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Context-Based Workplace Awareness

Concepts and Technologies for Supporting Distributed Awareness in a Hospital Environment

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Abstract. Maintaining an awareness of the working context of fellow co-workers is crucial to successful cooperation in a workplace. For mobile, non co-located workers, however, such workplace awareness is hard to maintain. This paper investigates how context-aware computing can be used to facilitate workplace awareness. In particular, we present the concept of *Context-Based Workplace Awareness*, which is derived from years of in-depth studies of hospital work and the design of computer supported cooperative work technologies to support the distributed collaboration and coordination of clinical work within large hospitals. This empirical background has revealed that an awareness especially of the *social, spatial, temporal*, and *activity context* plays a crucial role in the coordination of work in hospitals. The paper then presents and discusses technologies designed to support context-based workplace awareness, namely the AWARE architecture, and the AwarePhone and AwareMedia applications. Based on almost 2 year' deployment of the technologies in a large hospital, the paper discuss how the four dimension of context-based workplace awareness play out in the coordination of clinical work.

Key words: social awareness, context-aware computing, mobile computing, hospitals, pervasive healthcare, AwarePhone, AwareMedia

1. Introduction

An extensive body of research within Computer-Supported Cooperative Work (CSCW) has established how maintaining *social awareness* amongst co-workers fosters efficient coordination and collaboration (Schmidt 2002; Heath et al. 2002; Heath and Luff 1992). Studies of co-located cooperative work show that people tacitly and unobtrusively align and integrate their activities in a seamless and highly sophisticated manner without interrupting each other. For example studies of control rooms (Heath and Luff 1992) and of operating rooms (Heath et al. 2002) reveal the subtle social mechanisms that help people adjust their own effort to those of others co-located with them. Social awareness thus helps to minimize interruptions and disturbances when one is engaged in cooperative work.

Whereas social awareness can be achieved directly in co-located work, in spatially or temporally distributed work it needs to be mediated. For example, at the operating room (OR) suite of a hospital it is common to have large shared whiteboards that provide information on such things as the location of staff, list of patients, on-going surgery, and the status of each operation (Bardram 2000; Xiao et al. 2001). These whiteboards mediate a social awareness amongst the surgical personnel across time and space in an OR suite. Similarly, studies of the use of instant messaging (IM) show that creative use of the 'online' and 'status' information helps to maintain social awareness (Nardi et al. 2000). In this sense, tools such as whiteboards and IM mediate social awareness.

This kind of social awareness—co-located or distributed—makes cooperation more efficient in two ways. First, social awareness helps to minimize interruptions and disturbances among those engaged in cooperative work, because workers can see or reveal when it is an appropriate moment to engage in direct communication—a phenomenon that Kjeld Schmidt calls 'appropriate obtrusiveness' (Schmidt 2002). Second, maintaining social awareness of the work of colleagues helps people to align their own work activities to the work of others, including offering help or assistance if needed. For example, a skilled operating nurse can often prepare and supply the right surgical instruments in a timely manner during an operation through maintaining an awareness of the progress of the work of the surgeon and anesthesiologist.

The main focus in CSCW studies and technologies has been on this social dimension of awareness, i.e., on how people maintain awareness of other people, including what they are doing, where they are, and what artifacts they are working with. In this paper, we present a case study of how hospital clinicians maintain an awareness of work as it progresses. This study shows that in addition to this social awareness, people maintain and use an awareness of other aspects of the workplace, including awareness of specific locations, of specific activities (irrespective of who is performing them), and of how activities develop over time. By using the term '*workplace awareness*', this paper aims to highlight the fact that there is more to awareness than the social dimension; thus awareness also includes spatial, temporal, and activity-related dimensions.

Moreover, the study shows that clinicians constantly monitor their work context for 'cues' that reveal information about the status and progress of an ongoing task. For example, the charge nurse in a large operating room (OR) suite constantly monitors the progress of the operations being performed within each operating room so that s/he is able to accommodate any contingencies arising during the day. In this paper, we use the term '*context-based*' to indicate that workplace awareness is often based on information about the context of work, i.e. it requires access to information about where people are located, what they are doing, what is happening in a specific room, what is going to happen next, and

the status of any ongoing activity. Here, we use the term 'context' as it is used within Ubiquitous Computing, i.e. "[c]ontext is any information that can be used to characterize the situation of entities (i.e., whether a person, place, or object) that are considered relevant to the interaction between a user and an application." (Dey et al. 2001, p. 106).

Taken together, this paper introduces the term *Context-Based Workplace Awareness* to denote the mechanism of establishing awareness about the activities in a workplace based on access to information on work context. In particular, the paper investigates context-based workplace awareness in ubiquitous computing environments designed for hospitals. Thus our focus is on a technological and clinical work configuration in which users (i) are extremely mobile; (ii) are engaged in a high degree of collaboration entailing frequent interruptions and changes in activity; (iii) use public computers rather than personal ones; and (iv) work in a life—and time-critical environment. A core challenge in this environment is to enable these mobile, collaborative, and busy clinicians to be aware of relevant events going on within the hospital so that they can effectively align and coordinate their work activities. We argue that this kind of workplace awareness depends on collecting, processing, distributing, displaying, and sharing information about the constantly changing work context.

The purpose of the present paper is twofold: First, on the basis of studies of clinical work in hospitals, it aims to develop the concept of 'context-based workplace awareness', showing among other things how the four dimensions of workplace awareness—social, spatial, temporal, and activity-related awareness—are especially central to coordination in hospitals. Second, it aims to present technologies for mediating workplace awareness based on context information. The technologies consist of a general architecture for building computer applications to facilitate context-based workplace awareness, and two examples of such applications. We call the architecture 'The AWARE architecture' and the two applications 'AwarePhone' and 'AwareMedia'. The AWARE architecture builds on the notion of context-aware computing to capture, manage, and distribute information about the working context of the users, and uses this context information as a foundation for mediating social awareness among users.

The paper is structured as follows: Section 2 introduces the kinds of coordination and awareness challenges that arise within operating room (OR) suites, which constitute the empirical background of the paper. Section 3 defines context-based workplace awareness and its four dimensions based on the study of work in OR suites. Section 4 presents technologies for supporting context-based workplace awareness, including the AWARE architecture and the AwarePhone and AwareMedia applications. Section 5 presents the deployment of these technologies in one of the OR suites previously studied. On the basis of this deployment, Section 6 discusses how these technologies support social, spatial, temporal, and activity-related awareness. Section 7 presents and discusses related work on awareness technologies, and Section 8 concludes the paper.

2. Empirical background: coordination in surgical departments

Cooperation, coordination, interruptions, mobility, and social awareness are key characteristics of hospital work (Bardram 2000; Bossen 2002; Reddy et al. 2001; Xiao et al. 2001; Heath et al. 2002; Bardram and Bossen 2005). Due to the specialized nature of medical work in hospitals, cooperation and hence coordination is absolutely central in achieving an efficient flow of work. At the same time, medical staff members are extremely mobile, visiting many different buildings and floors in the course of each day. Thus a common observation is that much time is spent looking for co-workers and trying to locate them. Work is frequently interrupted due to extensive use of telephones and pagers. For example, a nurse may be disturbed by a doctor inquiring about a patient; by a fellow nurse who needs help; or by a patient triggering the alarm by 'pulling the cord'.

The scheduling and coordination of operations in an OR suite is an especially challenging task in any modern hospital. Performing surgery is a highly specialized and advanced procedure that involves surgeons, nurses, anesthesiologists, a patient, an operating room, and various kinds of equipment. In addition, cleaning, patient transportation, recovery, etc. have to be coordinated. This means that the many people involved in a surgical procedure must coordinate their work and constantly maintain an awareness of the progress of work in the OR suite as a whole. Furthermore, although substantial efforts are put into drawing up operating schedules in advance, the work of a surgical department is highly contingent and numerous events may affect and change the schedule. Such contingencies include the arrival of an injured patient admitted through casualty, delays to an operation due to unforeseen complications, illness among staff, and patients not being ready for surgery. In all such cases, plans need to be adjusted and the people involved must be made aware of these changes so that they can adjust their work accordingly.

