AwareMedia – A Shared Interactive Display Supporting Social, Temporal, and Spatial Awareness in Surgery

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ABSTRACT

Several CSCW studies have shown that coordination of work in hospitals is particular challenging, and that clinicians put much effort into maintaining mutual awareness on the flow of work. Despite these apparent challenges, very little work has been done to design technology which helps people coordinate highly cooperative work in such a critical setting. In this paper we propose a novel way of supporting coordination in this hectic and time-critical environment. AwareMedia is a system which promotes social, spatial, and temporal awareness in combination with a shared messaging system. AwareMedia runs on large interactive displays situated around the hospital, and it is designed especially to support coordination at an operation ward. We present the design, implementation, and deployment of AwareMedia and based on preliminary data from our on-going deployment, we discuss how AwareMedia is working *in-situ*.

Categories and Subject Descriptors

H.5.3 [**Information Interfaces and Presentation**]: Group and Organization Interfaces—*Computer-supported cooperative work*; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*graphical user interfaces*; J.3 [**Computer Applications**]: Life and Medical Science—*Medical information systems*

General Terms

Design, Human Factors

Keywords

Context-aware computing, social awareness, ubiquitous computing, pervasive healthcare

1. INTRODUCTION

The scheduling and coordination of surgeries at an operation ward is a particularly challenging task at any modern hospital. Performing surgery is a highly specialized and advanced procedure that involves surgeons, nurses, anesthesiologists, a patient, an operating room, and various equipment. In addition, cleaning, patient transportation, recovery, etc. have to be coordinated. This means that all the people involved in surgical procedures must coordinate their work and constantly maintain an awareness about the ongoing flow of work in the involved wards. Furthermore, although a substantial effort is put into making advanced operating schedules, the work around a surgery is highly contingent and numerous events may affect and change the schedule. These might include the arrival of an injured patient, the delay of an operation due to unforeseen complications, illness among the staff, and patients not being ready for surgery. In all of these cases, the plan needs to be adjusted and the people involved must be notified and informed. Getting status information and information about the most recently adjusted schedule passed on to all affected personnel is difficult due to a work environment where people are constantly moving around, talking to patients, performing surgeries, etc.

The coordination tasks faced by medical personnel are even more difficult due to the lack of good systems for supporting this type of scheduling and collaboration. In most operating wards, the main methods for notifying people about status or changes are requiring people to 'keep an eye' on operation schedule whiteboards or calling them over the telephone [1, 18]. The telephone is an efficient tool for communicating messages, but it has some major drawbacks by being highly interruptive and time-consuming [3].

In this paper, we present a novel design of digital coordination mechanisms to be used in a hospital setting. The overall motivation for this design is to maintain most of the desirable functionality of whiteboards, while improving them with computer technology. The central idea is to provide clinicians with a sense of *awareness* about the unfolding of work and what their colleagues are doing, combined with the use of *messages* to foster asynchronous and less disruptive ways of communicating. Based on our research into the coordination of work in a hospital, awareness information is further divided into three supplementary types of awareness: (i) *social awareness* where a person has an awareness about another person. This awareness may include knowing where he is, the kind of activity he is engaged in, or some self-reported status; (ii) *spatial awareness* where a person maintains an awareness about a specific place and can e.g. monitor what is happening there; and (iii) *temporal awareness* which provides an awareness about past, present, and future activities that are significant to a person. These three kinds of awareness are not comprehensive but the most important ones that we have observed in coordination in a hospital environment.

To explore the above issues and concepts, we designed, developed, and deployed AwareMedia which is a pervasive platform for supporting the close coordination and communication taking place in a hospital, with special focus on the work in an operating ward. AwareMedia provides a design for how to support the three types of awareness listed above as well as support for asynchronous,

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non-disruptive communication using a simple message functionality. AwareMedia runs on large interactive displays which are easily visible and accessible to all clinical personnel and, as such, designed to work like the frequently used whiteboards in hospitals (see e.g. [1, 18]). The system has been deployed since December 2005 in a large Danish hospital and is in continuous use daily. It is used for scheduling and coordination of all operations inside 3 operating rooms and is installed in several places around the hospital, including the operation rooms, bed wards, and recovery wards.

The primary goal of this paper is to report on the design of AwareMedia including some of its unique features specifically targeted for supporting intense, temporal coordination of critical work. Although this paper specifically deals with hospital work, a hospital is not the only place where this kind of coordination is relevant. In this sense, the design principles and features of AwareMedia may be useful in other settings. We demonstrate the usefulness of AwareMedia in coordination work by reporting our initial findings from the real-world deployment of the system. In this paper, our emphasis is on describing AwareMedia as a system and we thus concentrate our discussion on the more system-related issues of the deployment.

This paper starts by describing the AwareMedia system, its core design principles, its key interactive features that enable a shared awareness, and its underlying context-awareness infrastructure. Next, the paper explains how AwareMedia has been deployed in a large operating wards and it discusses how the system and its features are used in this context. Finally, we discuss AwareMedia in relation to similar CSCW systems before concluding the paper.

2. AWAREMEDIA

The design, development, and deployment process of AwareMedia is illustrated in Figure 1. Field studies of the work at operation wards have been going on for years. In these studies, coordination, collaboration, interruptions, and awareness continuously reappear as central, but challenging, issues. In the spring of 2005, we decided to design AwareMedia as a distributed, computer-supported collaborative work system for addressing some of these issues. The design was done in close cooperation with a group of clinicians and involved a series of idea-generating design and evaluation workshops. In November the system was installed and tested in the hospital, users were educated, and in December 2005 the system was put into use.

