of articulation work, charge nurses for surgical operating rooms connect multiple people, resources, and patients to ensure efficient and safe operation. For the last several years we have been conducting observational studies on the charge nurses working in a suite of operating rooms in a trauma center (e.g. [21]). The activities of the charge nurses in a trauma surgical suite were studied to illustrate communicative and cognitive work involved in orchestrating multiple trajectories in a fast-changing environment. As suggested by Simone & Schmidt [18], a crucial issue for development of computer supported cooperative work (CSCW) systems is to devise computational coordination facilities that support cooperating actors in managing the complexity of articulating their distributed and yet interdependent activities.

The charge nurse's primary duty is, to paraphrase one of the charge nurses we observed, "to make the ORs work." The charge nurse takes requests for surgery and translates them into a schedule of specific times and sequences in each of the individual operating rooms (total of six in the studied suite). If a case is not scheduled as the first case, its starting time cannot be scheduled. The order of the case is then scheduled "to follow" the first case for the respective OR. Charge nurses are scrubbed and attired to go inside the ORs. They do not have clinical duties ordinarily, although all three charge nurses we observed had extensive clinical experience working in the ORs. They are mobile during their shift and walk around, but the charge nurses primarily stay in the control desk located in a corridor through which surgical patients are brought in. A large whiteboard (365x122cm) is in front of the control desk. The whiteboard is used in part to show surgical schedules. A detailed study of the whiteboard was reported by Xiao et al. [21]. We will use "the charge nurse" as a representative of all three charge nurses observed.

As part of a larger study of coordination through the trauma care process, access was gained to conduct an ethnographic study of coordination activities associated with the management of the OR suite. Data were gathered by direct observation, interviewing, and photographing. Due to the sensitive nature of the work observed, most of the data were in the form of notes and still photographs but not transcriptions of audio-taped verbal communications. Over a period of 14 months, five researchers (three were registered nurses) observed the coordinating activities of the charge nurses on more than 20 days. Short interviews were conducted with nurses and physicians in front of the control desk.

In contrast to most ORs, day-of-surgery case scheduling in a trauma center is very dynamic. Much of the decisions on surgical case scheduling in trauma centers are made on the day of surgery, whereas in most other ORs the scheduling is usually determined days in advance.

4 Phenomenology of distributed monitoring

To understand the activities associated with the management of ORs, we performed observational studies. A set of distributed monitoring behaviors were observed.

Opportunistic. Key coordinators were constantly on the move and highly mobile. One of the reasons was to monitor activities in various locations that had relevance to the activities in the ORs. For example, the charge nurses were noted to check the workload situation in both the upstream (from where the patients may come to the ORs) and downstream (to where the patients are sent to from the ORs). Similarly, people often came to the scheduling board to see what was the latest status and plans.

Fluid interdependencies. One definition of coordination is the management of the interdependencies (Crowston & Malone, 1994). We observed that it could be difficult to determine interdependencies in any pre-scripted manner. One surgeon's activities may have little to do with another's in most situations but they may be brought into interdependent relationships when the two surgeons share the same operating room: the case of one surgeon follows that of the other surgeon. We observed that the case order (i.e. which case follows which othe case) was often changed as a day progressed, thus making interdependencies dynamic and fluid.

"**Rumors**." We observed that relevant information was sometimes presented as rumors. In one observation episode, for example, a resident (a physician in training) mentioned to the charge nurse that the attending surgeon (the staff surgeon) was seen resting on a bed and complained light-headedness. Since the attending surgeon had a case scheduled later of the day, the charge nurse embarked on an effort to verify the "rumor." The charge nurse would like to assess the possibility that the attending surgeon might not be able to perform the scheduled surgery. If that were the situation, the charge nurse would have to cancel the surgery and re-plan the schedule to maximize the utilization of the costly OR time.

Transactive responsibility. In collaborative environments, events often occur in different locations. As a result, people in different locations have access to different types of information. We observed that in the studied OR suite, people often volunteered information to help each other out. For example, one nurse working in ORs happened to pass the schedule board and informed the charge nurse that the case posted as on-going was in fact finished. Although it was the responsibility of the charge nurse to monitor the progress of all cases and to update the schedule board, other people shared the responsibility of distributed monitoring. One concept was proposed to capture this facet of high reliability teams: transactive responsibility [22].

