Design of Awareness Interface for Distributed Teams in Display-Rich Advanced Collaboration Environments

Kyoung S. Park[1], Jason Leigh[2], Andrew E. Johnson[2], and Yongjoo Cho[3]

[1] Digital Media Laboratory, Information and Communications University
517-10 Dogok-dong, Gangnam-gu, Seoul, Korea
park@icu.ac.kr
[2] Electronic Visualization Laboratory, University of Illinois at Chicago
851 S. Morgan, Chicago, IL, 60607, USA
cavern@evl.uic.edu
[3] Division of Media Technology, Sangmyung University
7 Hongji-dong, Jongno-gu, Seoul, Korea
ycho@smu.ac.kr

Abstract. This paper discusses design issues for enhancing awareness among distributed teams in the display-rich advanced collaboration environments. We conducted an exploratory design study of nine groups performing a set of collaborative tasks using a variety of advanced collaboration and display technologies. The result showed that group interaction and awareness was improved by the use of multiple public displays due to information visibility to all members. While maximized visibility supported work activity awareness, it also revealed a need to support shared resource awareness and more importantly task awareness for effective group coordination.

1 Introduction

With the emergence of collaboration technologies, people can easily communicate with one another and accomplish complex tasks even though they are distantly located. Major corporations launch global teams, expecting that technology will make virtual co-location possible. While these technologies are valuable, there has been a reassessment of the basic value of working co-located in physical spaces. A recent field study conducted at several corporate sites investigated the work of teams who were maximally co-located, i.e. working in war rooms [8]. One of the key features in war rooms is awareness. In a war room, a group of team members not only share the office space but also work together synchronously in all phases of the project. In some cases productivity in war rooms can be enhanced far beyond the corporate average [13].

An Amplified Collaboration Environment (ACE) is a distributed extension of a war room that aims at augmenting the traditional concept of the war room with technologies to permit distributed teams to make use of its problem solving benefits [7]. The Continuum is an ACE specifically targeted for supporting collaborative scientific

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Fig. 1. Two Continuum Amplified Collaboration Environments built at the Electronic Visualization Laboratory at UIC, to facilitate an explorative usability study.

investigation connected via high-speed networks to high-performance computer and data resources [10]. Current off-the-shelf collaboration tools such as NetMeeting® do not support the kind of interaction that occurs in real science campaigns. Scientists want more than just being able to videoconference and share spreadsheets with each other. They want to collaboratively query, mine, view and discuss visualizations of enormous data sets (in the order of terabytes) in real time. The visualization systems that are capable of displaying data sets of this size require more than desktop PCs.

Fig. 1 shows the displays that comprise fully constructed Continuum spaces at the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago. Two Continuum spaces are built at EVL to develop technologies and to facilitate an explorative usability study. The Continuum consists of following modular technologies: conferencing, content sharing, collaborative annotation, and wireless interaction. The Access Grid (AG) supports group-to-group collaboration in which a group of people at different locations can see and talk with one another simultaneously [1]. The high-resolution tiled displays provide shared content views of text documents, web pages, spreadsheets, graphs and charts, and scientific visualizations. The collaborative annotation is supported by shared touch-screen whiteboard on which collaborators may jot down notes and sketch diagrams. Also, remote access interface is supported to encourage users to work on these displays collectively.

We are currently investigating how the Continuum's tiled displays can be used in enhancing group awareness between distributed participants during intensive collaborative work. Awareness has been extensively studied in computer supported cooperative work (CSCW) research and identified as a key feature for collaborative systems [5]. Yet, maintaining awareness over the distance has been shown to be difficult because a lot of this information is not easily conveyed to remote users with today's technology. Tiled displays are typically used to project a single, extremely large, high-resolution visualization. It is our belief, however, that for collaboration, a better way to use a tiled display is to treat it as a large distributed corkboard that allows meeting participants to pin up information artifacts for all to see.

A few recent collaborative systems such as Notification Collage [4] and Semi-Public Displays [6] have used similar approaches. They use a large public display to foster awareness among distributed or co-located workgroups, but mostly focus on asynchronous collaboration. We aim to create shared workspaces where individuals can work in parallel while maintaining group awareness by giving the individual the ability to casually glance at others work over the distributed corkboard tiled display.