The notion of context-based workplace awareness is based on two large-scale studies of collaborative work in hospitals. The first study focused on collaboration within and between an inpatient ward and an OR suite in a plastic surgery department at Aarhus University Hospital. We carried out 40+ hours of focused participant observation (Jordan 1996) and held four future workshops (Kensing and Halskov Madsen 1991). Nurses, surgeons, and dentists participated in the study and workshops.

The second study focused on collaborative work within the anesthesia and surgical departments at Horsens Hospital. The three surgical departments specialize respectively in orthopedic, organ and obstetric surgery, and share one large OR suite consisting of nine operating rooms. We participated as observers in a large number of operations as well as studying the coordinating work involved in the planning, scheduling, and execution of operations in the OR suite (approximately 80+ hours of observation). As part of this study we also held a

number of future and evaluation workshops with nurses, surgeons, secretaries and managerial staff.

3. Context-based workplace awareness

People working in a distributed manner in different locations cannot maintain mutual awareness directly, but have to rely on mediation through shared artifacts. In hospitals, whiteboards are often used to communicate status information to all relevant personnel in an OR suite (Bardram 2000; Xiao et al. 2001). By combining knowledge of the work settings with different cues in the environment, people can get a feeling of the work situation. By looking at a desk, for instance, you might be able to tell if a given person is at work that day, if s/he was busy just before leaving the desk, and what s/he is currently working on. Similar information can be obtained by looking in online calendars, consulting the status update in IM, checking meeting rooms, or looking into the operating rooms at a hospital. Thus people use what we call 'context cues' observed in their environment to maintain awareness about the workplace. Or to put it another way: *the work context is used to mediate workplace awareness*.

The concept of *Context-Based Workplace Awareness* denotes the way that mobile, distributed, and busy co-workers maintain an awareness of the workplace by—explicitly or implicitly—monitoring and displaying their work context. The current status of people, places, and activities can be displayed through the work context by the deliberate or unintentional dropping of cues. In a ward, for example, a secretary may place a patient's medical records in a clearly visible position at the edge of the desk in order to display to the relevant doctor that new information has been added to the record. Similarly, staff may monitor the work context in order to maintain workplace awareness. For example, the charge nurse at the OR suite may monitor when the surgeon enters the operating room, knowing that from now on s/he should not be disturbed.

The interesting question, then, is what kind of cues about the work context would help co-workers to maintain workplace awareness. On the basis of our studies of the coordination of medical work in the surgical departments, we found that context-based workplace awareness can be divided into four dimensions:

- Social—an awareness of the social context of the work, i.e. an awareness of the people at work and what they are doing right now.
- Temporal—an awareness of the progress of activities over time: past, present, and future
- Spatial—an awareness of particular physical locations (both co-located and remote) and their context
- Activity—an awareness of particular activities and the context in which they take place, irrespective of who is performing them.

Essentially these four dimensions of context-based workplace awareness are related to maintaining an awareness of 'who', 'when', 'where', and 'what' in a

shared work environment. In all four kinds of awareness, context cues are both monitored and displayed. Based on our field studies, the sections below discuss in greater details these four dimensions and the displaying and monitoring of context cues.

3.1. Social awareness

Maintaining mutual awareness of the activities and whereabouts of a team of clinicians is central to the implementation and coordination of work in hospitals (Heath et al. 2002; Bardram and Hansen 2004). During our field studies and design process we observed how clinicians working in OR suites continually monitor each other's activities while similarly ensuring that important aspects of their own activities are visible to others.

For example, a recurrent challenge for young, inexperienced doctors in a hospital is to obtain advice from a more experienced colleague. The following observation from the plastic surgery department is quite typical:

> A young doctor is treating a patient and is checking an open wound to see if it is possible to put the transplanted skin on. The wound has been bleeding a lot and is flawed close to the edges. On the one hand it might be better to wait to transplant the new skin until the wound looks better, but on the other hand the transplanted skin might protect the wound and make it heal more quickly. The young doctor starts looking around for a more experienced doctor in the ward. Finally, he finds an experienced doctor in an office one floor up, and together they move down to the ward to look at the wound.

This situation illustrates that a key prerequisite for engaging in collaborative work is to be able to locate fellow doctor, which in practice often proves difficult. Clinicians therefore often use various kinds of cues to try to infer the current whereabouts and activities of a colleague:

> A patient wants to be transferred to a hospital closer to his home. The patient asks the nurse when he will be able to leave. The nurse calls the doctor on his pager and waits. Nothing happens. She looks at a printout of all the doctors' calendars, and the doctor in charge is apparently doing something called 'visions' today. The nurse wonders what 'visions' means and tries to find another doctor.

Thus knowledge about the activities of colleagues[1] is often used to help figure out exactly whom to contact.

In our design workshops we proposed using a computer system that gave junior doctors and nurses a fast and easy way to contact more experienced doctors. The less experienced doctor might often need advice immediately, e.g. when engaged in treating a patient. If the young doctor or nurse could be made aware of the activity and whereabouts of more experienced doctors (i.e. the

working context of these doctors), this would help him or her to find an appropriate moment to request advice.

The goal of designing for *social awareness* is thus to provide co-workers with a general awareness of their colleagues' current activities and where-abouts. The goal is not necessarily to show *exactly* what other people are doing, but to provide context cues that can be pieced together to form an overview of what other people are *most likely* doing. Relevant social context clues in a hospital environment are, for example, the role, current location, status, activity, and future plans of a specific person.

3.2. Temporal awareness

Temporality is a key aspect of medical work in hospitals (Zerubavel 1979) and studies have shown how an awareness of schedules, temporal rhythms, temporal patterns, and temporal cycles helps clinicians perform and coordinate their work (Bardram 2000; Reddy et al. 2001). Clinicians align their work to the schedule as it unfolds, adjusting as they go along to changes in it such as delays or cancellations.

Our observations and the design process revealed moreover 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 would expect temporal coordinating to be about the future, but that is not always the case. For example, information about past or cancelled operations is 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 paper-and-whiteboard-based scheduling system shown in Figure 1, is that you can easily spot changes to the program as they are hand written across the operation schedule printed by a computer system.

Updating the operation schedule, as shown in Figure 1, provides a temporal context that helps the surgical staff to maintain *temporal awareness* of past, present, and future activities and events that may be relevant to them. In the OR suite, the publicly available operation schedule for each operating room is an important constituent in maintaining this temporal awareness. However, changes to the operation schedule need to be communicated by telephone to relevant personnel not present in the OR suite. These include surgeons, the staff on the different wards, and those in the recovery ward.

3.3. Spatial awareness

Clinicians in a hospital, put a lot of effort into maintaining an awareness of what is happening in 'significant' remote locations such as wards or operating rooms. In OR suites, various sign systems are used to indicate the status of a given

Figure 1. The operation schedule in the OR suite at Horsens Hospital. The schedule is a printout from a computer-based booking and scheduling system, which is attached to the large whiteboard. As the work progresses during the day, changes and cancellations are handwritten onto the schedule. Relevant personnel such as surgeons and the staff on the wards are notified of changes by telephone.

operation (Bardram 2000; Xiao et al. 2001) 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 (Bossen 2002). These observations were confirmed during our field studies and design process.

The typical workflow in an operating room requires different people to be there at different times. First on the scene is the scrub nurse who prepares the room. Later the anesthesiologist arrives and makes preparations for sedating the patient. The patient is then rolled in by the hospital orderly and anaesthetized, at which point the surgeon arrives. After the operation the participants leave the room in the reverse order, and finally, the room is cleaned by the cleaning staff. All of those involved in the procedure are deeply dependent on knowing the current status of the operating room. In order for the orderly to know when to bring in the patient, he need to know when the anesthesiologist is ready; likewise, the surgeon needs to know when the patient has been anaesthetized.

Various means are used to maintain spatial awareness of the OR. As illustrated in Figure 2, clinicians can look into the room through the porthole in the OR door. But the most frequently used method is either for clinicians to call the

Figure 2. The door into the OR contains a porthole which helps clinicians to maintain spatial awareness of the workflow inside the OR without entering the room.

operation coordinator about the status of a particular OR, or for the operation coordinator to notify clinicians about its status. For example, it is very common for the coordinator to call the surgeon to tell him that s/he is now needed in the OR.