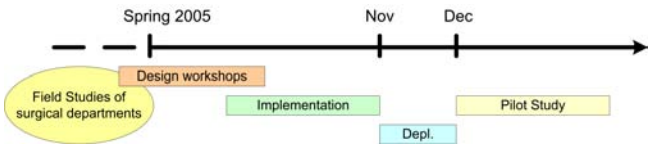

Figure 1: The design and deployment process of the AwareMedia system.

The outcome of previous research, our own field studies, and the cooperation with clinicians during the design process revealed a series of concepts and requirements for such temporal coordination technologies. The system should support:

- *Public and shared social awareness*, in the sense that social awareness is not personal ("I know what my colleagues are doing"), but rather publicly available among all cooperating users ("We all know what we all are doing"). For example, at an operation ward all clinicians should be able to access information on the current status and whereabouts of each other from e.g. large public displays.

- *Temporal awareness*, helping users to keep an awareness of past, present, and future activities. Temporal awareness is core in temporal coordination since it helps users align their own actions to a log of past activities, to current activities, and to the anticipated future flow of work. For example, a surgeon scheduled for an operation in the afternoon can plan his ward round accordingly, and can adjust the timing of the round if he is aware of any rescheduling of the operation. Similarly, clinicians often consult the operation schedule to see what kind of operation has occurred during the day in order to see, for example, what kind of equipment is in the room or to see who operated a certain patient.

- *Spatial awareness*, helping users to understand and be aware of activities taking place in a specific room. Hence, to a large degree awareness is not only tied to persons (social awareness) but also to places (spatial awareness). For example, knowing what is happening in an operating room, the status of the operation, the people in there (including the patient), and potential delays are of utmost importance in the coordination of work at an operation ward.

- *Communication*, supporting written or spoken communication which can be shared among collaborating clinicians. For example, a party-line functionality between all clinicians involved in a specific operation would be useful because all of them are rarely in the room at the same time. This communication should be both synchronous and asynchronous, enabling clinicians both to e.g. phone each other and leave messages.

2.1 The System

The AwareMedia system has been designed as a large publicly accessible interactive surface which allows clinicians to maintain a shared, temporal, spatial, peripheral awareness of the unfolding of work at an operation ward. The support for awareness is supplemented with some basic support for communication. The main design hypothesis is that the combined overview of people, place, and time will help clinicians be more efficient in the coordination of work, including managing contingent and critical situations. Furthermore, several studies of medical work in hospitals have revealed that large public whiteboards play an essential role in the coordination and scheduling of work (including operations) in hospitals [1, 2, 16, 18]. Hence, a fundamental design goal was to get information typically stored in clinical booking and scheduling systems 'back on the wall' by designing a large interactive display technology which could combine the affordances of whiteboards with the benefits of computer scheduling systems.

AwareMedia is a distributed system consisting of a number of services and clients. The clients were designed to run on large interactive displays. Figure 2 shows an example of an AwareMedia client. The left-hand side provides an overview of the 'coordination room', the people at work, the 'reserves', and a list of people associated with the ward. The right-hand side provides an overview of one operating room. If more displays are available, as in Figure 3, then more operating rooms can be shown on the additional screens.

Under the hood, AwareMedia is composed of four main types of technologies:

- Video streaming technology which broadcast video between all participating AwareMedia clients. Video from e.g. the