This paper presents a set of iterative design studies conducted to examine the system configuration of Continuum technologies for distributed teams tackling scientific problems. The study involves placing a group of collaborators in two separate Continuum spaces and asking them to perform a variety of information discovery tasks. The goal of this study was to explore design issues and group's needs on various collaborative tasks to facilitate war room like interaction for distributed teams. In this paper we describe the design changes of the Continuum technologies, the findings and lessons learned from the study with an emphasis on awareness issues, and ideas for future research directions.

2 Participants

Nineteen computer science graduate students volunteered as subjects in this study. All students had a high level of experience with computers and collaboration technologies such as email and instant messaging. Some students have used Microsoft's NetMeeting® or other commercial or research online meeting room systems. Some had experiences with information visualization tools, but none of them had prior experience with the XmdvTool tool [14] that was used as a part of this study. Most students had little to moderate experience with correlation statistics. All students expressed fairly high interests in collaborative work using the Continuum technologies.

3 Method

Table 1 shows the changes of group and system configuration over the iterative design studies. The study consisted of a pilot study followed by four iterative studies. For each study, the system configuration was varied, and we evaluated mainly on the configuration of the tiled display. The system configuration was changed in response to the participants' feedback and our observations. The iterative studies were conducted over three-week intervals due to the time required to reconfigure the systems for the each study. The pilot group was formed with three students, and two groups of four students were assigned in the following four design studies. All students participated in the two design studies, and each time the groups were given different question sets with similar difficulties, to reduce the learning effects from previous exposure. In the third and fourth study, we regrouped the members to see if they broadened their ideas best about the best way to use this technology.

Table 1. System configuration changes over iterative design studies.

Study	Group	System Configuration				
		Conference	Visibility	Seamlessness	Proximity	Size
Pilot Study	Pilot Group	Full-AG & mini-AG	Public visibility display	Discrete display		
Study 1	Group 1 Group 2	Full-AG & mini-AG	Public visibility display	Seamless display		
Study 2	Group 3 Group 4	Full-AG & Enhanced mini-AG	Public visibility display	Seamless display	With close-up display	
Study 3	Group 5 Group 6	Full-AG & Enhanced mini-AG	Less public visibility by full-screen	Discrete display	With close-up display	Full-screen
Study 4	Group 7 Group 8	Full-AG & Enhanced mini-AG	More private visibility display	Discrete display	With close-up display	Full-screen

The group was given a pre-test survey (e.g. technology familiarity, comfort, interest, and domain knowledge) and received one hour training about the technologies and some basic knowledge required in their first exposure to the tasks. The group members were then separated in two Continuum spaces and asked to solve a set of collaborative tasks (approximately 3-hour sessions). A post-test survey and interview was followed shortly at the end of the tasks for feedback about the usability of Continuum technology.

The tasks given to the groups were information query and gathering (45 minutes), information analysis and pattern detection of multivariate data (60 minutes), and collaborative brainstorming and design (30 minutes). In the information querying and gathering task, the group was asked to search and gather information on the web to answer specific questions. The group was given two focused questions and one trend question. In the focused questions, group members would need to simultaneously gather as much information as possible from the web. In the trend question, members would need to make a group decision based on their combined findings. In the information analysis and pattern detection task, the group was asked to perform an exploratory data analysis on a given dataset using the XmdvTool information visualization tool to answer questions. There were five specific questions given to the group where members would find evidence to verify or refute hypotheses. Two trend questions were given where members would need to search for inquired trends or patterns in the dataset. In the collaborative brainstorming and design task, the group was asked to brainstorm, prioritize, and summarize design ideas for Continuum technologies.

All groups were recorded using video cameras. An evaluator in each room also recorded group behaviors, which were taken into the observation notes. All activities of group members on the computers were also captured into log data files such as mouse

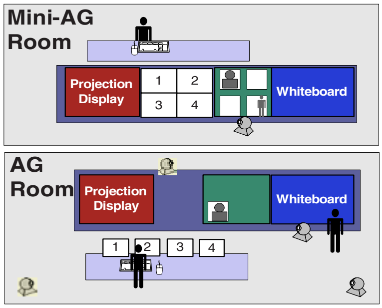

Fig. 2. The system configuration of evaluating the distributed corkboard in the pilot study.

movements across the screens. We also measured group performance such as work quality and group work process which included members' participation and contribution, group interaction for decision-making, information exchange, awareness and attention, influence, and team coordination. We also used post-test survey to measure user satisfaction for working with technology and work process.