As we discussed at the design workshops, it is therefore vitally important to design for *spatial awareness* to enable those who are not physically present at a given location to maintain awareness of specific features of it. In the OR suite, such features include the kind of operation taking place in a given operating room; the level of activity; the status of the operation; the various individuals in the room, including both the professionals and the patient; and any contingent issues, such as delays or unforeseen difficulties.

3.4. Activity awareness

Hospital clinicians always have to juggle a number of concurrent activities in their daily workflow. For example, even though a surgeon typically performs operation sequentially, there is a lot of preparation and documentation of operations that runs in parallel. Thus during the day he may visit one patient at the ward and prepare him or her for operation; he may take a look at some x-ray

images that may be needed in a later operation; he may see a patient for a check-up; he may dictate an entry regarding an operation into a patient's file; and he may also find time to perform an actual operation. To illustrate:

> In the course of an operation some lymph nodes are removed from a patient because they contain a malignant cancer. After the nodes have been removed the surgeon takes five samples from each side of the wound and sends them to the laboratory. The laboratory has to test the sample to see if the edges are clear; that is, to check that the entire malignant area has been removed. If the lab result is positive the wound can be closed, if the result is negative more skin has to be removed. While the lab is doing the test the doctor keeps busy by going on a ward round. However, he constantly checks back for the lab result.

In this case, the surgeon needs to maintain awareness of the activity of the lymph-removal operation and the associated activity of the lab test while working on other activities.

Various means are used to maintain activity awareness in a hospital. For example, the surgeon above may phone the lab at regular intervals or he may ask the lab to page him, when the test results are ready. Similarly, the cleaning staff and the hospital orderly constantly monitor the progress of work inside the OR by e.g. looking through the portholes or monitoring the status indication on the scheduling whiteboard in order to adjust their work to the on-going operations. Another common strategy is to print out the work plans for each doctor and post these on various whiteboards to give some indication of their activities during the day.

Thus a central issue discussed during design sessions concerned ways to help distribute information about different activities. The tasks in question seemed to fall into two broad categories: (i) giving general information about an activity, and (ii) notifying specific subscribers about the progress of that activity. In the first category, for example, comes the task of providing status information on operations and information on a person's current activity, e.g. which operation a surgeon is currently performing. An example of the second category is allowing a surgeon to subscribe to a system whereby the lab notifies him/her when the test results are available. In the latter case, we discussed the need for a way to prioritize these notifications since some of them would be more important than others.

4. Technologies for context-based workplace awareness

Technological support for context-based workplace awareness should help users to monitor and displays relevant context cues. In a collaborative and mobile working environment such as a hospital, such technology can help to distribute context information across time and space. Computer systems can support

context-based social awareness by presenting users with context cues relating to the workplace. Such context cues can be obtained and managed by *context-awareness* technology (Dey et al. 2001); a context-awareness sub-system can automatically capture, manage, and distribute context information about people, places, plans, and activities, and this context information can then be displayed to, or monitored by, relevant users, thereby fostering a shared workplace awareness. In this paper we do not adhere to the traditional definition of context-awareness, i.e. giving the computer a sense of the user's context. Rather we focus on distributing some of the context information that is monitored by a context-awareness system to the system's various users. In this way, context information can be used as context cues to make people aware of what is going on in the workplace.[2]

Other projects have shown how the context cue 'where people are located' can be gathered by context-aware systems and presented to the user to support certain kinds of social awareness (Dey et al. 2001; Cheverst et al. 2000; Tollmar et al. 1996). The weakness of many of these systems, however, is that they only support a single context cue (i.e. physical location), which might indicate several very different activities. For example, if a surgeon is situated in an operating room, s/he might be there to operate, to get a specific instrument, to ask for advice, or for some completely different purpose. We therefore suggest that users of a context-based workplace awareness system should be presented with a set of different context cues rather than only one. Furthermore, it is important to enable people to 'display' context cues about themselves.

For this purpose, we have been researching the design of a system architecture and end-user applications for supporting context-based workplace awareness in a hospital. These technologies are presented in this section. Section 4.2 presents the AWARE architecture, which is a general-purpose architecture for building context-based workplace aware applications. Sections 4.3 and 4.4 present two such applications for use in the OR suite, namely the AwarePhone and the AwareMedia systems. The two applications are the result of an extended design process with clinicians, which is briefly outlined in Section 4.1.

4.1. Designing aware applications for hospitals

The AwarePhone and AwareMedia applications, and the underlying AWARE architecture were designed in the course of a 4-year participatory design process in close collaboration between a number of clinicians and researchers. The AwarePhone was the first application to emerge from this process, and was designed together with clinicians from a plastic surgery department at Aarhus Hospital (Hansen 2006). The application was designed on the basis of input from the field study, and this version was refined and given an initial evaluation at a scenario-based evaluation workshop. The input from the design of the

AwarePhone was consolidated in the design of the more general-purpose AWARE architecture (Bardram and Hansen 2004).

The AwarePhone and the AWARE architecture were subsequently refined and used in the participatory design process in collaboration with the operating department at another hospital (Horsens Hospital). With the help of a wide range of clinicians at Horsens Hospital, the AwareMedia application was designed and implemented on the basis of the AWARE architecture, which also meant that AwareMedia were integrated with the AwarePhone. In late 2005 these technologies were deployed at Horsens Hospital, as described in Section 5.

The design methods applied throughout the participatory design process involved detailed field studies of collaborative work in both hospitals; future workshops to brainstorm ideas; video prototyping; paper prototyping; and a series of design workshops in which different version of the systems were evaluated by the clinicians. The overall design rationale emerging from this design process is outlined below, and the detailed design of the applications that emerged from this design process are reflected in the AwarePhone and the AwareMedia systems, discussed in Section 4.3 and 4.4.

- Based on our field studies, the four awareness dimensions—social, temporal, spatial, and activity—should be supported by providing appropriate context cues, and it should be easy to add new types of context cues to the system.
- Since the context information may be incorrect or not up to date, it is useful to keep redundant context information; for example, it is useful to have several ways to see where a person is located.
- Because clinicians rely heavily on direct communication (often using mobile phones), passive awareness technology should be combined with active communication channels such as messaging and voice communication.
- Due to the time-critical nature of medical work, the applications should provide an overview rather than detailed information; for example, the current status of an operation can be indicated in a simple text or a color rather than in detailed information on elapsed time or delays in minutes. Furthermore, it is essential that clinicians should be able to see relevant information at a glance. Thus as far as possible login procedures should be avoided, as should efforts to hide information and limit access only to certain roles.
- Resembling the whiteboards used pervasively in hospitals (c.f. Figure 1), awareness information should be integrated into publicly available interactive displays mounted on walls in relevant places. One should avoid using office-based computing equipment such as desktop and laptop computers, which are often hard to get to.
- In order to create and maintain a shared awareness of the current state of play in the hospital, awareness information should be distributed and shared amongst networked interactive displays.
- Bearing in mind the great mobility of hospital staff (Bardram and Bossen 2005), awareness information should also be available from portable devices.

4.2. The AWARE architecture

The overall goal of the AWARE architecture is to support context-mediated social awareness amongst mobile, distributed, and collaborative users, such as hospital clinicians. In addition, the goal was to design a general-purpose architecture that could be applied in the design and development of different end-user applications running on different types of devices.

From a technical point of view, the architecture should be able to adapt to different methods and technologies of sensing context and awareness information, such as different location-tracking technologies; it should be able to run in a distributed and heterogeneous execution and network environment; it should be event-based so that is can broadcast event notifications about changes in awareness information to relevant subscribers; and it should be able to integrate with other collaborative technologies, thereby enabling user to make a smooth transition from mutual awareness to direct collaboration. For example, it should enable people to communicate via a messaging system.

The core idea in the AWARE architecture is to combine CSCW system components for providing *social awareness* among collaborative users with Ubiquitous Computing components for obtaining *context-awareness*. This two-fold strategy is reflected in the architecture, as shown in Figure 3.

