Workspace Awareness in Real-Time Distributed Groupware: Framework, Widgets, and Evaluation

Carl Gutwin, Saul Greenberg & Mark Roseman

Department of Computer Science, University of Calgary,
2500 University Dr NW, Calgary, Alberta T2N 1N4, Canada.

Tel: *+1 403 220 6015*

Fax: *+1 403 284 4707*

EMail: {*gutwin,saul,roseman*}*@cpsc.ucalgary.ca*

URL: *http://www.cpsc.ucalgary.ca/projects/grouplab/*

The rich person-to-person interaction afforded by shared physical workspaces allows people to maintain up-to-the minute knowledge about others' interaction with the task environment. This knowledge is *workspace awareness*, part of the glue that allows groups to collaborate effectively. In real-time groupware systems that provide a shared virtual space for collaboration, the possibilities for interaction are impoverished when compared with their physical counterparts. In this paper, we present the concept of workspace awareness as one key to supporting the richness evident in face-to-face interaction. We construct a conceptual framework that describes the elements and mechanisms of workspace awareness, and apply the framework to the design of widgets that help people maintain awareness in real-time distributed groupware. Our evaluation of these widgets has shown that several designs improve the usability of groupware applications.

Keywords: workspace awareness, real-time groupware, shared workspaces, widgets, CSCW.

1 Introduction

Recent work has shown how a shared physical workspace (such as a chalkboard, a control panel, or a tabletop) and the artifacts in that space act as stage and props for rich person-to-person interaction (Brinck & Gomez, 1992; Segal, 1994; Tang, 1991; Tatar et al., 1991). Information available in and through the physical workspace allows people to maintain an awareness of others' locations, activities, and intentions relative to the task and to the space — awareness that enables them to work together more effectively. We call this workspace awareness: the collection of up-to-the minute knowledge a person holds about the state of another's interaction with the workspace (Gutwin et al., 1995; Gutwin & Greenberg, 1996). As will be shown, workspace awareness helps people move between individual and shared activities, provides a context in which to interpret other's utterances, allows anticipation of others' actions, and reduces the effort needed to coordinate tasks and resources.

Recently, real-time distributed groupware has been developed to emulate aspects of physical workspaces — e.g. (Baecker, 1993; Greenberg et al., 1995). Its goal is to let people who are in different places work together at the same time in a shared *virtual* workspace. However, interactions in groupware workspaces are impoverished when compared with their physical counterparts, partly because support for maintenance of workspace awareness is not yet a design priority for groupware designers.

In our work building real time groupware, we want to support the rich interaction that is possible in a traditional shared workspace. Consequently, we are looking closely at the concept of workspace awareness, with the goal of supporting its maintenance through special groupware widgets. We believe that if such widgets can help people maintain their workspace awareness, the system can better support the subtle, fluid, and facile interaction that is evident in face-to-face collaboration.

The purpose of this paper, therefore, is to present and apply the concept of workspace awareness. We begin by presenting scenarios from an observational study we carried out, in order to explain what workspace awareness is and how it works in face-to-face situations. Next, we set out the problems of supporting workspace awareness in groupware, and then describe previous work on awareness in CSCW. The paper then outlines a conceptual framework of workspace awareness, specifying the elements that comprise it and the mechanisms used to maintain it in face to face settings. We apply the framework to the design of a variety of widgets that we have constructed in GroupKit, a groupware toolkit (Roseman & Greenberg, in press). The widgets serve both to illustrate the possibilities of computer support for workspace awareness, as well as the difficulty in designing adequate replacements for our natural awareness mechanisms. Finally, we report on initial results from usability evaluations of four widgets.

2 Workspace Awareness

This section looks at what workspace awareness is and how it works in actual face-to-face situations, and then considers the problems of supporting awareness in groupware.