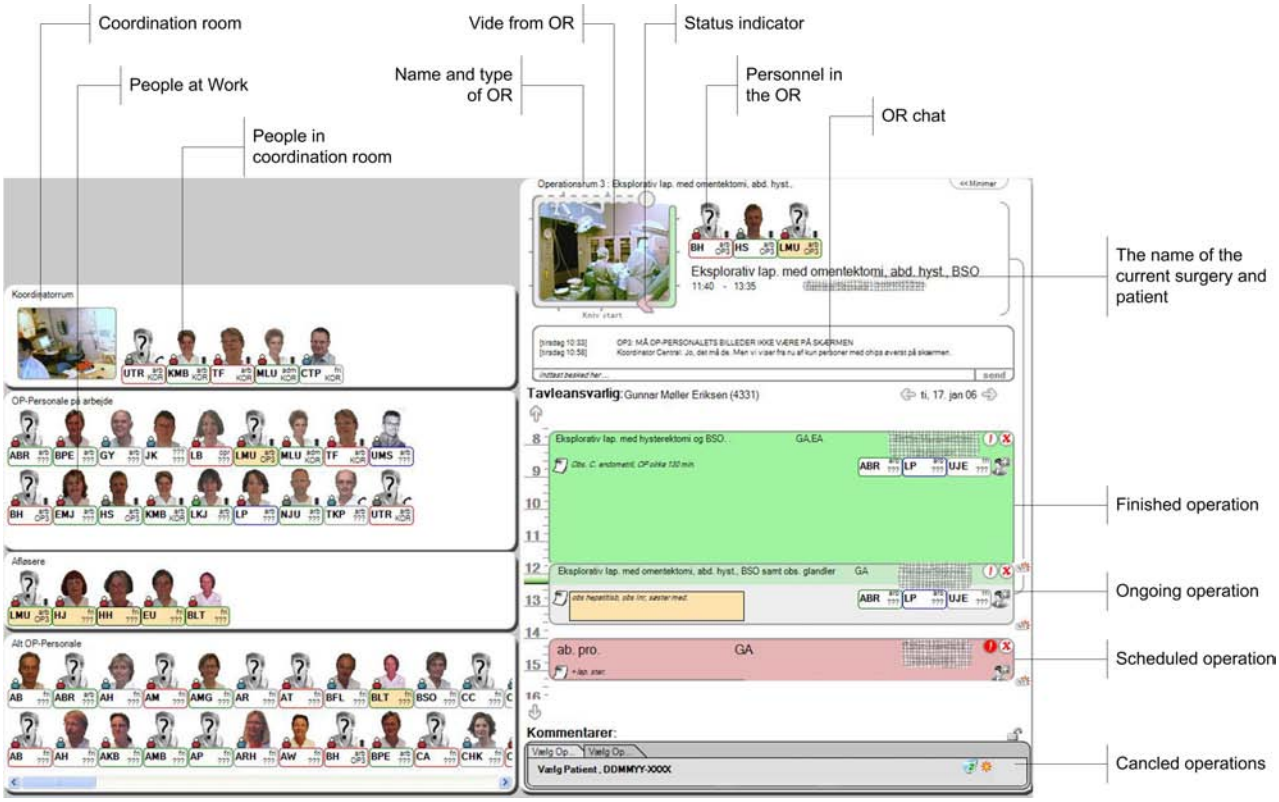

Figure 2: AwareMedia showing video connection between the different operating rooms, status information for an operation, and the operation schedule.

operating room support a general spatial awareness on the unfolding of work during surgery.

- Operation scheduling technology is responsible for showing an updated view of the surgeries currently scheduled. This system supports temporal coordination through scheduling and re-scheduling of operations.

- Context-awareness technology provides information about the activities and whereabouts of the clinical staff. Awareness information is based on sensor technology revealing context information like location, status, and activity. The location information is gathered by a location tracking system, tracking the location of medical staff and patients.

- Instant messaging technology that provides a simple written and spoken communication pathway between cooperating users.

Two typical deployments of AwareMedia are shown in Figure 3 and 4. In Figure 3, AwareMedia is deployed in the 'coordination room' used at most operation wards as the central place for planning and coordination of all operations. Here, AwareMedia runs on multiple large publicly accessible displays and provides an overview of the work in several operating rooms. These displays are designed to resemble the whiteboards normally used and allow for shoulder-to-shoulder collaboration and discussion. In Figure 4, AwareMedia is deployed inside an operating room on a 20" touch screen. This configuration allows people inside the operation room to 'look out' into the coordination room and into other operating

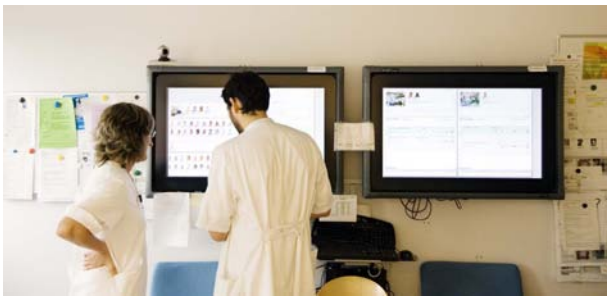

Figure 3: The deployment of AwareMedia on two 42" touch screens in the coordination room.

rooms. It is quite normal that surgical staff is responsible for operations in two operating rooms and it is hence important to maintain an awareness of the unfolding of work in another room.

A core design principle in AwareMedia is to create *redundant awareness information* by making the same awareness information available in many places and in several forms. For example, status and location information for a person is displayed on that person's icon, and location can also be seen from the placement of the icon in a specific place (e.g. in an operating room), and from the video images. In this way, AwareMedia provides a broad avenue of supplementary awareness information which helps the user to quickly judge the status, activity, and location of a person.

An important design decision was to allow access to the system without requiring users to identify themselves before using the system. During our design workshops it was decided to make a system

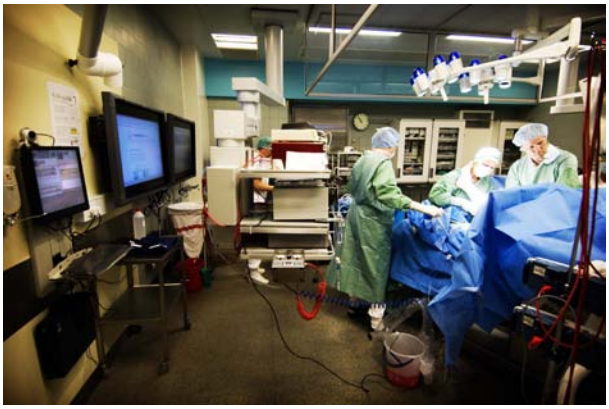

Figure 4: The deployment of AwareMedia on a 20" touch screen in an operating room (to the left in the picture).

which had the same public access as whiteboards have. Only authorized persons have access to the operating ward where the displays in the coordination room and the operating rooms are located. Hence, only trusted people can access the system. It was also decided to deploy AwareMedia in the patient ward and in the recovery ward. These places are still restricted to authorized personnel, but for privacy reasons, video is not broadcasted outside the operating ward.