The architecture of the AWARE framework is organized in four layers: (i) the Client layer contains end-user applications using the framework as a back-end system; (ii) the *Awareness layer* contains the *Awareness Service*, which maintains an awareness of people, how they link together socially, and how to reach them;

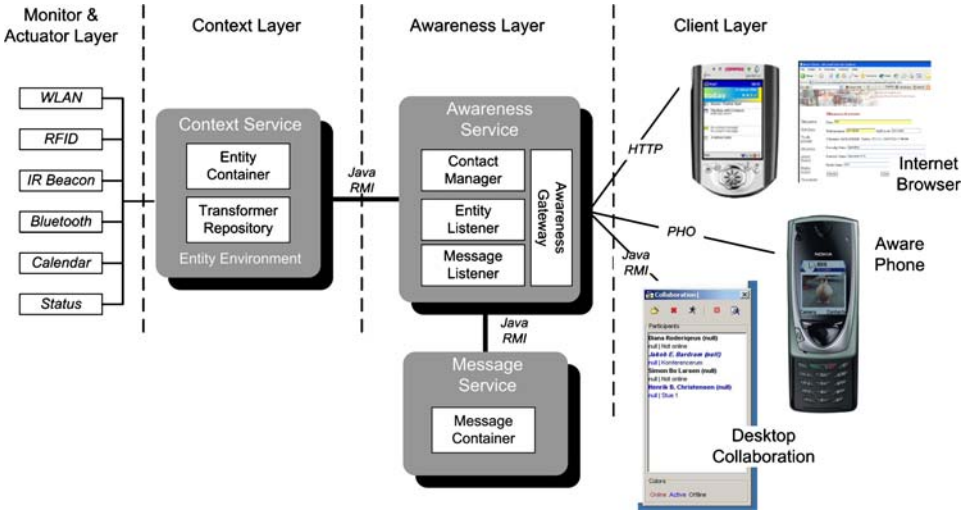

Figure 3. The AWARE system architecture. The architecture is divided into four layers: the Client layer, the Awareness layer, the Context layer, and the Monitor and Actuator layer.

(iii) the *Context* layer; and (iv) the *Monitor and Actuator* layer, which are part of the context-awareness infrastructure on which the AWARE framework is built.

The *Awareness Service* has two main responsibilities. First, to maintain information about users subscribing to the AWARE system, and about whom they want to maintain social awareness, and to handle event-based notifications of changes to these users' contexts. This is achieved through close collaboration between the *Contact Manager*, the *Entity Listener*, and the *Message Listener*. Second, the Awareness Service must handle connections to clients using different protocols, respond to their requests, and know how to notify them about relevant events. The *Awareness Gateway* component is responsible for this behavior.

The Contact Manager keeps track of the contacts for each user, i.e. those individuals about whom this user wants to maintain social awareness. This is a simple list of other users in the AWARE system, much like the list of contacts in an IM system (an example of a contact list can be seen on the AwarePhone in Figure 4).

The Awareness layer in our current implementation furthermore contains a *Message Service*, which is a simple message broker that enables users to post messages to each other. Strictly speaking, the Message Service is an optional part of the AWARE architecture because it could be replaced by an IM service, an SMS/MMS message service, or another more elaborate cooperation and/or workflow system. The key point, however, is that the AWARE architecture needs to be integrated with such messaging or collaboration systems in order to support users in smooth transitions between maintaining a shared social awareness to entering into direct collaboration. In this way it becomes possible to embed messaging and collaboration functionality directly in the client applications, as in the AwarePhone.

Figure 4. Users listed on the AwarePhone. The format is < name > (< status >) < activity > | < location >.

The context infrastructure is responsible for monitoring context cues in the users' environment, including displaying cues from users, and for storing, managing, and distributing these cues in the awareness service. The context infrastructure is implemented using the Java Context-Awareness Framework (JCAF) (Bardram 2005), which supports the acquisition, management, transformation, and distribution of context information. The *Context Service* is a long-lived process that maintains context information about relevant entities in the real world, such as staff, places, things, patients, beds, pill containers, etc. Examples of context information include location, noise level, a person's activity, or people nearby. The context service also handles the distribution of context information to clients, using either a request-response or a publish-subscribe pattern. Thus the context service handles subscribers to context events and notifies relevant clients of changes to entities. The *Context Monitors* are hardware and/or context data-specific processes that register changes in the physical or digital environment. A monitor adapts this context information according to the data model used in the context service. Examples of context monitors are location monitors based on Bluetooth monitors, which are designed to locate Bluetooth-enabled equipment. Other monitors might gather information about planned activities in users' personal calendars, or status information in an Instant Messaging system.

The Awareness Service uses the context infrastructure by connecting to a Context Service and registering itself as a listener to entities relevant to the AWARE framework, such as personnel, rooms, and activities. The Awareness Service then receives notifications of relevant changes. When e.g. changes to a user's context occur, relevant clients are notified. For example, if person A has person B in his list of contacts, then A is notified if person B moves from one location to another, or when other context information relating to B is changed. Similarly, if person X sends a message to person Y, and person Y reads this message, then this information is propagated to person X's device. Applications running on the device can now treat these events appropriately, i.e. updating the user-interface or notifying users.

Support for heterogeneous devices is handled by the *Awareness Gateway*, which is able to transform protocol-specific requests to the Awareness Service and translate these using the internal AWARE API for responding to clients. This API consists of the collected APIs from the Context Service, the Awareness Service, and the Message Service, respectively. An important responsibility of the gateway is to know how to contact a user, by knowing his current device (e.g. a mobile phone), its communication protocol, and relevant technical information on physical addresses and communication port numbers.

4.3. The AwarePhone

On the one hand, the phone plays an absolutely central role in the coordination of work in a hospital. On the other hand it is also the source of many disturbing

interruptions. In order to reduce the number of interruptions from telephone calls, we designed the AwarePhone application and implemented it as part of the AWARE architecture.[3] The AwarePhone is an application that runs on a smart phone, which can display a contact list for a user and support simple text messaging. The working context for each user is displayed on the contact list and this enables the user to maintain an awareness of the context of a colleague before initiating a call. The AwarePhone is integrated with the telephone functionality on the phone as well as the messaging system in the AWARE architecture. This means that the user can choose either to initiate a direct phone call to one of the users listed on the contact list or to write a message. Priorities can be attached to a message, thereby indicating the degree of urgency.[4]

In the current version of AwarePhone, the contact list displays three context cues for each person: (i) 'Personal Status', which can be set from the phone, (ii) 'Activity' which is the operation that a person is scheduled to perform at the moment, and (iii) 'Location' as revealed by our location tracking system. These three context cues were chosen as the key clues during our design workshops. Figure 4 shows how users are displayed in a contact list on the AwarePhone. This phone belongs to 'Anette Row' and she can see on it the social context of her contacts. For example, in Figure 4 the surgeon 'Jens Ole Storm' has a status labeled 'opr', i.e. operating; he is scheduled to perform an operation called 'Ucementeret Hofte' (a hip replacement operation), and is located in 'OR4', i.e. operating room 4. It would therefore be unwise to try and call him right now.

To support the AwarePhone, location, status, and activity monitors were added to the AWARE architecture, and a special-purpose PHO protocol was designed and plugged into the Awareness Gateway. The PHO protocol uses a compact string format over a TCP/IP socket between the AwarePhone and the Awareness server.

In terms of the concept introduced above, the AwarePhone is especially designed to support workplace awareness. The system supports social awareness among clinicians by displaying cues about their current activities. The user can also however add an operating room to the contact list. The same context cues—location, activity, and status—are displayed for an operating room which means that the user can access information about what operation is taking place in the OR at the moment and what the status of the operation is. In this sense the AwarePhone is also designed to support spatial awareness. Although the AwarePhone gives less support to temporal awareness, the clinicians' and operating rooms' current activities are also displayed.