2.1 Episodes from a Study of Group Interaction

To help us understand workspace awareness, we observed pairs of people working together over a physical workspace. Each pair was assigned the task of composing a two-page layout of a newspaper using materials we provided — paper articles, pictures, and headlines. The episodes that follow are a composite of those that we saw in our observational studies. Each episode shows how people contribute to or benefit from awareness of one another in the workspace:

- *Mixed-focus collaboration*. Linda and Mark start the task together, with both attending to the same part of the workspace. As they talk, they decide that Linda will work on page one and Mark on page two, and they determine roughly which objects will go on each page. They then shift their focus of attention to their individual pages, and start laying out the material. As work progresses, their focus shifts back and forth between individual and shared activity, and between different parts of the layout.

- *Lightweight information gathering*. Mark's attention is briefly drawn from his own work by Linda moving objects back and forth in her area. With a quick glance, he notices that she is working on article one, that she has moved from the top left part of the page to the top right, and that she appears to be having trouble getting two columns of the story to fit into the available space.

- *Integration of information with previous knowledge.* Linda notices Mark move over to work on the headlines at the top of page 1. Recalling the instructions that the editor had given them earlier, she says, "Let's not forget to leave space for that picture that they want in there."

- *Anticipation of another's actions*. Mark watches Linda position her first article down the length of the page, and thinks that this may be the way she plans to position all of her articles, so he speaks up: "Um, I think we should decide on sort of a consistent layout for the two pages together because I'm doing things in the top half and the bottom half, and it looks like you're going all the way down the page."

- *Using awareness of activity*. Linda knows that Mark is working on article two, so when she finds a column from that story hiding under the desk, she hands it to him, saying, "I think this is one of yours."

- *Interpreting references*. Mark and Linda are busy with their own tasks when Mark says, "Do you think that this should go down here?" Linda glances over to see what he is pointing at and then says: "It'd look OK, but I'm not sure it'll fit." Later, Mark hears the sound of paper being cut with scissors, and without looking up, says, "Can I have those when you're done?"

These episodes are ordinary and commonplace, and none of them on their own has any great effect. However, they are made possible by workspace awareness, and though small, will be joined by many other moments of opportune collaboration. Taken together, these actions allow a group to be significantly more effective than an

individual. Workspace awareness lowers the overhead of working together, creates new opportunities for collaboration, and provides people with a larger context for their actions (Dourish & Bellotti, 1992).

As the above scenario shows, workspace awareness can be seen both as a product and a process. The product is the state of understanding about another person's interaction with the workspace, that allows people to interpret events, anticipate needs, and interact appropriately. The process is the continuous cycle of extracting information from the environment, integrating this information with existing knowledge, and using that knowledge to direct further perception. The maintenance of workspace awareness involves several human cognitive processing skills including pre-attentive processing, attention allocation, perception, working memory management, comprehension, and projection (Endsley, 1995). These skills are the basis for higher-level mechanisms such as gaze awareness (Ishii & Kobayashi, 1992), gestural communication (Tang, 1991), and deictic reference (Tatar et al., 1991).

While the process and product of workspace awareness in a face-to-face situation seem trivial, things become far less clear when trying to support workspace awareness in a real- time groupware system.

2.2 Workspace Awareness Problems in Groupware

When shared activity moves from a face-to-face setting to distributed groupware, many things change that impair people's abilities to maintain workspace awareness:

- The perceivable environment shrinks drastically. Where people could see all of a fairly large physical workspace, they now have only a tiny viewport through the computer screen.

- Some means of communication are weakened: our hands' capabilities for expression are only poorly approximated with a mouse cursor (Hayne et al., 1993), and speech loses much of its audio quality and directional component over typical voice links.

- Common ways of interacting with computer applications, such as through menus or function keys, hide actions that are visible in a physical workspace.

- Computer systems cannot handle many of the ingrained perceptual and physical abilities that we use to maintain workspace awareness in a face-to-face setting, and must replace them with means of perceiving the environment that are comparatively slow and clumsy.

- Groupware approaches that allow participants to control their own views of the virtual workspace (Stefik et al., 1987) can further obscure people's locations and activities.

- Video techniques that bring people's hands and bodies into the virtual workspace are limited by scalability and resolution problems (e.g. most cannot handle more than two people) (Ishii & Kobayashi, 1992).