Design implications. How to support the information needs for distributed monitoring ? The findings reported above suggest several design guidelines to support collaborative work in a dynamic work environment. First, the distributed monitoring should be supported with maximum context information, so that people could interpret events within the context of collaborative work (as opposed only to their own immediate work context). Secondly, the provision of the context information should be passive: no-one should expend efforts to update information regularly. Thirdly, the provision of information should not reduce dramatically the opportunistic information encounters. In other words, if provision of context information substitutes the need completely of interacting opportunistically, people may not be able to interact and handle the fluid interdependencies. It is difficult to anticipate all the interdependencies.

5 Supporting coordination: A video-based toolset

To experiment with different strategies of supporting distributed monitoring and develop design principles of CSCW systems, 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.

In addition to data communication networks, a video network was established. 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 no requirements of user training, no active user input or maintenance of data, and co-existence of the new interfaces with current interfaces.

There are two user interfaces. The first interface is VideoBoard, a hybrid whiteboard (Figure 1). Graphical, imagery, and text objects are projected on to the OR board currently in use. The second interface is on personal digital assistants (PDAs), wirelessly connected to the secured intranet. The VideoBoard enables projected objects (called iMagnets) amongst the physical objects of a large magnet whiteboard (4x8 feet or larger). The projected objects currently include video images, clocks, progress bars, text messages, and status icons. These iMagnets work in tandem with physical objects, such as magnetic strips, magnetic icons, and handwritings on the whiteboard. Users interact with iMagnets through a tangible user interface (TUI): a circular barcode recognition system with two cameras and image analysis software. TUI currently allows the users to place and reposition iMagnets. Improvement on the VideoBoard system is on-going.

Figure 1. *Sample layout of VideoBoard. The existing whiteboard is overlaid with projected computer generated objects. Note that video images from the cameras in the ORs and text are embedded with other regular OR board objects (magnets, handwritings, papers).*

The VideoBoard was designed to allow experimentation of different types of coordination support for the management of ORs (specifically, for the so-called day-of-surgery management, as opposed to longer term management). The VideoBoard incorporated several key functionalities: (1) Embedded, hybrid display of video images from 16 different sources. The video images could be real-time (30 frames/second) and low-scan video (2 frames/second). (2) Display of messages. Display of messages from a variety of sources, such as text pagers, email and other messaging sources. (3) Visualization of various schedules (such as surgical cases posted, staffing patterns, and availability of key personnel). (4) Visualization of surgery progression. Most surgical cases go through a set of landmark events, such as room ready, equipment set up, patient ready, surgery start, closing, etc. These events could be displayed against progression bars to display time elapsed (stopwatch) and expected time to finish (timer). (5) Other on-line decision support tools, such as anticipated staffing requirements, historical duration data (e.g. surgery duration, case turn-over time, etc).

The VideoBoard was put to a pilot trial period to solicit opinions of how it may help support distributed monitoring. Although more systematic evaluation studies were planned, presently only observational notes were available to report.

The value of being able to "see" into operating rooms along with the scheduling information through the VideoBoard was evident During the pilot trial period, when the VideoBoard was taken down, either because of system instability or maintenance, the charge nurses would immediately contacted to restore the VideoBoard. Various of uses of Videoboard were observed. The events inside the ORs were not more easily assessable by the people working in the ORs. They were observed of glancing at the video images when looking at the surgical schedules. The charge nurses were observed to use the video images to assess the progress of anticipated events. For example, one charge nurse reported that she would wait for a few minutes after a surgery finished before calling for housekeepers to clean the OR. By being able to see the room status, she reported that she was informed better and therefore able to monitor the surgery process better.

The VideoBoard was only a start of the current planned intervention and experimentation with tools supporting distributed monitoring. Future steps included wide dissemination of video through wireless and wired connections.

6 Conclusions

Collaborative work almost always rely on planning and monitoring of plans to ensure safety and productivity.

In many settings, the monitoring in collaborative work is distributed: the task of monitoring is carried out by a number of people. Information technology has the potential to reduce the burden of accessing information through passively providing context information. Due to the dynamic and fluid nature of many task domains, to anticipate and pre-script monitoring responsibilities and tasks may be impossible. With information technology, context information, such as that provided through video, can be effortlessly transmitted and accessed. Understanding of distributed monitoring in the context of collaborative work could provide us with insights to guide the design of new information technology applications.

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