4.4. AwareMedia

The AwareMedia system has been designed as a large publicly accessible interactive surface that allows clinicians to maintain a shared, temporal, spatial, peripheral awareness of the progress of work in an OR suite. Resembling the

whiteboards used pervasively in hospitals (c.f. Figure 1), AwareMedia supports publicly available interactive displays mounted on walls in relevant places, like the coordination center (see Figure 8) and the operating room (see Figure 9). The support for awareness is supplemented with basic support for text-based communication. The main design hypothesis is that the combined overview of people, place, time, and surgical activity will help clinicians be more efficient in coordinating their work, including managing contingent and critical situations. Because large public whiteboards play an essential role in the coordination and scheduling of operations in hospitals, 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 that would 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 5

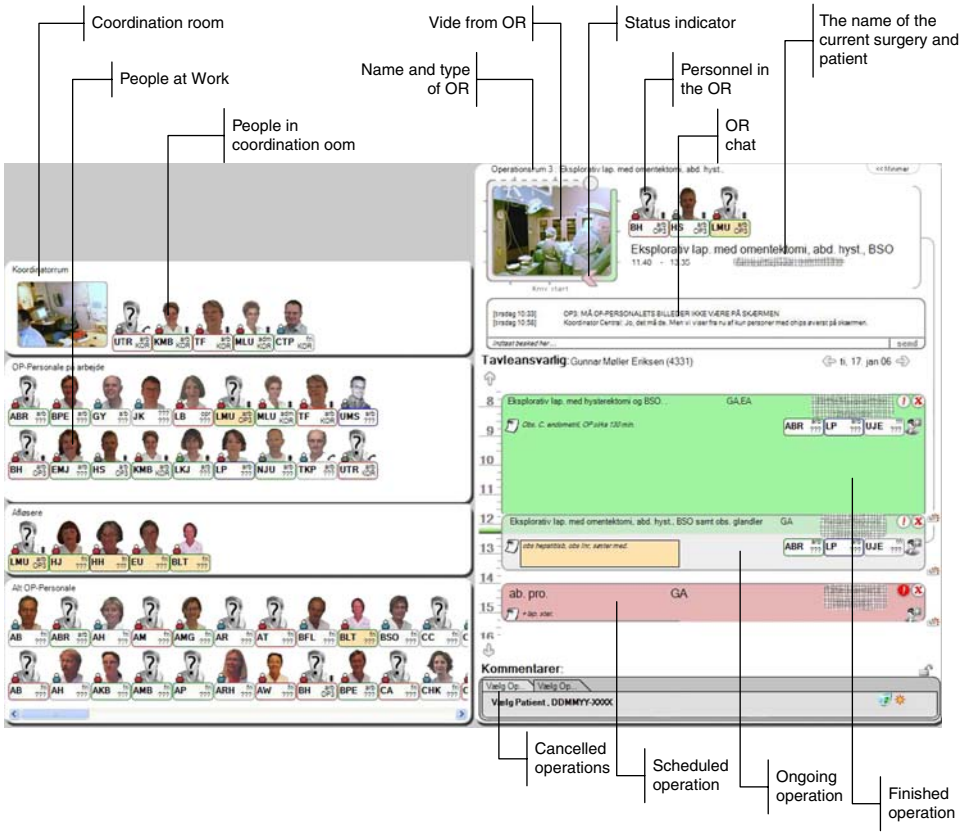

Figure 5. AwareMedia showing video connection between the different operating rooms, status information for an operation, and the operation schedule.

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 OR suite. The right-hand side provides an overview of one operating room. If more displays are available (as shown in Figure 8), then more operating rooms can be shown on the additional screens. AwareMedia is a standard Windows application and runs on any Windows XP PC. All installations of AwareMedia, however, are performed on dedicated PCs with dedicated touch screens, and AwareMedia runs as a full-screen application occupying the whole screen estate and cannot be closed, resized, or moved. In this way it provides a stable, consistent view much like that provided by whiteboards.

A key 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 on a given person is displayed on that person's icon, and location can also be seen from the placement of the icon in a specific location (e.g. in an operating room), and from the video images. In this way, AwareMedia provides a broad avenue of supplementary awareness information that helps the user quickly to judge the status, activity, and location of a person.

Spatial awareness is provided in the top right corner of each OR in the AwareMedia interface. This consists of the video feed from the OR, the status bar running around it, the list of clinicians in the OR, plus information about the patient and the operation taking place in the OR. 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 involved. 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 invading privacy by revealing details such as the part of the patient that is being operated on. The status bar is wrapped around the video image and reveals the current status of the operation, indicated by the text below the video image. For example, "Patient bedøvet" means "Patient anaesthetized". The status bar is cyclical, reflecting the cyclical nature of all operations. While the status indicator (the small arrow) moves down the right side of the image, the surgery is being prepared and the patient anesthetized; when the status bar moves across the bottom, the patient is being operated on; when it moves up, the patient is being closed and wheeled out; and when it moves 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 of 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 more detailed awareness of exactly who is in the room right now. The name and type of operation are given below the list of clinicians

involved, and below that, the name and social security number of the patient in the operating room. Note that this view of the people in the room reveals who is *actually* in there, including the patient, and not who is scheduled to be there. The location tracking system tracks the clinical staff's mobile phones or special electronic tags. Thus the patient's name is visible only when s/he is actually in the room. Besides supporting awareness, this feature also has implications for patient safety, since clinicians would immediately spot if the wrong patient entered the room.

Support for temporal coordination is evident in two places in AwareMedia. First, the status bar that runs around the video feed in AwareMedia gives direct information on the recurring temporal cycles in an operation (Bardram 2000). Second, the operation schedule as such supports temporal awareness. The schedule shows the planned operations for the day, including the type of operation, the patients, allocated clinicians, and notes. In order to support awareness of temporal changes, the schedule also reveals whether an operation is delayed (flashing yellow), whether an acute operation is scheduled (highlighted in red), and whether an operation has been cancelled (moved to the bottom of the schedule). The design process confirmed that these kinds of cues were sufficient to help clinicians maintain temporal awareness about the progress of activities in the OR suite, even when they were remotely situated in other parts of the hospital. Thus, changes to the schedule no longer needed to be communicated by telephones, thereby avoiding a lot of disturbing phone calls.

Users are show in AwareMedia in the same manner as in the AwarePhone interface. Each user icon consists of a small image of the person and his or her initials (the three capitalized letters). Since there are 120–130 people associated with the OR suite, linking initials and images helps users become acquainted with the names and faces of people with whom they do not collaborate daily. The two smaller labels show the person's location and self-reported status. Status includes items of a general nature such as 'working' or 'away' as well as more specific (clinical) items such as 'operating' or 'on ward round'. In addition, the AwareMedia icons contain further information not shown in the AwarePhone contact list. 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 substitute who has not been scheduled for a specific operation but can roam around the OR suite and assist where needed. The icons are thus information-heavy, but the use of different types of visual media such as text, colors, and icons, keeps the information easily readable.

Finally, like the AwarePhone, AwareMedia also supports simple message communication. The chat box available for each OR can be used to post messages to the operating room from other AwareMedia clients as well as to and from the AwarePhone. In AwareMedia, the chat box will flash yellow until

clicked to indicate the presence of a new unread message. People using AwarePhone can send and receive messages to and from the ORs. For example, a nurse in an OR can use AwareMedia to send a message to the surgeon that the patient has been anaesthetized and is ready for surgery. The surgeon will receive this message on his AwarePhone.

5. Deployment of awareness technologies in a hospital setting

In November 2005 the system was deployed in the OR suite at Horsens Hospital and by December 1st 2005 it went into pilot use (Hansen et al. 2006). At the time of writing, the original system is no longer in use. After the prototype system had run for almost 2 years it was replaced by a commercial system based on the same principle as the research prototype. The findings presented in this paper are based on the research prototype.

The OR suite employs a total of approximately 130 clinicians with 30–50 people present in the department during a normal day shift. Most operations are scheduled from 7 am to 4 pm during weekdays, but emergency operations may be carried out during evening or night shifts.