Within this strange new situation, the groupware designer must try and recreate the conditions and cues that allow people to keep up a sense of workspace awareness. Unfortunately, many of the things that supported workspace awareness in face-to-face situations disappear in the transition to a groupware setting. For example, in the page-layout example discussed above, people made use of peripheral vision, rapid glances, three-dimensional sound, and the ability to see the entire workspace, none of which would be available in a groupware system. Whereas face-to-face interaction has inherent mechanisms and affordances for maintaining workspace awareness, the groupware designer is faced with a blank slate — any support for building or maintaining workspace awareness must be explicitly determined and built into the groupware system.

It is not immediately obvious what information people need to maintain workspace awareness, or how that information should be presented within a groupware system. We have been forced to look more closely at these issues, and the next sections present the work that we have done in bringing together knowledge about workspace awareness that can be used in designing groupware widgets. The product of our investigations is a conceptual framework of workspace awareness that is detailed below. First, however, we step back for a moment to show the context that this framework fits into. The following paragraphs describe awareness in group work more generally and how various kinds of awareness have been looked at in CSCW research.

3 Related Work on Awareness

People are aware of many different things when they work in groups, some of which relate to the group, and some to the task or situation more generally.

For example, people maintain awareness of an association of people, their reasons for being together and their shared knowledge, which we call *organizational awareness*. Organizational memory is one way of tracking organizational awareness — e.g. (Conklin & Begeman, 1988). Another example is *task awareness*, which involves understanding the purpose of a task, the specific goals and requirements of the group in pursuing the task, and how the task on hand fits into a larger plan. Project management software is one type of system that supports task awareness. *Situation awareness* is another area that has been extensively discussed in the human factors community — e.g. (Adams et al., 1995; Endsley, 1995), and refers to the state of knowledge that an individual requires to operate or maintain a complex and dynamic system (such as an aircraft or a nuclear generating station).

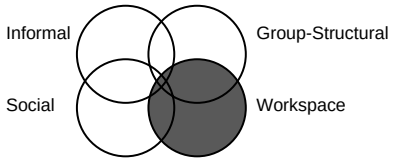

Figure 1: Types of awareness in group work.

Within CSCW, researchers have proposed four types of awareness that apply more specifically to groups working face to face, and these are shown in Figure 1. We use a Venn diagram to indicate that these different kinds of awareness overlap, inform one another, and interact during group work.

Informal awareness of a work community is the general sense of who's around and what they are up to — the kinds of things that people know when they work together in the same office. Informal awareness is the glue that facilitates casual interaction. CSCW researchers have attempted to provide this sense of social presence to distributed groups through the use of media spaces — e.g. (Baecker, 1993). Media spaces use long-term links that show continuous video or snapshots of offices and common areas at a remote site.

Social awareness is the information that a person maintains about others in a social or conversational context: things like whether another person is paying attention, their emotional state, or their level of interest. Social awareness is maintained through conversational cues such as back-channel feedback, and through non-verbal cues like eye contact, facial expression, and body language. The maintenance of social awareness in distributed groups has been explored in CSCW through desktop video-conferencing — e.g. (Borning & Travers, 1991), video tunnels (Buxton, 1993), or the mixing of video and computational workspaces to allow eye contact within a work-surface (Ishii & Kobayashi, 1992).

Group-structural awareness involves knowledge about such things as people's roles and responsibilities, their positions on an issue, their status, and group processes. CSCW research has looked at support for meeting rooms — e.g. (Valacich et al., 1991), group decision-making — e.g. (Kraemer & Pinsonneault, 1990), representation of arguments and positions — e.g. (Conklin & Begeman, 1988), floor control — e.g. (Greenberg, 1990), and explicit roles — e.g. (Leland et al., 1988).

This brings us to workspace awareness, different from the other forms in Figure 1 because of the integral part played in the collaboration by the workspace. When interaction happens in a workspace, maintaining knowledge about others' interaction with the space and its artifacts becomes highly relevant. Workspace awareness has also been recognized in CSCW research (although under different names), and our work builds directly on these efforts — e.g. (Baecker et al., 1993; Beaudouin-Lafon & Karsenty, 1992; Dourish & Bly, 1992; Dourish & Bellotti, 1992).