2.2 Spatial Awareness

In a hospital, clinicians put a lot of effort into maintaining an awareness of 'significant' locations such as patient wards or operating rooms. In operation wards different sign systems are used to reveal the status of an operation [1, 18] and whole patient wards can be augmented with signs and symbols that reveal the status of the work and the where-about of clinicians, patients, and artifacts [5]. These observations were confirmed during our field studies and design process. The goal of designing for *spatial awareness* is, therefore, to provide people with an awareness of distinctive features of a specific location. In the operating ward, providing spatial awareness of an operating room includes revealing what kind of operation is taking place in there; the level of activity; status of the operation; the kind of professionals in the room, including the patient; and any contingent issues, like delays or unforeseen troubles.

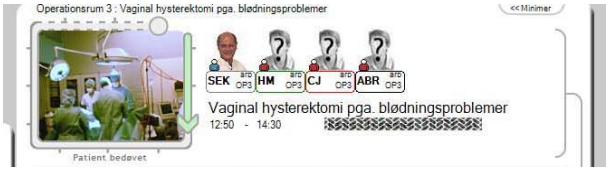

Figure 5: Support for spatial awareness in AwareMedia.

Figure 5 shows how spatial awareness is provided in the top right corner of the AwareMedia interface. The purpose of the live video stream from the operating room is to provide an overall picture of what is going on in the room, including the types of activities and people in there. The video is deliberately kept in a low quality resolution (160×120 at 6 frames/sec) which has turned out to be a good compromise between providing just enough information in order to convey what people in the room are doing (e.g. preparing for operation, operating, closing the patient, or cleaning the room) while not being privacy invading by revealing details like the part of the patient being operated. The status is wrapped around the video image bar which reveals the current status of the operation indicated by the text below the video image. "Patient bedøvet" means "Under anesthetics", for example. The status bar is cyclic, resembling the cyclic nature of all operations. Status is set by pressing the status bar on the touch sensitive screen or by voice command. Hence, status can be set without touching the display, which is a nice feature in a sterile environment like the operating room. While the status indicator (the small arrow) is moving down on the right side of the image, the surgery is being prepared and the patient anaesthetized; when it is moving across at the bottom, the patient is being operated on; when it is moving up, the patient is being closed and wheeled out; and when it is moving across the top, the room is being cleaned and prepared for the next operation. The combination of the video image and the status bar is designed to give a very concentrated view on the current status of the operation room.

To the right of the video image there is a list of the clinical personnel in the room. This view provides a more detailed awareness of exactly who is in the room right now. The name and type of the operation is located below the list of people, and below that, the name and social security number of the patient in the operating room (not visible in Figure 5). Note that this view of people in the room reveals who is *actually* in there, including the patient, and not who is scheduled to be there. The location tracking is done by tracking the clinical staff's mobile phones or special electronic tags. Thus, the patient's name is only visible when the patient is actually in the room. Besides the support for awareness, this latter part also has some implications for patient safety since clinicians would immediately spot if a wrong patient would enter the room.

2.3 Temporal Awareness

Temporality is core to medical work in hospitals [20] and studies have shown how scheduling, temporal rhythms, temporal patterns, and temporal cycles helps clinicians perform and coordinate their work [1, 16]. Clinicians align their work according to the unfolding of the schedule and especially to changes, like delays or cancellations, to the schedule. Furthermore, our observations and design process revealed that *temporal hindsight* or awareness of events that *do not* take place can also be an important constituent of coordination and scheduling. On the face of it, one should expect planning and coordinating to be about the future but that is not always the case. For example, information about past or cancelled operations was important in many situations, such as when determining who is most able to perform an extra operation, which relatives to inform about delays or cancellations, which beds to release for other purposes, etc. One of the advantages of the former paper-based scheduling system is that you can easily spot changes to the program as they are hand written across the operation schedule printed by a computer system. We aimed at imitating this feature by making past and cancelled operations occupy a salient position in the UI.

The goal of designing for *temporal awareness* is hence to provide medical staff with an awareness of past, present, and future activities and events which may be relevant to them. In the operating ward, the operation schedule for each operating room is an important part in temporal coordination and hence in temporal awareness.

Support for temporal coordination is evident in two places in AwareMedia. First, the status bar which runs around the video feed in AwareMedia (see figure reffig:room) directly supports recurrent temporal cycles in an operation [1]. Second, figure 6 shows how the AwareMedia interface supports temporal awareness. This schedule shows the planned operations for the day, including the

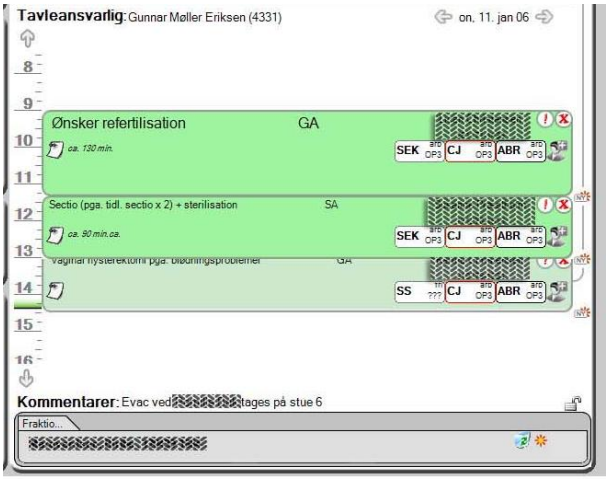

Figure 6: Support for temporal awareness in AwareMedia.

type of operation, the patient, allocated clinicians, and notes. In order to support an awareness on temporal changes, the schedule also reveals if an operation is delayed (flashing yellow), if an acute operation is scheduled (highlighted as red), or if an operation is cancelled (moved to the bottom of the schedule). During the design process, it was verified that these kinds of cues were sufficient to help clinicians maintain an temporal awareness about the unfolding of activities in the operating ward, also from other remotely situated parts of the hospital. Thus, changes to the schedule needed no longer to be communicated using telephones, thereby saving a lot of disturbing phone calls.