Figure 6 illustrates the deployment of AwareMedia clients. At the OR suite, AwareMedia is deployed in the so-called 'Coordination Center' and inside three of the ten operating rooms (OR 3, 4, 9). An OR typically runs 3–6 operations a day, which means that the system supports 10–15 operations a day. Outside the OR suite, AwareMedia clients are deployed in the recovery ward, in the patient ward three floors up in a separate building, and in a number of offices such as

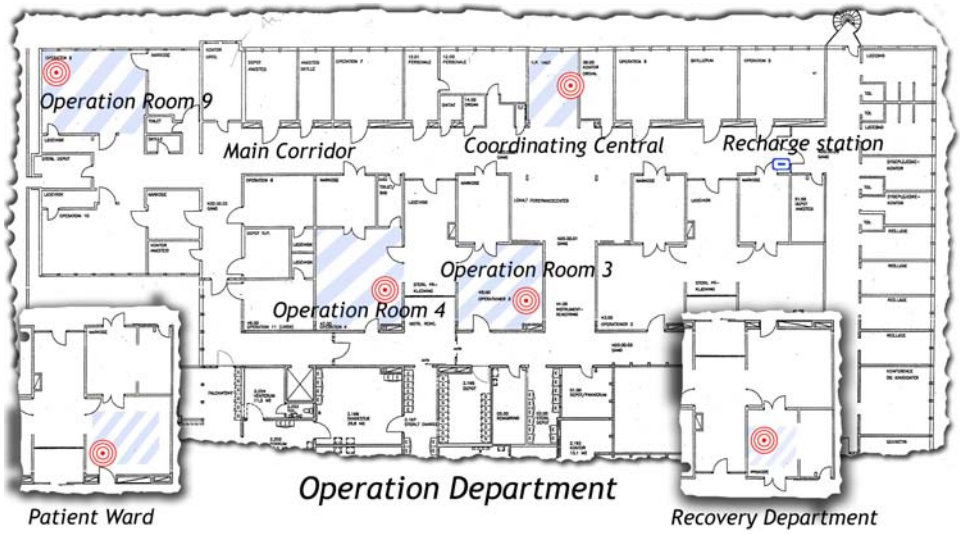

Figure 6. The deployment of AwareMedia at the OR suite.

those of the secretaries. Figure 7 illustrates how these clients are distributed across the hospital. In total, 10 AwareMedia clients are deployed in different places in the hospital and 15 mobile phones have been handed out to selected clinicians, including surgeons, charge nurses, and operation technicians. All servers and services in the infrastructure are deployed on one server.

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 proved sufficiently so locate people within rooms, which is the level of accuracy required for our purposes. The main advantage is that existing Bluetooth devices (e.g. the AwarePhones) can be used for tracking. We track people only when they are near some of the installed clients shown in Figure 6 and avoid putting location monitors in places where tracking should be disabled, such as bathrooms, the canteen, etc.

Two typical deployments of AwareMedia are shown in Figures 8 and 9. In Figure 8, AwareMedia is deployed in the 'Coordination Center' used in most OR suites as the central place for planning and coordinating all operations. Here, AwareMedia runs on multiple publicly accessible displays, and provides an overview of the work in several ORs. These displays are designed to resemble the whiteboards normally used and allow for shoulder-to-shoulder collaboration and discussion. Figure 9 shown how AwareMedia is deployed inside an OR on a 20″ touch screen. This configuration allows people inside the OR to 'look out' into the coordination center and into other ORs. Surgical staff is often responsible for operations in two ORs simultaneously and it is therefore important to maintain an awareness of how the work is progressing in both rooms.

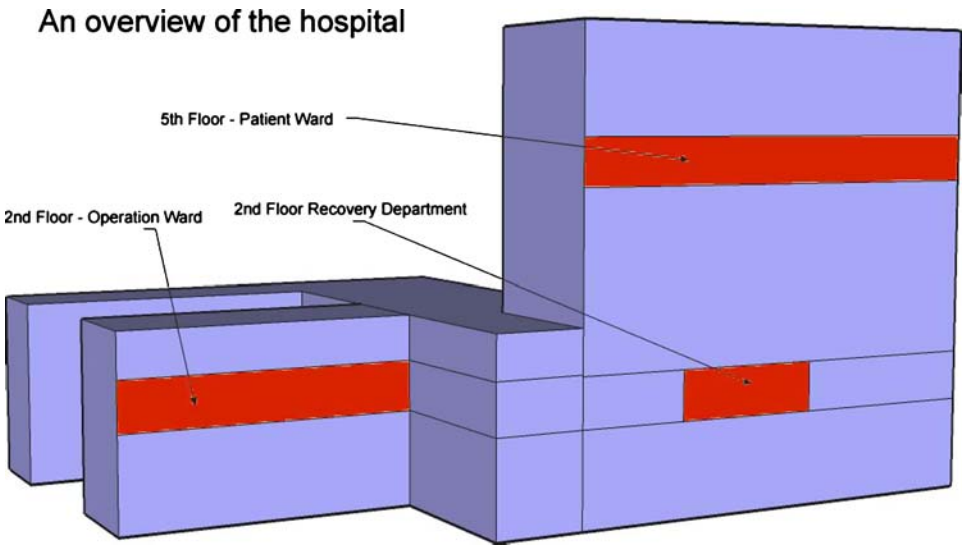

Figure 7. An overview of the hospital and the wards involved.

Figure 8. The deployment of AwareMedia on two 42″ touch screens in the coordination center.

6. Discussion

To evaluate whether the systems had an impact on the daily collaborative and coordinating work of the Operation Suite, we collected a wide range of data about the use of the system. A logging system registered daily interaction with the system, including the use of messages. A questionnaire focusing on users' experience of the system was handed out to the clinicians in the department, and over 40 responses were collected. Structured observations were used both before

Figure 9. The deployment of AwareMedia on a 20″ touch screen inside the OR (to the left in the picture).

and during the deployment to capture those aspects of the interaction context that were not accessible through log analysis: for example, the number of users using the system or the number of users visually referring to it without actually interacting with it. Finally, fourteen structured interviews were carried out with doctors, nurses and support staff after the system had been used for 3 months. In this section we will present and discuss some of our findings from this research, focusing on how the systems supported the various dimensions of context-based workplace awareness.

6.1. Social awareness

The main purpose of social awareness is to help clinicians minimize inappropriate obtrusiveness in hospitals and hence reduce the negative consequences of badly timed interruptions. Interruptions in a surgical context can have very serious consequences; people may lose concentration or lose valuable seconds: it takes time to resume one's previous activity after an interruption. Interruptions can also affect the quality of the work. For instance the sterile environment may be affected by a person opening the door to deliver a message or to check the status of an operation. In the questionnaire, 65% of the clinicians agreed that the system had led to fewer interruptions (Hansen and Bardram 2007) and in the interview, the clinicians explained that this was achieved mainly because clinician initiating a collaborative request had some cues about the working context of the recipient. As one of the coordinating nurses explained:

> If acute patients need to be added to the schedule you can immediately inform the [staff in the] operating room about the change in the order of patients. And you can use the messaging system 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 regular 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 operation [referring to the status bar and the video in the AwareMedia system].

The first quote illustrates the nurse's ability *to use the system* to disseminate 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 uses this information to plan her interaction and cooperation with them. In other words, she uses the system both to avoid interrupting inappropriately and to *time* interruptions when these are necessary.

6.2. Spatial awareness

One of the main tasks in the coordinating work in an OR suite is to ensure that the right patient, surgical team and equipment meet at the right time in the

operating room. A great deal of time is therefore spent on maintaining spatial awareness of the location of key personnel, resources and patients. However, the charge nurse is not the only person struggling to maintain this spatial overview. Large white boards are also used in the wards to keep track of the patients currently in the department; the recovery department spends time searching for patients in order to be able to answer questions from relatives; and young doctors search for nearby specialists to consult them on difficult cases.

In the questionnaire, 65% agreed with the statement that the system had made it easier to locate key personnel (Hansen and Bardram 2007). The interview supported this finding. The following quote is from the charge nurse in the OR suite:

> I have a better overview of where the clinical personnel are located in the department and that is an advantage. As a leader, I often need to talk with the people in the OR suite or have a conversation with a specific person. It [is] really nice for me to be able to say: "Okay—now I know that they are there". It gives me a better overview.