Element	Relevant Questions
Identity	Who is participating in the activity?
Location	Where are they?
Activity Level	Are they active in the workspace?
	How fast are they working?
Actions	What are they doing?
	What are their current activities and tasks?
Intentions	What are they going to do?
	Where are they going to be?
Changes	What changes are they making?
	Where are changes being made?
Objects	What objects are they using?
Extents	What can they see?
Abilities	What can they do?
Sphere of Influence	Where can they have effects?
Expectations	What do they need me to do next?

Table 1: Elements of workspace awareness.

4 A Framework of Workspace Awareness

We have built a conceptual framework of workspace awareness that structures thinking about groupware interface support. We believe the framework necessary because groupware designers face two operational problems:

1. They must know what awareness information a groupware system should capture about another's interaction with the workspace.

2. They must consider how this information should be presented to other participants.

The framework presents a set of basic ideas that are critical for the design of awareness support, and that allow techniques for widget designs to be identified, described, and compared. The following sections detail the parts of the framework: first, the elements that make up people's workspace awareness, and second, the mechanisms that they use to gather awareness information.

4.1 Elements of Workspace Awareness

The first part of the conceptual framework is a list of elements that people may keep track of when they work with others in a shared space (see Table 1). Workspace awareness in a particular situation is made up of some combination of these elements (although we do not claim to have covered all the elements used in all situations).

The elements are for the most part common sense things that can be seen in many kinds of workspace collaboration, and can be related to questions that people ask themselves during group work (column 2). Awareness of identity is simply knowing who you are working with, and often, the answer to "who is participating?" is obvious based on seeing and hearing others in the room. The other questions in

the table show that several of the elements can be put into two rough groups — one that relates to what is happening and one that relates to where it is happening. Elements that deal with 'what' involve the amount of activity, the nature and content of actions, the changes that are made to artifacts, people's capabilities for action, and their expectations for action from each other. Those dealing with 'where' involve where in the workspace people are focusing, the extents of what they can see, where they are making changes, the particular objects that are being used, and the extended area within which they can indirectly cause changes to the workspace (through connections and constraints between artifacts).

These elements provide a basic vocabulary for thinking about awareness requirements and groupware support. Designers can use the framework to analyse existing face-to-face situations. For example, the group page-layout activity described earlier required that people stayed aware of where on the page others were working and of large movements of artifacts, but not of small changes to the placement of the columns. In addition to considering which elements are more or less important in a particular situation, there are several further ways that a designer can assess how elements are used. For example:

- Several elements relate to the past as well as the present. For example, awareness of past activities or past location is useful in many situations, especially when someone needs to bring themselves up to date on what has been going on in an area of the workspace.

- Awareness elements can constrain one another. For example, knowing where someone is working can limit what they can be doing.

- Some elements can be further specified in terms of the granularity at which the information is useful. For example, in a task that does not involve much close interaction, participants may only maintain a general idea of where others are working.

- Awareness information will vary in character depending on the situation. For example, location information can be relative to a participant, absolute in terms of the workspace, or determined by the semantic structure of the artifacts (such as section numbers in an outline).

Several CSCW projects have implemented various support for elements of workspace awareness, although often in an application-specific, limited, or ad-hoc manner. Research has considered elements such as view location — e.g. (Baecker et al., 1993; Beaudouin-Lafon & Karsenty, 1992), fine-grained location — e.g. (Tang, 1991; Hayne et al., 1993), content of activity — e.g. (Beaudouin-Lafon & Karsenty, 1992; Dourish & Bellotti, 1992; Stefik et al., 1987), presence — e.g. (Ellis et al., 1991; Sohlenkamp & Chwelos, 1994), changes — e.g. (Ellis et al., 1991; Sohlenkamp & Chwelos, 1994; Stefik et al., 1987), and activity level — e.g. (Ackerman & Starr, 1995).