2.4 Context-Mediated Social Awareness

Maintain a mutual awareness about the activities and whereabouts within a team of clinicians has proven to be central to the unfolding and coordination of work in hospitals [10, 3]. During our field studies and design process we observed how clinicians working in the operating ward continuously was monitoring the activities of each other and correspondingly was rendering important part of their activities visible for others.

The goal of designing for *social awareness* is hence to provide people with a general awareness of their colleagues, what they are doing and where they are. The goal is not necessarily to show *exactly* what other persons are doing, but to provide cues that can be pieced together to form an overview of what other people are *most likely* doing. Relevant context clues in a hospital environment are, for example, location, status, activity, and future plans.

Figure 7: User icons with status and location context cues.

Figure 7 shows how all users are displayed in AwareMedia. Each user icon shows a range of condensed information. The icon shows a small image of the person and his or her initials (the three capitalized letters). Considering that 120-130 persons are associated with the operating ward, associating initials and images helps users become acquainted with the names and faces of people with whom they do not collaborate with daily. The two smaller labels reveal the location as reported by the location tracking system and a self-reported status, similar to an instant messaging application. Status includes more general items like 'working' or 'away' as well as more specific (clinical) items like 'operating' or 'ward round'. The small antenna on the icon indicates that the user is wearing a location tag and a small phone icon indicates that the person's mobile phone is being tracked. The color of the small icon to the left indicates the person's profession and the colored line-border under the picture shows information about working hours (e.g. black means working from 7.00-16.30). Finally, a filled yellow oval means that the person is a replacement, who is not scheduled for specific operations, but can roam around the ward and assist where needed. Overall, the icons are information heavy, but by using different types of visual means like text, colors, and icons, the information is kept easily readable.

2.5 Communication

The support for spatial, temporal, and social awareness in AwareMedia provides an overview about what is going on in the work setting. The awareness information visible on the displays can reduce the number of explicit awareness requests like phone calls about delayed surgeries or calls requesting information about the status of the current surgery. However, in the spectrum between explicitly calling a person to deliver a message and providing awareness information, we identified a need to deliver non-urgent information in an unobtrusive but direct manner. We chose to implement a messaging system to facilitate this type of communication.

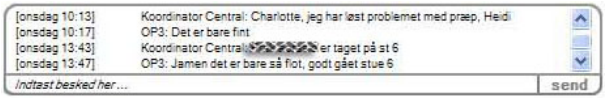

Figure 8: The chat window for an operating room.

Figure 8 shows the instant messaging available for each operating room. The chat can be used to post messages to the operating room from other AwareMedia clients as well as sending messages from the operating room to other locations. The chat will flash yellow until clicked to indicate the presence of a new unread message. People using a mobile phone are also able to send messages to the operating theatre and people with mobile phones can receive messages as well. For example, the messaging system can be used to notify a surgeon on his mobile phone that the patient has been anaesthetized and is ready for operation.

2.6 Underlying Architecture

The overall system is based on a distributed architecture shown in Figure 9. The AwareMedia architecture is an example of an hybrid collaborative architecture, which uses a peer-to-peer architecture for routing video between participating clients, and a client-server architecture for distributing information on operations, status information, location, etc.

The architecture extends the AWARE architecture [3]. The server side runs an *AwareMedia server* which contains information on scheduled operations, clinical personnel, patients, types of operations, and other data used in the AwareMedia client. From the AWARE architecture, the server inherits an *awareness service* which is responsible for broadcasting awareness information on persons and locations, like the operating rooms; a *context-awareness service* which is responsible for maintaining information on the context of people and locations; and a *message service* responsible for relaying messages between people and locations. Context cues

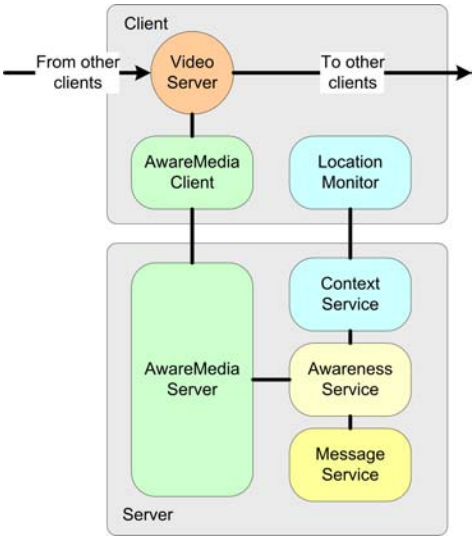

Figure 9: The overall AwareMedia architecture.

used in AwareMedia is the location, self-reported status, and the activity of people. Activity is mapped to the currently scheduled operation for a user.

The client runs three separate processes: the *AwareMedia client* responsible for the user interface displayed in Figure 2, a *video server* responsible for acquiring, distributing, and showing the video images (realized through P2P multicasting), and a *location monitor* that constantly scans for Bluetooth devices and reports back to the context-awareness subsystem of the server.