4 System Configuration

In the pilot study, we evaluated the initial system configuration of the Continuum. The Continuum uses the tiled display as a distributed corkboard where information is visible to all members and users can casually glance over at other's work. This pilot study was tested to understand how the distributed corkboard would help group awareness and parallel work for distributed group's collaborative work. Each Continuum space had an Access Grid, a shared whiteboard, a projection screen, and 4-node tiled display (see Fig. 2). On the left a projection display was provided to allow users to project one of the tiled display screens in a large format. Next to it was the tiled display (1 x 4 table mounted in the full AG room; 2 x 2 wall mounted in the mini-AG room). The Switcher program allowed any user to grab the remote keyboard and mouse control for any of the tiled display screens [7]. It provided a way to quickly switch user's input control from a laptop or tablet PC to any tiled display nodes. Next was a plasma screen that was used for AG multi-site video conferencing. To the right was the plasma touch-screen that was used for shared whiteboard. The whiteboard was connected between two sites via NetMeeting. Only one keyboard and mouse was provided in each site, e.g. the two co-located members had to share one input control.

In the first study (as shown in the left image of Fig. 3), we evaluated the seamless distributed corkboard that was designed to give users an illusion of one continuous display. The main technology addition was SpaceGider, a software interface that allowed users to navigate their mice across four tiled display screens seamlessly [2]. We tried to replicate the display setting as much as possible in both sites: the tiled display (2 x 2 layout) on the left wall, AG display in the middle (4 cameras and 2 microphones in full AG setting, and one camera and one microphone in mini-AG setting), the shared touch-screen whiteboard on the right, and four keyboards and

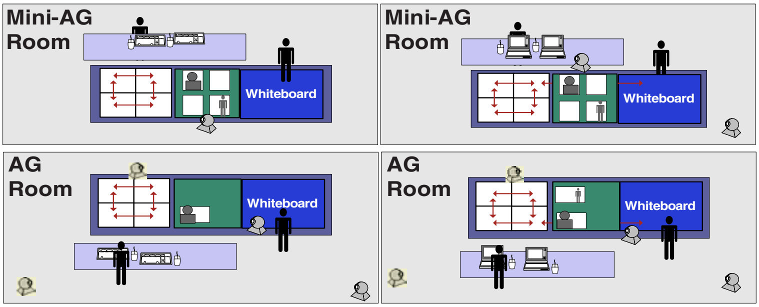

Fig. 3. The system configuration of evaluating the seamless distributed corkboard using SpaceGlider in Study 1 (on the left) and the seamless distributed corkboard with personal displays in Study 2 (on the right).

mouse (one input control for each user). Full-sized keyboards and mice were given to the participants to encourage them to casually look at others' work on the tiled display. The shared whiteboard between rooms were connected using the NetMeeting's shared whiteboard application.

In the second study (as shown in the right image of Fig. 3), the system configuration was changed to add personal displays and improve the mini-AG setting. The personal displays, such as table PCs, were provided to give users a close-up view. In mini-AG setting, we added another microphone and a video camera with a magnifying filter on the close-up camera to help casual interaction between distributed participants. In addition, we used SpaceGlider to connect four tiled display screens and the whiteboard.

In the third study (as shown in the left image on Fig. 4), the system was configured to provide a discrete flexible tiled display to support an easy transition between individual work and group work. It allowed users to view either four individual screens or one screen maximized over the entire tiled display. Any user could turn on or off a full-screen option (to maximize his/her workspace over the entire tiled display) at any time. This desktop sharing was implemented by using Aura [11]. The tablet PC was used to mirror one of the tiled display with each tile screen having a distinct background color for easy identification of workspace. We provided Switcher for users to access the tiled display and the whiteboard which allowed the users to jump to any of the displays. To improve the display layout, we swapped the location of AG and the tiled display so that the tiled display was centered and next to the whiteboard.