4.2 Workspace Awareness Mechanisms

After considering elements of workspace awareness, the next part of the framework looks at how people obtain the information that updates their state of knowledge. Determining precise mechanisms in face-to-face situations is difficult, however, since they can be subtle, hard to observe (sound cues, for example), or buried within several layers of inference. Instead, we present a general set of information-gathering mechanisms that have been discussed in previous literature, and discuss how they are used for maintenance of workspace awareness:

- *Direct communication.* People explicitly communicate information about their interaction with the workspace; this communication is primarily verbal, although gestures (Tang, 1991) and deictic references (Tatar et al., 1991) are also common.
- *Indirect productions.* People commonly communicate through actions, expressions, or speech that is not explicitly directed at the other members of the group, but that is intentionally public (Dourish & Bellotti, 1992; Heath & Luff, 1991).
- *Consequential communication.* Watching or listening to others as they work provides people with a great deal of information about their interaction with the workspace (Segal, 1994).
- *Feedthrough.* Information can also be gathered by observing the effects of someone's actions on the artifacts in the workspace (Dix et al., 1993).
- *Environmental feedback.* People also perceive higher-level feedthrough from the indirect effects of another's actions in the larger workspace. For example, in a control room situation, seeing some measured value decrease can provide evidence that another member of the team has initiated a particular procedure.

Groupware designers must consider how information about various elements is transmitted and gathered, and must allow people to continue using natural mechanisms like those listed above, or others specific to particular domains and situations. With knowledge of these mechanisms, and of how they are used to maintain different elements of awareness, a designer can begin to create techniques and widgets that provide people with appropriate information about others in a virtual workspace.

By setting out elements and mechanisms of workspace awareness, the conceptual framework provides a vocabulary and a starting point for thinking about and designing groupware support. The following section describes several widgets that were designed using the framework, and outlines the results of a usability study carried out to evaluate their effect on a groupware application.

5 Workspace Awareness Widgets

We have used the conceptual framework above in the design of many groupware widgets that help people maintain workspace awareness (Gutwin et al., 1995; Gutwin et al., 1996). We have initially concentrated on awareness of identity, location, and actions, three elements that are particularly relevant to relaxed-WYSIWIS ('what you

see is what I see') groupware (Stefik et al., 1987). In these systems, people can change the location or representation of their view onto the workspace to suit the needs of their immediate task. Relaxed-WYSIWIS view sharing is more natural and more flexible, but because people may not see the same thing, they can lose track of who else is in the workspace, where they are, and what they are doing.

The following paragraphs focus on four inventions that illustrate a range of approaches to helping people keep track of others in a relaxed-WYSIWIS workspace: radar views, multiple-WYSIWIS views, workspace teleportals, and the WYSIWID ('what you see is what I do') display.

5.1 Radar Views

Radar views are a class of widgets based on miniature overviews of an entire workspace. These miniatures have been seen in video games and some groupware systems — e.g. (Baecker et al., 1993). Our basic radar view (see Figure 1) adds information about other people's interaction with the workspace to this miniature. Since the overview provides a spatial representation of the workspace, location information is a natural addition. The radar display shows the extent of what each person can see by marking view outlines (inspired by SASSE's text overview (Baecker et al., 1993)) and also shows finer-grained location by including miniature telepointers that represent each person's mouse cursor (Hayne et al., 1993). These additions support awareness of another person's general and specific location in the workspace.

The radar view also supports awareness of activity. The radar shows all movement of and changes to artifacts in the workspace, which provides information about others' actions with feedthrough. Adding telepointers to the display adds a second source of information about what people are doing and where they are working. Telepointers in the radar also allow for gestural communication and deictic references even when people's main views are different. In addition to these techniques, it is easy for groupware designers to provide task-specific feedback about types of activity, such as selection of objects or use of different tools.

The basic radar view conveys identity by showing each participant's view outline and telepointer in a unique colour. One problem with this approach is that it can be difficult to sort out which view rectangle belongs to whom. To simplify interpretation, we have constructed a 'portrait radar' that attaches names or pictures to the view rectangles, allowing more natural identification (see Figure 2). The portraits sit behind the artifacts in the display, so this portrait radar is most useful in sparse workspaces or where artifacts are transparent. In future, we may replace these static pictures with live video images.