3. DEPLOYMENT

In November 2005 the system was deployed at the operating ward of a local hospital and by December 1st 2005 it went into pilot use [9]. At the time of writing, the system runs continuously with very limited support. The operating ward employs in total ca. 130 clinicians with 30-50 people present at the department during a normal day shift. Most operations are scheduled from 7 am to 4 pm during weekdays, but emergency surgeries can occur on evening or night shifts.

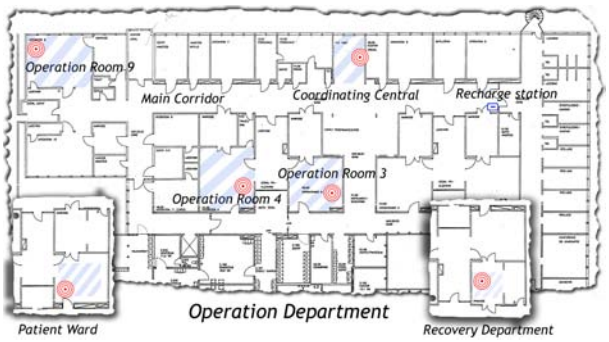

Figure 10: The operating deparment with deployed clients.

Figure 10 illustrates the current deployment of the system. At the operating ward, the system is deployed inside three of ten operating theatres (OR 3, 4, 9); two of them used for orthopedic surgeries and one for obstetric surgeries. One operating theatre typically runs 3-6 operations a day which means that the system supports 10-15 surgeries a day. Outside the operating ward, the system is deployed in the pre-surgery ward, in the recovery ward, in the patient ward three floors up, and a number of offices like the secretaries' offices. Figure 11 illustrates how these clients are distributed across the hospital. In total, there are 30-50 users outside the operating ward. In total, 10 clients are deployed in different places in the hospital (see Figure 11) and 15 mobile phones have been handed out to selected clinicians.

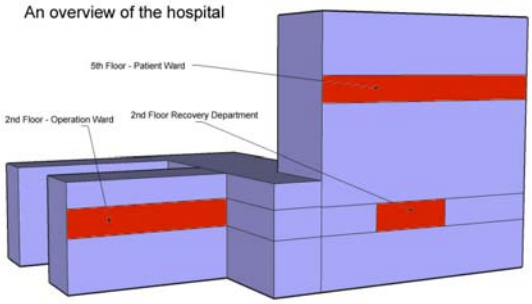

Figure 11: An overview of the hospital and the wards involved.

All servers and services in the infrastructure are deployed on one server host. Depending on the context, three kinds of client configurations have been deployed:

1. A 20" touch screen, a webcam, a PC running AwareMedia and the video server, and a location monitor. This setup was mainly used in the operating rooms where clinicians could look into the coordination room, change status, and use the chat (see Figure 4).

2. The two 40" touch screens deployed in the coordinating room at the operating ward. The coordinating room needed to keep an overview of all the operating theatres and we provided two large screens for easy access and extra screen estate.

3. A standard PC with the AwareMedia software and a location monitor. This setup was used in the patient ward and in the recovery ward.

AwareMedia is a standard .NET application and can hence run on any Windows XP PC. All installations of AwareMedia are, however, done on dedicated PCs with a dedicated touch screen. Furthermore, AwareMedia runs as a full-screen application occupying the whole screen estate and cannot be closed, resized, or moved.

Location tracking is based on Bluetooth. The location monitor uses a modified Bluetooth USB dongle to scan the local environment for Bluetooth devices. This location mechanism is not very accurate but it has turned out to be sufficient to locate people within rooms, which is the desired accuracy for our purpose. The advantages are that we can use the existing Bluetooth devices (like a phone) for tracking and that it is very cheap. We only track people near some of the installed clients shown in Figure 10 and avoid putting location monitors in places where tracking should be disabled, like bathrooms, the cantina, etc. Clinicians are tracked using their phone or by using a small Bluetooth tag. The tag can be reused by clinicians by reassigning it e.g. between two shifts.

4. AWAREMEDIA IN USE

Before and during the deployment we have collected data about the use of the system to evaluate if the AwareMedia system has an impact on the daily coordinating and collaborating activities. An

extensive logging system register the daily interaction with the system, including sent messages. Structured observations have been used both before and during the deployment to capture the interaction context not accessible through log analysis. For example, the number of users using the system or the number of users visually referring to the system without actually interacting with it. Fourteen structured interviews were carried out with doctors, nurses and supporting staff after the system had been used for three months. In this section we will present and discuss some of these findings, focusing on the users' conception of the system.

4.1 Awareness, Interruptions, and Messages

Upon installation, the use of the system underlined our line of reasoning that awareness information was particularly useful in coordination work. As an operating nurse put it:

> *[With the system] people are starting to react earlier than before. We can see the surgery in theatre 4 is delayed so the last patient can be operated in theatre 4 instead. And that is a clear advantage because then the surgeon can just throw the gloves and move on to the next patient. That is a huge advantage because sometimes the last patient needed to be postponed to the next day.*

It seems that the spatial awareness of the unfolding of work inside an operating room allows people in other rooms to react quickly to a delayed surgery and to reschedule the surgery. Similarly, the social awareness about the whereabouts of the clinical staff was used extensively - typically, to locate replacement workers or specialized workers (e.g. operating technicians), but also to find the best time to contact e.g. a doctor.