In the fourth study (as shown in the right image on Fig. 4), the system was configured to provide a presentation-style display. The presentation-style display allowed only one individual's private workspace, i.e., tablet PC to be visible at a time on the public group display, i.e., tiled display. With this configuration, group members could work individually on their tablet PCs and anyone could choose to show his/her workspace onto the tiled display. Also, they could hide their workspace if they did not want to show it to others. They could show their individual workspace on the tiled display as either one large full-screen or four identical (cloned) small screens. Individual workspaces had the same distinct background colors given in the third study.

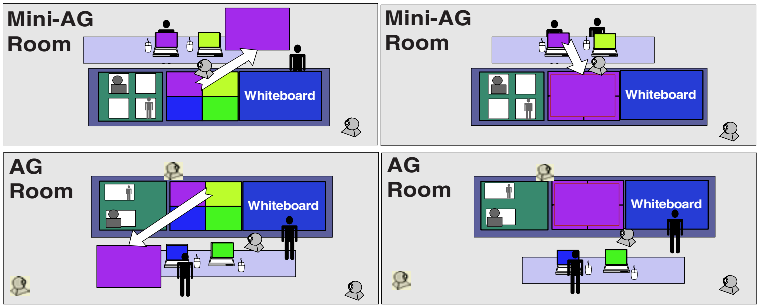

Fig. 4. The system configuration of evaluating the discrete flexible display with personal displays in Study 3 (on the left) and the presentation-style display with personal displays in Study 4 (on the right).

This time, participants were only allowed to switch between his/her workspace and the whiteboard on the tablet PCs. Besides the configuration changes on the tiled display, the other settings were the same as the third study.

5 Observations

5.1 Communication

Similar to war rooms [8, 13], overhearing pattern was also observed over the AG in this design study – when one member was explaining something to others, remote members could overhear and interject clarifications and corrections. We argue that the sufficient quality of audio conferencing is necessary to capture all conversations to support overhearing and easy communication. The first study showed the need to improve mini-AG setting. We believe this was because the group members talked to remote collaborators freely at various places in the room. Also, Group 3 had audio problems during the task, but it was not easily overcome by the use of other mediums such as text chat.

The result of this design study shows the necessity for additional video cameras for group member close-up view and additional video images of shared resources to convey members' spatial reference. In fact, participants often gazed at the video image of the remote collaborator's close-up face during the course of a discussion. This close-up view of the collaborator's face helped them get some forms of deictic reference or small feedback signal (e.g. nodding, murmuring, or facial expressions from the listener). The video window of remote collaborator's view placed close to meeting participants also seemed to help casual interaction among remote participants.

The additional camera and microphone in mini-AG setting introduced since the second study seemed to help increase remote interaction. For example, the read-and-write collaboration occurred between two distributed members over the AG. The read-and-write collaboration is a pattern of collaboration between two members to

Table 2. The frequency of read-and-write collaboration pattern

	Read-and-write collaboration between local participants		Read-and-write collaboration between remote participants	
	Information query and gathering	Information analysis and pattern detection	Information query and gathering	Information analysis and pattern detection
Study 1	2	7	0	0
Study2	9	7	0	2
Study 3	3	2	2	3
Study 4	4	2	0	0

transfer data across displays via voice channel. That is, one person read text (e.g. answers) from the tiled display while the other wrote it down on the whiteboard. Table 2 shows the total number of frequency of groups' read-and-write collaboration pattern. This read-and-write collaboration between remote members was observed in the second and third study, but it disappeared in the fourth study.

In the fourth study, no particular audio and video problem occurred, but the groups tended to have less interaction over the AG. The participants indicated that the decrease in the number of remote interactions was due to less visibility. They said that during the first or second study, they could maintain group awareness by seeing each other's work and talking to each other to ask questions and discuss ideas when they were given the distributed corkboard; whereas, they had to rely on strictly on overhearing to obtain such awareness information.

Interestingly, it was observed that the participants in the second and third study used the video of whiteboard view (or overall view) for shared resource awareness, i.e., to get information about who was using the shared whiteboard. In particular, Group 5 showed a large amount of whiteboard usage, which was similar to that of Group 2. But, unlike Group 2, Group 5 participants quickly adopted using the whiteboard view which reduced further possible conflicts. We expected frequent use of the video sources for shared whiteboard awareness by group members, but they opted for verbal communication to announce their intentions prior to using the whiteboard or being done using the whiteboard. These actions helped resolve possible conflicts, but they were burdensome. This result indicates that we should provide simple awareness tools (such as, beep sound indicating someone's using the whiteboard when another member is also approaching the whiteboard) to help ease the burden of turn taking among the group members on shared resources.