5.2 Multiple-WYSIWIS Views

Radar views provide only a low resolution representation of others' views, especially if the workspace is large. If more detail about the artifacts in each participant's view is required, our multiple-WYSIWIS widget can be used, which shows a scaled-down duplicate of each person's view of the workspace (see Figure 4). All of the other person's actions in the workspace, including cursor movement and manipulation of artifacts, are visible within the display. This widget provides some of the benefits of

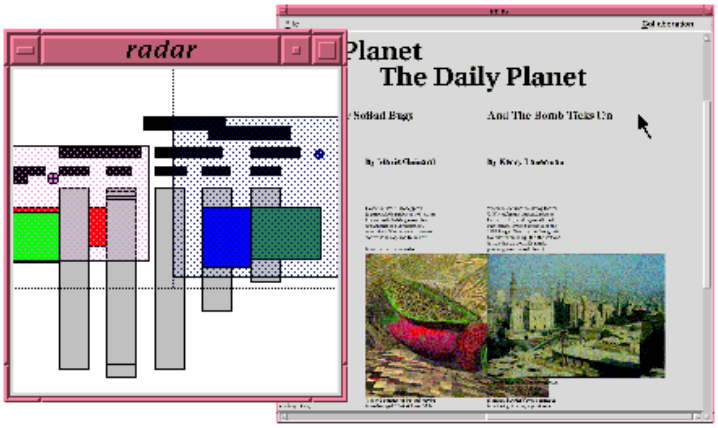

Figure 2: Radar view of a newspaper layout editor, with view outlines (dotted rectangles) and telepointers (crossed circles). The main view is shown reduced in size at right.

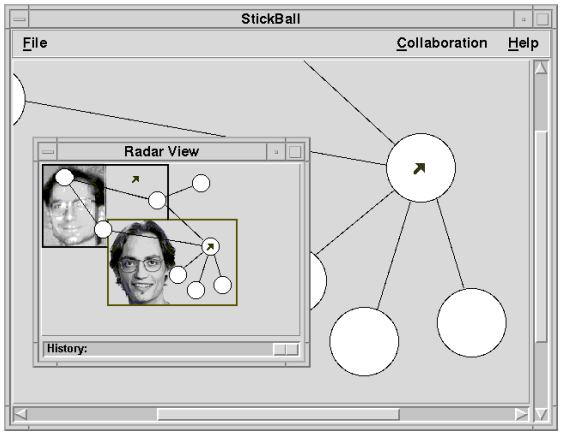

Figure 3: Portrait radar on a graph editor. The radar window is inset over the main view.

the WYSIWIS approach by once again giving the group a common (though composite) view of the workspace, but still allows people individual control of their main views.

5.3 The 'What You See Is What I Do' Widget

In some cases, people need to see detail about another's actions at full size. Since limits on screen space usually preclude a full-size duplicate of another person's view, we have designed a 'what you see is what I do' (WYSIWID) widget that provides full-size details, but shows only a limited part of the other person's view (Figure 5).

The widget shows only the immediate context around another person's cursor, since most actions in graphical applications will involve the mouse. As a person

Figure 4: Multiple-WYSIWIS view. The main view at left shows the local user's view of the workspace; the inset window shows a remote participant's view.

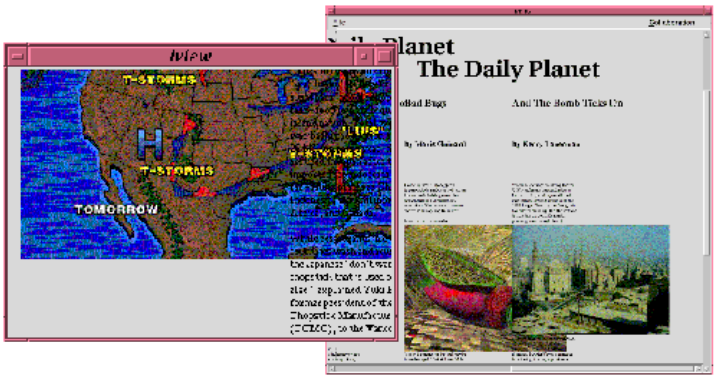

Figure 5: The 'what you see is what I do' widget. The inset window at left shows a full-scale but limited area around a remote user's cursor; the local user's main view, reduced in size, is shown at right.