> *If I know where the doctor is located sometimes I will not call him, e.g. when he is talking to a patient. Then I say, okay, maybe this is not the right time and [instead] I prepare some equipment.*

The quote is from another nurse commenting on how social awareness information about doctors can be used to pick a more appropriate moment to contact a doctor. Besides picking another time to communicate, social awareness was also used to prioritize between different people and to chose communication means according to the situation. For instance, if people on the video image seem to be busy, a message is more appropriated than a phone call.

The ability to send messages was a highly appreciated feature and 50-150 messages were sent every week between operating rooms and the coordinating central. In particular, the unobtrusive nature of message communication was valued in passing messages that did not require immediate response and messages to people involved in other activities. A doctor comments on his use of messages.

> *There was a colleague I needed to get in touch with. He was operating a hip and that takes between $1\frac{1}{2}$ - 2 hours, so there is no point in calling him because his phone is outside the theatre and you do not want to interrupt a person who is operating. Then I just wrote to him [the operating theatre chat] that he should call me when he was done. Interviewer: Did he do that then? Yes, he did, that was great.*

Several interviewees emphasized that the main advantage of the awareness information and the messaging system is the system's ability to guard against unnecessary interruptions. Interruptions in a surgical context are very serious, people may lose valuable concentration, lose valuable seconds, or the sterile environment may be affected by a person opening the door to deliver a message or check a status. Even during panicky conditions, certain social codes for when to interrupt, and when not to, are to be kept.

> *If acute patients need to be put on the schedule you can right away tell the operating room of the change in the order of patients and you can use the message function if there is something that needs to be done. [...] That is — you do not walk in and interrupt.*

> *Of course I can call from that thing [points to the phone], but it is easier to say - ah, right now is a good time to interrupt because I can see how far they are with the surgery [referring to the status bar and the video]*

The first quote, from a head nurse, illustrates the nurse's ability *to use the system* to propagate messages or changes to the operation program without interrupting. The second quote illustrates how she uses the system's status bar and the live video to monitor her colleagues and use this information to plan her interaction and cooperation with them. In other words, she both uses the system to refrain from interrupting but also to *time* her interruptions, when such are necessary.

4.2 Redundant Information

As explained above, an important design principle is to provide redundant awareness information. For instance, a person might be represented at up to four different locations on the interface (as a replacement, in the room, on the schedule, and on the video).

During use, this design principle was appreciated since the correlation of redundant information can provide a more accurate view of the current situation.

> *At the same time as I am checking the status bar I am checking the video in the coordinating central to see if the two things match. Sometimes people forget to move the status bar.*

In this situation the nurse checks both the video and the status bar to make sure that they are consistent. In this case, inconsistency is mainly a result of the fact that the status bar has not yet been updated. But in some situations, inconsistency can provide valuable information. For example, if a doctor is scheduled to be performing a surgery, the video and status bar show that the surgery is half way, but the doctor is located in another part of the operating ward. These context clues can be used to deduce that there might be a break in the operation schedule while the laboratory is testing a sample and that the doctor has used this break to attend to other activities.

4.3 Simple, Stable, and Predictable Displays

As explained above, one of the most fundamental deployment decisions was to install dedicated computers and displays for running AwareMedia, even though it can run on any standard PC. As such, the useful awareness and communication information is persistently visible which means that it is *always* there for ad hoc coordination, scheduling, awareness, and communication. Such 'persistent displays' contribute to a stronger sense of simplicity and predictability. A similar observation was done by studying a smaller display for revealing room scheduling information outside meeting rooms [14].

The stability and predictability of AwareMedia displays enable users to quickly learn how to use the awareness display and how

to read the different available context cues. For example, the fact that all icons of users are identical in all places they are used, helps maintain a stable representation of a user and his context cues, like his location, status, activity, job role, etc. Also the fact that all instances of AwareMedia running in the hospital show the same display helped users to easily move between the coordination room and the different operating rooms. Furthermore, the system's predictable and stable interaction mechanisms allowed users to develop a reasonably well-defined set of normative rules for using the system. For instance, the users in the operating ward developed a set of rules for using the messages and the procedures for doing rescheduling.

This dedicated display of AwareMedia contributes to making a simple, stable, and predictable view which is useful in getting a quick overview during the otherwise hectic workday at the surgical ward. Although the system is a highly interactive display system, it was most of the time used passively. During three work days we observed and counted the amount of people using AwareMedia in the coordination room and it turned out that 54% of the time, clinicians were using it by only looking at it.

4.4 Open Issues

During the first two month of the deployment, we were monitoring the use of the system closely are were able to mend different problems which arose in use. This co-presence and co-development is the main reason for the positive sentiments toward the system. Even though this may constitute a methodological problem, we found it necessary in order to create a useful system for the users. Looking back on the more longitudinal use of the system, there are however four more challenging aspects of the system which we need to look closer into in the future. First, having messages posted to the OR as a bulletin board is not always an appropriate design. Often you want to supplement this with a more traditional point-to-point instant messaging approach, e.g. being able to send a message to a person or a place which is not a an OR.