5.2 Visibility

The distributed corkboard supported high visibility of all members' work activities. The group members were aware of what others were doing by glancing over their tiled screens. They could also easily refer to the contents on the screens. Such visibility supported by the distributed corkboard was useful when the group worked together to solve problems sequentially. While working together, one participant controlled the mouse on tile screens while the others could see this manipulation and added their insights into the analysis. It was also useful when the group moved frequently between individual work and group work. In this case, individual work on tile screens could become a focus of group attention when the group wanted to work together. However, visibility seemed to be less useful when the group divided the task and then simply combined individual work. In this case, the group members worked largely independently, and interaction was limited to sharing task progress or asking for assistance.

It was observed that visibility became more important as the groups showed increased interaction and collaboration between remote members, e.g. remote instruction. When a Group 4's member helped her remote collaborator, she wiggled her mouse cursor to point out what she referred to on her screen. Visibility helped implicit peer learning since it allowed users to observe how others tackled the same problem. Some participants reported that they got ideas and learned from others by observing what others were doing so that they did not have to ask questions, e.g. how to select all variables in the data set. Some also said they shared searching strategies and built new strategies from those of other group members by looking at the other's work. Visibility also supported the immediacy to access to information and experts. For example, members found useful information or answers from collaborators' work, and one's difficulty could be shown to remote collaborators. Overall, the participants indicated that they did not pay much attention to the distributed corkboard tiled display but it was helpful to have information visible on the tiled display all the time.

Another important pattern was that the participants often asked others to take a look at one of their screens, to point out their interests. They also used this pattern to get group attention bring them into group discussion by showing one's finding to others. Table 3 showed the pattern of "look at (this)" or "see (my screen)" to draw attention when a member wanted to indicate his or her finding to the collaborators. This is a typically associated pattern when one wants to bring other user's attention to a certain part of the display during the collaborative work session. The frequency of "look at" pattern seemed to be varied by the group's working style, but it appeared consistently throughout the studies.

The presentation-style display in the fourth study disallowed a user's casual glancing over at another's work but instead allowed information to be visible by presenting one's workspace to the tiled display so that the whole group members could see. However, such reduced visibility resulted in degrading group performance and interaction, as compared to the groups in the third study. Unlike the previous studies, the "show me" pattern appeared due to less visibility (See Table 3). This pattern was an explicit request to make information visible – for example, one group member asked the other to show his/her workspace or another member offered to show his/her own workspace in order to share information with others. This pattern was observed when one wanted to present something to others or to solve the problem together when someone had a problem.

Having experience with the distributed corkboard, the participants disliked going back to a classical round-robin style of Power Point Presentation model of collabora-

Table 3. The frequency of Look at and Show me pattern

	Look at		Show me	
	Information query and gathering	Information analysis and pattern detection	Information query and gathering	Information analysis and pattern detection
Study 1	6	13	0	0
Study2	14	38	0	0
Study 3	6	13	0	0
Study 4	13	1	7	11

tion. They wanted to see all of the information on the tiled display and compare to each other. The fourth study's participants stated that they could easily see information over the distributed corkboard when they wanted to see and needed to share, whereas they had to request to see information over the presentation-style display. This request became a source of delay when the group wanted to share information.

5.3 Awareness

Some participants benefited from using the distributed corkboard to maintain group awareness. The group members seemed to use various channels to be aware of their partner's activities. According to post-test user surveys, the participants maintained group awareness by listening to conversations, asking what people were doing, looking at the AG video windows, and looking at other's work over the distributed corkboard. While the distributed corkboard seemed to help overall group awareness, the participants often checked task progress over the AG, to get task awareness. That was done by asking the remote collaborators which question they were working on, or by informing them about what they had done and what they were going to do next. This pattern of synchronization was observed constantly throughout the studies and more frequently observed when the group showed mixed focus collaboration, i.e., the members worked independently on their individual workspaces most of the time and worked together from time to time on one of their individual workspaces to verify or discuss findings.