Widget	Awareness of identity (who is in the workspace)	Awareness of location (of view, extents, focus, and changes)	Awareness of actions (objects used, changes made, activity level)
Radar view and Portrait radar	participants indicated by unique colour (or by picture)	view extents shown with outlines superimposed on miniature of workspace telepointers show fine-grained location	movement and changes in miniature view (at low resolution) telepointers show activity and allow gesturing (at low resolution)
Multiple-WYSIWIS view	each scaled-down view identified by participant's name	view location must be determined from knowledge of workspace view extents represented by size of scaled view telepointers show fine location	movement and changes shown in each scaled-down view (moderate resolution) telepointers show activity and allow gesturing (moderate resolution)
WYSIWID display	widget shows remote participant's name	view location must be determined from knowledge of workspace view extent not shown full size shows precise location of remote cursor	all actions shown in full detail
Workspace teleportal	window title shows the name of participant who is being 'visited'	view location must be determined from knowledge of workspace view extents not shown main-view telepointers show precise location	actions shown in full detail, but are only visible after teleporting telepointers show activity and allow gesturing

Table 2: Summary of workspace awareness support provided by the widgets.

moves their cursor on a remote machine, the background of the widget pans to keep the display centred around the pointer.

5.4 Workspace Teleportals

Finally, in some situations people wish to see another person's entire view in full size. We have created graphical and textual workspaces where pressing a mouse button temporarily 'teleports' the user to another person's location, returning to their original view when the button is released. This technique allows people to 'glance' at another's work area without much effort. This device is difficult to show in a figure, but works by rapidly scrolling to the remote participant's location when the mouse button is pressed, and then scrolling back again when upon release.

Group	System 1	System 2
1	Basic	Radar
2	Radar	Basic
3	Mini	WYSIWID
4	Scrollbar	Basic
5	Radar	Mini
6	Mini	Scrollbar
7	Radar	Radar + WYSIWID
8	Radar	Basic

Widget	# Pairs
Basic	4
Scrollbar	2
WYSIWID	2
Miniature	3
Radar	6

Table 3: System configurations and total pairs for each widget.

5.5 Summary

As a summary, Table 2 compares the widgets in terms of the three workspace awareness elements mentioned above (identity, location, and activity). Since the widgets support other elements as well, these are listed parenthetically within the main categories. The table summarizes the techniques used in the widgets to help people maintain awareness in relaxed-WYSIWIS groupware systems.

One key difference between the widgets is that they show a gradual transition from favouring global context to favouring local detail. Although they all support awareness of identity, location, and activity, the tradeoffs in their design imply that they will be useful to different degrees in particular groupware applications. We have tested how well three of these widgets, the radar view, the workspace teleportal, and the WYSIWID display, worked in one groupware system. The next section briefly outlines the initial results of a usability study carried out to evaluate these widgets.

6 Usability Evaluation

We conducted a study of a shared workspace system that incorporated various awareness widgets, in order to evaluate how well our designs supported the maintenance of workspace awareness. We were particularly interested in knowing whether information in the widgets was easy to interpret, whether they distracted users from their tasks, and whether users thought that the displays were worth the screen space that they used.

We constructed a relaxed-WYSIWIS groupware editor for manipulating the layout of a two-page newspaper page, similar in spirit to the setup of the face-to-face situation described earlier. About one third of the total workspace could be seen at a time on a 19-inch computer monitor. The system provided simultaneous access to the shared workspace for multiple participants, and allowed users to move pictures, headlines, and columns of text. Eight pairs of undergraduate and graduate computer science students participated as subjects. Each pair completed two layout tasks, each limited to fifteen minutes and each using a different system configuration. In different conditions, as shown in Table 3, the layout editor provided either a basic shared workspace, including telepointers and the workspace teleportals, or the basic workspace augmented with one of several awareness widgets:

- A multi-user scrollbar, which shows each person's view location as a coloured bar beside the regular horizontal and vertical scrollbars of the workspace.
- A workspace miniature, which is similar to the radar view but shows only the workspace objects, not the participants' view rectangles or telepointers.
- A radar view, as shown in Figure 2.
- A WYSIWID view, as shown in Figure 5.