Secondly, the location system did not work properly because there were not sufficient tags to give each person a personal tag. Tags had to be places in a recharge plug and re-assigned to different persons each morning. We have observed that the clinicians stopped using these tags, which indicates that the benefit of location tracking does not outweigh the cost of recharging and reassigning them every day. On the other hand, however, the use of personal mobile phones for location tracking was used continuously. Hence, it is important to use location tracking devices which are personal and which either runs for an extensive period of time, or are devices which are used for other purposes, like the mobile phone. In our future research, we will no longer use the Bluetooth tags but will rely primarily on the use of personal mobile phones.

Thirdly, because the displays were designed to be open and easy accessible everybody can go and change information on them. This constitutes a wide range of problems. For example, we observed that people could accidentally move an operation in time by just leaning against the display. This particular problem was mended by adding a 'lock' icon to the interface, but this is not the right solution. More generally, the system need to incorporate access control since legally speaking, we need to track who is altering clinical information.

Finally, there is an open issues regarding privacy in such public displays. The whole purpose of making public displays is to make information publicly available. However, patient data and e.g. surgical procedures are highly sensitive data where privacy concerns are important. Furthermore, when using video streams from an operating room, we are exposing patients in the most vulnerable situation you can imagine. Hence, privacy is an important issue. There is, therefore, an inherent contradiction at stake here – how can we make private data publicly available? We cannot provide one answer to this challenge and we believe that it to a large degree depends on the concrete application and its deployment conditions. In our current deployment of AwareMedia, the large displays are only visible from inside the surgical ward and its operating rooms, which are only accessible by authorized personnel, and not by e.g. patients, relatives, or visitors. In addition, AwareMedia does not broadcast video outside the operating ward. However, there is a request from the clinicians to use AwareMedia in e.g. the waiting lounge of the hospital. The current design of AwareMedia cannot be used in such public places where personal medical data cannot be shown. We think that by making the system aware of its current deployment context may help accommodate such privacy concerns and we are currently pursuing this line of research.

5. RELATED WORK

Little work on the design of coordination and scheduling systems for medical work has been reported. However, a wide range of systems have been proposed over the years for other settings, mostly office and academic environments, or more public places in general. AwareMedia combines and extends the design of a wide range of these systems, including systems using large interactive public displays, systems for providing social awareness, video media spaces, instant messaging (IM) systems, and scheduling and calendar systems.

A wide range of research has been done to make systems for social awareness, including Elvin [7], the 'Awarenex' which supports a mutual awareness by listing people, their location, and their current online schedules [17], and StudioBRIDGE which is an IM-based system that integrates individual presence information with additional awareness information about groups, locations, and events of the community [19]. Some work has also been done in the use of large displays for awareness purposes. Designed as a public bulletin board, the Notification Collage [8] allows distributed and co-located colleagues to post media elements onto a real-time collaborative surface that all members can see, including live video from desktop cameras and activity indicators. Similarly, Kimura [12] provides users with an awareness on the progress on their work and colleagues, and display this on peripheral large displays. All of this research on social awareness has, however, primarily focused on providing one user with a personal awareness on his or her colleagues current work, whereabouts, and status, and has mainly been tested in office-like environments. Common to these systems is that they share awareness information for individual or personal use. The main distinction of AwareMedia from this previous work is that it integrates awareness information about people, places, and events in time (operations) into one *publicly shared display* where all relevant persons can see what their colleagues are doing, where they are, etc.

Early projects on providing awareness to distributed workgroups gave a sense of remote participants, their locations, and their activities through audio and video [6, 4]. The use of video in AwareMedia is a direct successor to this early work. One small, but important, difference is that video in AwareMedia is used for *spatial awareness* and not for social awareness, which was the primary focus in Rave and Portholes. The media space in AwareMedia is, however, using modern webcam technology and is as such deeply integrated into the display, user interface, and architecture of AwareMedia. This use of a media space underlines the basic design principle of providing a rich picture on awareness having redundant awareness information available.

The use of instant messaging (IM) has been exploding recently and IM is now an important source of awareness information for many office workers [13]. Some work has been done to support IM on large shared displays for workgroup interaction which seeks to extend the benefits of IM beyond people's personal machines and into publicly accessible groupware [11]. Even though most IM systems support conferences with more than two participants, this continues to be the exception rather than the rule. In AwareMedia, in contrast, groupcast communication is always default in order to support the shared public awareness involving all persons in the operating ward. Furthermore, messages are not directed to persons but to locations, like the operating room.

6. SUMMARY

In this paper we have presented AwareMedia, which is a system designed to support social, spatial, and temporal awareness in a hospital and enables users to use simple, shared messaging for easy and asynchronous communication. Key features of the system include the use of video media spaces for providing spatial awareness of e.g. an operating room; using consistent user representations for social awareness; displaying past, present, and future operations for temporal awareness; using a location- and context-awareness subsystem for revealing context cues to users; using a shared messaging system for broadcasting messages related to rooms (as opposed to sending messages to people); and the use of stable, persistent, and predicable interactive displays situated in strategic places around the hospital.

AwareMedia runs continuously at a operating ward and is deployed in ten different settings, including three operating rooms. After three months of deployment, the system handles all operations in the three ORs and the clinicians have abandoned using the old paper-based operations schedules. The space in this paper did not allow for detailed reports from the deployment of AwareMedia, but there is substantial evidence that the system helps clinicians to coordinate their work in new ways by providing a shared awareness. This helps them time interruptions appropriately, eases simple message communication, and helps locate people within the ward. The facts that AwareMedia shows the same contextual information in many redundant ways and that it is a stable, persistent, and predictive display for easy visual reference, was also reported as a major benefit of the system.

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