The presence of tablet PCs (close-up display) introduced in the second study helped the group members focus on their individual work, but it seemed to result in reducing the number of users' glancing over at other's work on the distributed corkboard tiled display. The overall subjective rating showed that the participants focused on their own work using close-up personal displays and then checked other's work once in a while over the distributed corkboard or by quick glimpse to local collaborator's personal display. The participants in the third study also showed this similar behavior, i.e. working mostly on their close-up displays and occasionally checked the tiled display to see others' activities. Interestingly though, even though they looked at other's work occasionally, the participants perceived the importance of having the distributed corkboard because it supported the immediacy of information – that is, when they needed to work together, they could easily refer to "look at" the particular screen or maximize the screen so that all of them could see and discuss.

The presentation-style display provided users with more private workspaces with limited information sharing capability among group members. It only allowed one member's private workspace to be publicly visible over the tiled display. It also did not allow users' casual glancing over at collaborator's workspace. As it was discussed earlier, the groups in the fourth study showed less remote interaction. Group 7 showed the divided work pattern, and a large percentage of their conversation over the AG was devoted to task awareness (about 60% during information query and gathering and about 88% during information analysis and pattern detection). Group 8, in contrast to Group 7, showed the pattern of group's working together in the information analysis and pattern detection task; however, a fairly large amount of interaction over the AG had been shown for task awareness and the "show me" pattern. The participants in these groups commented that they did not look at the tiled display in casual manner unless the work was presented.

5.4 Seamless or Discrete Display

The seamless distributed corkboard seemed to introduce users to feel more continuity of the tiled display. For example, the participants even tried to move the windows (e.g. a web browser) from one tile screen to another. While SpaceGlider gave users the illusion of tiled display as one big continuous display, the multiple mouse pointers presented in the same screen made the individual mouse identification more difficult. This problem was identified by user's mouse accidentally entering the adjacent collaborator's screen, i.e., when they tried to adjust the window size at the screen corner.

Similarly, the second study groups also had mouse sharing and identification problems due to SpaceGlider. The groups stated that SpaceGlider was intrusive to their work by causing unnecessary mouse conflicts. These groups also wanted to move windows from one screen to another. However, with SpaceGlider connecting the tiled display and the whiteboard, the groups said they felt no continuity of the workspace because of the AG plasma display. This led us to change the physical layout of the displays in the third study, i.e. swapping the location of the tiled display and the AG display, to increase the continuity when moving a mouse across the displays among the tile screens and the whiteboard.

To solve this mouse sharing problem with SpaceGlider, some groups suggested multiple independent mouse pointers to support simultaneous access to displays. Other groups suggested a solution of providing awareness tools (i.e. distinguishable mouse pointers to indicate who owns a certain screen) and locking mechanism where another mouse could not enter the workspace that was already owned by other members. Since the seamless display presented mouse sharing problems, we changed to provide the tiled display as discrete display using Switcher in the third study. When compared to the seamless display, the pattern of wanting to move windows from one screen to another disappeared with the discrete display. The number of mouse conflicts was also reduced, and the participants felt this was less conflicting. Similar to the third study, the pattern of desiring to move windows from one screen to another was not observed in the fourth study because of the discrete display. There was no mouse conflict over the tiled display since this configuration did not permit mouse sharing over the other's workspace.

The groups commented that Switcher was preferred to SpaceGlider because of the responsiveness to the user's action for a display – i.e. better to press a key to switch screens then to move a mouse. Switcher was also limited to one individual workspace and did not allow users to accidentally move a mouse to the next workspace. While the groups preferred Switcher for multiple users' collaborative work, they also stated that they would prefer SpaceGlider against Switcher if a single user used the tiled display.

5.5 Resolution, Proximity to Display, and Display Size

The proximity to display was also an important factor in the design of display-rich environments. In the first study, those participants who were assigned to use the upper tile screens had to frequently stand up for a close look at the screen due to the distance of the screen. This result led us to provide the close-up view display such as laptop or tablet computers in the following studies. The presence of tablet PCs helped resolve the proximity to display issue but raised the size issue. The second study groups thought perhaps increased distance from the tiled display would help them focus on monitoring all the displays, but the fonts had to be big enough to read at such distance. They also suggested maximizing the window to fill all screens of the tiled display to help their group discussion.