Another way in which the system helps in this respect is to reduce the number of steps needed to maintain a spatial overview. In the following example an anesthesiologist explains that he does not need to move around the OR suite so much because he now has a spatial overview of what is going on inside the different operating rooms. The anesthesiologist observes that because he is able to monitor the work inside the operating room from the outside, he does not enter these rooms as much as he used to do. This—he argues—has certain positive effects, both in terms of reducing the amount of disturbing traffic inside the OR and in maintaining hygiene inside the room.

> Interviewer: Do you feel that the system has made your work easier; does it make any difference?
>
> Anesthesiologist: Once I got used to it, I started to look at the video feeds and the time arrow. I have used it the last 4–5 times I have been responsible for coordinating anesthesia. I no longer visit the various operating rooms as much as I used to do.
>
> Anesthesiologist: [talking about entering the operating rooms] ... so, I actually don't go into the operating rooms as much now that I have a web cam streaming video.

The spatial overview is also used between departments. For example, in order for the wards to plan their work they need to know how work is progressing in the OR suite. The nurses on the wards often therefore call the charge nurse in the OR suite to get an updated on plans relevant to their patients. This entails a lot of communication and hence disruptive phone calls to the charge nurse. One of the goals of the AwareMedia system is to reduce the need for such direct

communication by supporting spatial awareness of the work inside each operating room. The following quote indicates that promoting such spatial awareness indeed helps reduce the need for explicit communication.

> Head nurse on a ward: We still use a lot of time calling each other. But [the system] has helped a lot with regard to communication with the OR suite. I used to call the OR suite a lot—many times each day. [...] I haven't registered how much less I call them now, but I can definitely feel a difference. And the OR suite agrees—they can also feel a difference.

6.3. Temporal awareness

Temporal awareness helps clinicians be aware of what has happened, what is happening right now, and what is going to happen. In AwareMedia and AwarePhone, support for temporal awareness was given through the operating schedule and the status bar. When asked in the questionnaire, 67% of the clinicians agreed that the system made coordination easier and 66% found that they could handle changes in the daily operating schedule more easily (Hansen and Bardram 2007). In the interviews, moreover, the clinicians claimed that the system increased the number of operations performed because it was easier to coordinate and gather resources for unscheduled operations:

> [Using the system] people react more quickly than before. If we can see that the operation in OR 9 is delayed, then the last patient [scheduled for OR 9] can be moved to OR 4 instead. This is a clear advantage, because then the surgeon can just take off his gloves and move on to the last patient [who is ready for surgery in OR 4]. This is a huge advantage, because otherwise the last patient has to be postponed to the following day.

Thus temporal awareness of the progress of the work in an operating room allows the charge nurse and other staff to react quickly to delays in the schedule and where necessary to reschedule operations. This ability to maintain an accurate view of the progress of work in time and space allows the charge nurse to intervene and change related and interdependent schedules more quickly.

The temporal awareness provided by displaying the operation schedule in AwareMedia is also used in coordinating work across departments. Thus a nurse at the recovery ward explained:

> If you are aware of the fact that three patients are going to arrive at the same time—e.g. at 11 o'clock—you can plan your work accordingly. If you need a coffee break, you know you have to take it before these patients arrive. Similarly when planning your lunch. There is often a boom in the number of patients arriving at lunchtime. We can see on the screen which patients are due to arrive and can prepare for that.

6.4. Activity awareness

One of the main features of medical work is the constant prioritizing of incoming tasks. Activity awareness helps the clinicians to maintain an overview of the various activities in progress and their current status, which again helps them to prioritize the most important tasks. For example, maintaining an awareness of the surgical activity itself irrespective of who is involved, or where it is being carried out, is often relevant to the ward. The status of the operation in the system (as revealed by the status bar and different color schemes for acute, delayed, or completed operations) helps mediate this activity awareness. The following quote illustrates how the system is used to maintain awareness of a specific operation, which the nurse needs to monitor in order to be able to inform anxious relatives.

> Ward nurse: We always allow the relatives to stay in the department. Some relatives are very nervous at the thought of their child, husband, or wife going into surgery. They can stay in our common room ... And even though we have told them they have to expect the operation to take a couple of hours, they often—sometimes after just an hour—start asking how it is going. So instead of calling and interrupting the charge nurse and asking her "how far have you got with the operation", I can go into the system and see. Or—if they [the relatives] are calling from home, then I can quickly look at the system and see if the patient is out of the operation, or if they are still undergoing surgery, and how far along they have got. That is probably the thing I use most.

A recurrent criticism of the system, however, was, that the scrub nurse in the operation room has to update the status bar manually. Nevertheless, it seemed that this updating was performed efficiently because so many other departments relied on the information in question. If for some reason the status bar was not updated, people from the other departments would start using the messaging system to ask if the status information was correct. This peer-pressure thus forced the staff in the operating room to update the information correctly.

As we pointed out in our presentation of the concept in Section 3.4, activity awareness can be achieved through notifying staff as to how a job is progressing. In the AWARE technologies we did implement a rudimentary mechanism for doing this by linking a predefined message to status changes in the status bar. A typical example is to send the message 'Prepare for surgery (patient in OR)' to the surgeon when the patient has entered the OR room. A surgeon may often be involved in several parallel activities and may therefore need to be prompted to go to the OR when required. On the other hand, there is no need for him to be in the OR before he is needed and he can easily attend to other jobs—such as talking to patients—while the current patient is being prepared for surgery. In general the surgeons liked this notification scheme (in fact it was they who had suggested it), but during the deployment period it was unfortunately used very

little, mainly because it was not possible for the clinicians themselves to set up the rules for sending out notifications without technical help from us. What happened instead was that the nurses inside the OR would manually send a message to the surgeons, which from the surgeons' point of view had the same effect. But for the nurses this entailed more work.

6.5. Accuracy and privacy in context-based workplace awareness

A recurrent challenge when using context-aware technologies is the degree of accuracy in the sensed context information (Hansen and Bardram 2007). For example, establishing the location of a person is highly contingent on the type of location technology used. Moreover, although context information is sensed to a high degree of certainty, errors arise from a number of other sources. For example, users may leave their location tags in their offices, or they may fail to update their status information. For this reason the design of the AWARE technologies incorporates a high degree of *redundancy* by providing several context cues for the same kind of awareness information. For example, in Figure 4 the surgeon named 'Gerhardt Teich' appears to be scheduled for an operation named 'Skulderskopi' in Operation Room 9 ('OP9'). However, he is physically located in the ward ('P5') and his personal status is set to 'stg', which is an abbreviation for 'ward round'. Thus by looking at the context cues for Dr. Teich we can reasonably conclude that he is currently going round the ward. Instead of trying to resolve different and even contradicting context cues, the AWARE applications leave these cues to be interpreted by the users themselves.

The main aim behind context-based workplace awareness is to provide users with insight into the working context of their colleagues in order for them to time any interruptions appropriately. Revealing users' contexts, however, involves privacy concerns. In the design of AwareMedia and AwarePhone, it was an open question whether clinicians would agree to have information about their whereabouts, status, and activities sensed and broadcast around for others to see. Most users, and especially the management of the OR suite, felt a need openly to discuss these privacy issues in relation to the system.[5] As the head nurse explained:

> It was important from the beginning that people did not feel that this was a surveillance system monitoring what they were doing. But it is a surveillance system in the sense that you track the operations and where people are located. However, it's important to tell people that we are observing work processes and not people as such. We discussed these issues quite extensively in the beginning [of the project], but at no point have I heard of anyone feeling they were being kept under surveillance.

While we were designing the system we expected privacy issues to emerge. But judging from our studies of the use of AwareMedia, there seem to be few

concerns about these matters. Most privacy concerns seem to have been accommodated during the introduction of the system, which emphasized that the overall goal of the AWARE technologies was to promote coordination and awareness. For example, the broadcasting of video was referred to as 'just' extending the view from the existing portholes in the door of the operating rooms and as such did not reveal any information that was not already available.