The multiple-WYSIWIS and portrait radar views were not used, as they will be part of a later evaluation. Data collected in the study included experimenter observation, videotape of the sessions, questionnaires filled out by the subjects after each task, and records from an interview conducted at the end of the session.

In general, all pairs completed their tasks and produced reasonable layouts. We observed a variety of working styles, ranging from 'divide and conquer' to tightly coupled collaboration. Regardless of the style, there was evidence that the pairs maintained an awareness of each other's use of the workspace, and acted on that information to collaborate with their partner and complete their task. We observed that subjects did make use of the various awareness widgets, and they reported that several of the widgets provided useful awareness information. In particular, most subjects greatly favoured the conditions that included the two widgets that were based on a miniature of the workspace.

Subjects made considerable use of the radar view, the miniature, and the teleportal. Subjects liked these displays, and found them to be useful for maintaining awareness of their partner. The radar view was distracting to only one of the eight people who used it, and it was universally considered easy to interpret, possibly because its overview mimics the workspace. All of the subjects who used the radar view reported that it was well worth the screen space it used, both because it kept them up to date on their partner, and because it also provided information that was useful to them as they carried out their individual tasks. The teleportal used no screen space at all, and while this is of course economical and non-distracting, it provides no visual affordance to novice users that teleportation is possible. Several subjects reported that they would have used the teleportal more often, but that they forgot that it was there.

Subjects were less enthusiastic about the WYSIWID display, complaining that it was difficult to determine what was going on within it. The problem may have arisen from the somewhat jumpy animation that the display exhibited; however, there were other problems with the fit between the WYSIWID and the layout task that may have reduced its usefulness. The task did not demand that participants make precise actions, or that they monitor the small details of what others did, and so the full-size but limited-context view was likely too focused for the requirements of the task.

Subjects also found the multi-user scrollbar to be less useful than the other widgets. Two factors in this display may have led to problems: first, it shows location on an abstract scale that does not allow a simple determination of actual workspace location or of what others can see; and second, the widget provided

location information in two dimensions (horizontal and vertical) that forced users to mentally integrate the information in order to determine someone's actual location.

Overall, the displays that provided a bigger picture (especially the radar view) were found to be more appropriate, even though they contained less detail. When compared with the plain shared workspace condition, subjects always preferred having the extra awareness information, and often seemed to engage in more interaction about the task (this observation is currently being explored further). The radar view was successful in enriching the kinds of interaction that happened in the shared workspace, and one subject went so far as to remark "it was just like working over a big table."

7 Conclusions and Future Work

In this paper, we have presented the concept of workspace awareness as a critical design concern for real-time groupware, and have constructed a conceptual framework that gives designers a starting point for building awareness support into groupware. We also showed several awareness widgets that we have built using the framework, and discussed how they affected the usability of a realistic shared-workspace groupware system. Our evaluation reinforces our beliefs that workspace awareness is a significant part of collaboration, and that workspace awareness can be supported through groupware widgets. This research presents several avenues for further work, including:

- Expanding and validating the framework through additional studies of face-to-face groups.
- Building additional awareness widgets for other elements and mechanisms, such as a fish-eye view that smoothly integrates radar and detail views (Greenberg et al., 1996).
- Further evaluating the widgets, both in terms of the framework and in usability studies of realistic applications.
- Investigating other issues of applying the framework to groupware, such as the possibilities of going beyond existing face-to-face mechanisms for maintaining awareness.

Although the widgets make clear advances in supporting particular awareness elements and mechanisms, much work needs to be done before groupware workspaces approach the richness and simplicity of face-to-face interaction.

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