To address the size issue, we provided the flexible tiled display that allowed users to maximize one individual workspace into the entire tiled display. Group 6 used this full-screen option for group discussion where all members worked together to verify one individual's finding during the information query and gathering task. This group also used this option for personal use (and subgroup discussion) during the information analysis and pattern detection task, e.g. to make a scatter plot graph bigger to see the patterns easier. However, this full-screen tiled display for personal use did not interfere with other members since they could still work on their tablet PCs. Group 6 found this option useful because, sometimes, the image on the tiled display was not big enough. Some participants also indicated that the full screen was used for grabbing other's attention.

The presentation-style display did not allow the group to share information side by side, because it only allowed sharing one individual screen at a time. This affordance created a resolution problem when the groups needed to see two or more views together for a comparison. For example, when Group 8 worked together solving problems one after another during the information analysis and pattern detection task, the group immediately realized the need for multiple screens on the tiled display after the group requested "show me your screen" followed by "show you my screen".

6 Discussion

In the everyday world people are aware of events around them whether that event be just other people, conversations or objects. In the group collaborative work, awareness information is always required to coordinate group activities. In this design study, we have experienced several dimensions of awareness problems such as the mouse identification and conflict problem using SpaceGlider, the whiteboard conflict and resolution between remote participants, and task awareness. Unfortunately, the participants spent much time negotiating these problems and explicitly informing or asking each other their intentions and activities. The use of multiple video sources helped them be more aware of remote participants and it was somewhat useful for resolving the group resource sharing problems. But such problems can be further reduced by the provision of awareness information such as audible or visual cues to indicate who is using shared resources and the coordination tool such as the group activity history tool to manage task progress.

The notion of awareness was defined as “an understanding of the activity of others, which provides a context of your own activity [3].” A huge body of work on awareness has been done both within computer supported cooperative work and outside of it. There were various types of group awareness: activity awareness, availability awareness, process awareness, and many more [12]. Activity awareness is knowledge about the activities of other members on the shared workspace. This includes workspace awareness, i.e., an understanding of others’ interaction with the shared workspace [5], and artifact awareness, i.e., information about what (artifact) has changed, in asynchronous systems. Availability awareness is a general sense of who is around and whether those people are available to meet or participate in an activity – for example, instant messenger status cues provide this awareness information. Process awareness is a sense of where members’ tasks fit into the stages of the project, what the next step is, and what needs to be done to move the process.

In this design study, the participants constantly but subconsciously gathered awareness information of remote collaborators through various channels, such as overhearing conversations, glimpse of video windows and of the distributed corkboard and the whiteboard. With the high quality Access Grid conferencing, the participants could overhear when problems arose and they helped each other or worked together even though they were remotely located. Casual glancing over at other’s work over the distributed corkboard and the shared whiteboard helped them be aware of activities of others. Even though our participants said they did not pay much attention to other’s work, the results showed that glancing helped maintain group awareness between remote collaborators. With the presentation-style display that did not support glancing, there was less interaction between remote participants and a greater degree of explicit notification to share individual findings and strategies.

Awareness information can be gathered through overhearing conversation, paying attention to general level of activity, casually looking over the shoulder, and monitoring progress of work. In this design study, overhearing and a general sense of progress monitoring among remote participants was supported through high quality audio and video. Casual glancing was also supported through the maximally visible

Table 4. The frequency of attention calls to group (i.e., all members), subgroup (i.e., the remote site members), and individual locally and remotely.

	Attention call to group, subgroup, and individual	Attention call to individual over the AG remotely	Attention call to group
To get task awareness	56	26	15
To ask remote user to do	54	39	4
To ask for help	55	34	7
To inform or discuss findings	29	7	16
To inform or discuss strategies	36	19	9
To initiate work	32	18	8
To get shared resource awareness	23	19	2
To get user activity awareness	25	16	5
To look at	20	13	4
To talk about problems	8	6	1
To talk about mouse sharing problem	14	1	10*
To talk about screen sharing problem	5	4	1
To talk about whiteboard sharing problem	3	3	0
To talk about audio problem	3	4	0
To indicate reference	3	0	0

**Note that nine attention calls to group occurred during Group 1's information query and gathering due to mouse conflicts.*

distributed corkboard. However, our system did not effectively support conveying user's attention over the distance. Interestingly, a few participants did try to use non-verbal gesture (e.g. looking at the camera and raising his hand towards it) to draw the remote partner's attention. Most participants showed that they just spoke out loud to get others' or group attention. Some participants used the 'full-screen' option or 'show' screen on the tiled display to get group attention as well.