However, the issues of privacy for the clinicians are a much more delicate question and are still under further research. It should be noted that the AWARE architecture as implemented in Horsens Hospital did not log context information. Thus the architecture could reveal e.g. where a person was right now, but not where he was a moment ago. When the system was being introduced this was brought up as one of its key privacy-preserving features. When we talked to the hospital management, however, they were interested in statistically analyzing the flow of work in the OR suite in order to make it more efficient. Thus for statistical purposes it would be useful to log context data, including the location of clinicians. This poses an obvious dilemma, which should be addressed in the future development of the system.

7. Related work

A wide range of technologies have been proposed for supporting cooperative work within hospitals and, more generally, for supporting awareness and communication among distributed workers in general. This section will discuss the relationship between the AWARE, AwarePhone and AwareMedia systems and these other technologies.

7.1. CSCW systems for hospitals

In a study similar to ours, Munoz et al. (2003) address the need for context-aware communication in hospitals. They reach some of the same conclusions concerning the importance of providing contextual information such as location, role, and status to medical personnel in hospitals. On this basis they extend the IM paradigm to include context-awareness, thereby enabling clinicians to send a message by specifying context instead of a recipient. Furthermore, clinicians can locate each other on a map of the hospital.

Their focus is slightly different from ours: theirs is on communication based on context-aware messaging, while ours is on using contextual information to mediate social awareness, thereby enabling people to communicate as they please, including by sending messages, making telephone calls, or going directly to the person and engaging in face-to-face conversation. Moreover there are certain technological differences. The context-aware IM system uses PDAs connected via WLAN, which is also used for location estimation based on triangulation. The AwarePhone are connected via GPRS and use Bluetooth for

location. During our evaluation sessions, we discussed whether it would be useful to have a map on the phone. The clinicians, however, deemed this of little use, since they know the layout of the hospital very well and therefore considered a text-based location to be more efficient than a map. The only people who might have use for a map were new clinicians starting internship at the hospital, or patients and relatives. However, few clinicians wanted patients and relatives to be able to locate them through such a system.

7.2. Technologies for extending the IM paradigm

Other research prototypes have explored how to extend the IM paradigm to also include cues on e.g. location, online calendar information, and other context information in the contact list—both on desktop computers and in mobile PDAs (Bradner et al. 1999; Fagrell et al. 2000; Tang et al. 2001). For example, the 'Awarenex' system extends the 'ConNexus' IM system to mobile devices (the Palm) and supports mutual awareness in the contact list by listing people, their location, and their current online schedules (Tang et al. 2001). Similarly, the MyVine system analyzes speech, location, computer activity, and calendar entries. From these data the system seeks to determine whether a given person is present and available and, if so, to suggest suitable communication channels (Fogarty et al. 2004). These systems mainly analyze the contactee's situation and leave the decision on how to contact them to the contacter. The MatchBase systems architecture aims to improve the over-all efficiency of communication by supporting context-aware communication that regards improvement in the handling of interruptions as a bipartite issue that concerns both contacter and contactee (Gross et al. 2006).

Unlike this work, with its focus on extending the IM paradigm, the awareness and messaging system in the AWARE platform is not an IM system; groupcast communication is always the default way of communicating, which supports shared public awareness involving all those working in the OR suite. Moreover, in AwareMedia messages are not directed to individuals but to locations, such as the operating room or the coordination center. In this sense, the messages in the AWARE platform are more like post-it notes left for the relevant people (or roles) in the right places, or like the Stick-e Document System (Brown 1996).

7.3. Awareness technologies

A wide range of research has looked into systems for social awareness, including Elvin (Fitzpatrick et al. 1999), which supports mutual awareness by listing people, their location, and their current online schedules (Tang et al. 2001); StudioBRIDGE, which is an IM-based system that integrates individual presence information with additional awareness information about groups, locations, and community events (Yee and Park 2005), and the Event and Notification

Infrastructure (ENI) (Prinz 1999), which has been extended to support contextualized awareness notifications (Gross and Prinz 2004).

Some work has also been done on the use of large displays for awareness purposes. Designed as a public bulletin board, the Notification Collage (Greenberg and Rounding 2001) 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 (MacIntyre et al. 2001) allows users to be aware of the progress of their and their colleagues' work and display this on peripheral large displays, and 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 (Huang et al. 2004).

However, the main focus of all this research on social awareness has, been on providing one user with a personal awareness of his or her colleagues' current work, whereabouts, and status, and it has primarily been tested in office-like environments. Common to these systems is that they share awareness information for individual or personal use. The main way in which AwareMedia differs from these previous efforts is that it integrates awareness information about people, places, and events in time (operations) into one *publicly shared display* where all relevant individuals can see what their colleagues are doing, where they are, etc.

Finally, the aim of Media Spaces is to provide an awareness to distributed workgroups by giving them a sense of remote participants, their locations, and their activities through audio and video (Dourish and Bly 1992; Bly et al. 1993). The use of video in AwareMedia follows directly from this early work. One small, but important, difference is that video in AwareMedia is used for *spatial awareness* rather than social awareness, which was the primary focus in Rave and Portholes. Moreover, the media space in AwareMedia is not a stand-alone space; it is closely 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 of awareness with redundant sources of information available.

8. Conclusion

The term 'context-based workplace awareness' introduced in this paper emphasizes how semi-automatically sensed information about the context of work can be used to provide workplace awareness among co-workers distributed in time and space. Based on studies of work in a hospital setting, the paper discusses how context-based workplace awareness is comprised of four types of awareness: social, temporal, spatial, and activity.

The paper shows how context-based workplace awareness can be supported by computer technology. Specifically, we have presented the AWARE architecture as a general-purpose architecture for implementing such awareness technologies. The core design principles in this architecture are to support context sensing and

management, and use this context information to provide awareness information available to subscribing client applications. The architecture presents a new approach to supporting awareness by using a context-awareness infrastructure as the basis for mediating workplace awareness. To demonstrate the applicability of the AWARE architecture, two clinical applications targeted for coordination and communication in OR suites were designed and implemented: the AwarePhone, which provides users with context information about colleagues and important places in the hospital (e.g. operating rooms); and the AwareMedia system, which is an interactive whiteboard system for operation scheduling, communication, coordination, and awareness.

Through deploying these systems in an OR suite and associated departments over a period of 18 months we have gained insight into the usefulness of the proposed awareness technologies and the underlying concepts. This deployment has confirmed that providing a combination of social, temporal, activity-related, and spatial awareness is indeed useful in coordinating medical work and ensuring the smooth flow of operations in a hectic and time-critical environment. Moreover, the combination of these awareness cues typically provides redundant information, which—even when these are contradictory—can help users judge and infer the activity and whereabouts of their colleagues.

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Notes

1. This is not to be mistaken for the concept of ‘Activity Awareness’ discussed in Section 3.4. We refer to ‘the activity of a person’ as a part of this person’s context while ‘Activity Awareness’ refers to maintaining an awareness of the progress of a specific activity, regardless of who is performing it.
2. Note that the word ‘awareness’ is used in two very different ways here. In CSCW, ‘awareness’ is a human/social phenomenon that people posses; a person can have an awareness of people, activities, or artifacts. Within Ubiquitous Computing ‘awareness’ is a technical term; if a computer system is ‘context-aware’, the system is aware of its user’s context and knows, for example, where it is, who is using it, what activities in is being used for, etc. In this paper, we use the term ‘awareness’ in the former meaning. Hence ‘context-based workplace awareness’ is an awareness possessed by human actors about the workplace, but this awareness is based on information about context that is sensed through using context-aware technology.
3. As discussed in (Bardram and Hansen 2004) the AwarePhone was first built as a stand-alone prototype and subsequently implemented as part of the AWARE architecture. Thus the need to

create awareness systems such as the AwarePhone was a basic source of inspiration for the design of the AWARE architecture.

4. The need to be able to specify priority for a given message was one of the reason for not using SMS messaging on the telephones but building our own messaging sub-system
5. Note that here we are discussing privacy issues as they relate to the *clinicians*. However, there are also privacy concerns that relate to patients, since the system uses video in the operating room. However, this is not the place for entering into the issue of patient privacy, which merits a separate discussion; rather, our focus here is on workplace awareness amongst collaborating clinicians. On a more practical level, however, it should be noted that the cameras in the operating rooms were deployed in such a way that they did not show any part of the patient's body but 'shot' over the operating table.

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