Table 4 shows the total number of attention calls to group (i.e., all members), subgroup (i.e., the remote site members), and individuals located locally and remotely. Most attention calls were made to individual located remotely (57%) followed by group (24%), subgroup (12%), and individual located locally (7%). We expected more of these attention calls to be about problem discussion and conflict resolution or initiating group discussion, but the result showed that attention calls overall were initiated mainly to get task awareness and to ask remote users for assistance or ask them to do a certain action. Most attention calls to individual remotely were triggered to ask for remote help or action. Most attention calls to group were to get task awareness or inform/discuss findings and strategies. We also observed that calling out for group attention usually led to a transition from individual work to group focus work.

As shown in Table 4, attention calls were also made to get shared resource awareness and user activity awareness. We observed a few occasions of two remote participants trying to access the shared whiteboard at the same time which resulted in conflicting actions, i.e., one tried to move to the next page while the other tried to write down notes. Obviously, this is not a surprised finding. Previous work have already discussed conflicts on shared resources caused by the lack of shared input feedback, such as unexpected changes on group shared workspace by other user's input [2, 9]. In our design studies, the turn-taking pattern emerged to compensate this shortcoming: always asking others to check the availability of these resources before using them or informing others after using them. This was the reason that such many attention calls were observed for shared resource awareness.

7 Conclusions and Future Work

In this paper we presented iterative design studies to explore design issues for enhancing group awareness and performance among distributed teams in the Continuum. The Continuum is an Amplified Collaboration Environment designed to support intensive collaborative work among distributed teams using advanced collaboration, computation, and visualization technologies. The study involved placing a group of collaborators in two separate Continuum spaces and asking them to perform a set of collaborative scientific tasks, information querying and gathering, information analysis and pattern detection, and collaborative brainstorming and design, while varying the technology configurations. Group interactions and their use of the available tools were observed to determine which tools assisted them in accomplishing the tasks.

The value of the Access Grid is that it enables distributed team members to be brought together into common spaces (called as virtual venue in AG) for group interaction. Through the high-quality AG, distributed members get a sense of awareness and overhear conversations, which enable casual interaction. The study findings confirmed the value of having all information artifacts of group member's work and their activities visible for collaborative work. The distributed corkboard tiled display afforded all work visible at a glance, and this feature helped group members be aware of progress and problem that others faced during collaborative work sessions. Although the participants stated that they did not pay much attention to the distributed corkboard tiled display especially with the close-up displays, we believe this display was used as a peripheral group display. When this visibility was taken out such as in the presentation-style display, it was fairly obvious to see the awareness problem where members explicitly showed or asked to show information from their private close-up display to the public group display.

While the distributed corkboard helped group awareness by being able to casually glance over at other's work, we need to address more awareness issues observed in our studies, such as shared resource awareness and more importantly task awareness among group members. Distributed participants needed more shared resource awareness as the number of their interactions on these resources increased. Thus, we need to provide awareness tools that indicate who currently owns which resources so as not to have resource conflicts or have members explicitly ask for or notify the use of shared resources. We also need to support tools that help group awareness of the overall state of the task progress such as to-do list or action items. This is particularly necessary for the group whose members work simultaneously in parallel but share work process and results during the course of collaborative work.

Moreover, we observed that the participants often gazed at the video image of remote collaborators during discussion and did lots of hand gestures over the displays to point at different interests. User's hand gesture, eye gaze, and physical proximity to shared resource were powerful indicators of attention, but our participants suffered from a lack of this information. We believe the system showing simple attentive cues would encourage more natural interactions. Further investigations will be made to evaluate and improve the features discussed in this paper, and we will continue to work on improving the Continuum technologies to support real world distance collaboration among distributed teams.

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