ENHANCING COOPERATIVE WORK

IN AMPLIFIED COLLABORATION ENVIRONMENTS

BY

KYOUNG SHIN PARK
B.S., Mathematics, Duksung Women's University, 1991
M.S., EECS, University of Illinois at Chicago, 1997

THESIS

Submitted as partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Computer Science
in the Graduate College of the
University of Illinois at Chicago, 2003

Chicago, Illinois

ACKNOWLEDGMENTS

I wish not only to acknowledge, but to sincerely thank, a number of people for their assistance, patience, and encouragement in completing this dissertation. Without them, this work may not have seen the light of completion. First and foremost, I thank my advisor and thesis committee, Andrew E. Johnson, Jason Leigh, Thomas Moher, Thomas A. DeFanti, Luc Renambot, and Steve Jones, for the valuable comments and idea refinements. I am also indebted to my colleague, Jin-man Lee, for many useful comments and discussions. I thank my husband and son, Yongjoo Cho and Sungshin Cho, my parents and parents-in-law, my sisters and brothers, for enduring unforgettable years. Without their support and encouragement, I would not have finished my program.

I would like to thank the subjects who volunteered their time for the ACE design study and the members of the CAVERNsoft group at EVL. I would also like to express my gratitude to Jung-min Lee for data collection and analysis, Yevgeny Ostrovsky and Allan Spale for operating Access Grid, Seung Kang for audio and video support, Preeti Singh for helping out the experiments, Alan Verlo, Patrick Hallihan, and Lance Long for technical assistance, Greg Dawe and Jonas Talandis for initial system setup, Dana Plepy, Laura Wolf, and Maxine Brown for helping the development of the IRB protocol and the promotional materials, and Allan Spale and his mom for improving this document. I would also like to thank all the other EVL students and staffs for their cooperation.

KSP

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF ABBREVIATIONS

ACE	Amplified Collaboration Environment
AG	Access Grid
AGAVE	Access Grid Augmented Virtual Environment
BIRN	Biomedical Informatics Research Network
CSCW	Computer Supported Cooperative Work
CVE	Collaborative Virtual Environment
CAVE	CAVE Automatic Virtual Environment
CAVERN	CAVE Automatic Virtual Environment Research Network
EVL	Electronic Visualization Laboratory
GMD	German National Research Center for Information Technology
GriPhyN	Grid Physics Network
HCI	Human Computer Interaction
JPL	Jet Propulsion Laboratory
LCD	Liquid Crystal Display
MUD	Multi-User Dungeons
NEES	Network for Earthquake Engineering Simulations
NSF	National Science Foundation
PDA	Personal Digital Assistant
SDG	Single Display Groupware
TRECC	Technology Research Education and Commercialization Center
UI	User Interface
URL	Uniform Resource Locator
VR	Virtual Reality

SUMMARY

Amplified Collaboration Environments (ACEs) are integrated ubiquitous tools and spaces that support collaborative scientific investigation using advanced computation and visualization technologies. ACE, such as the Continuum, adapts information to be optimally displayed using a variety of technologies such as multi-site video conferencing, interactive stereoscopic computer graphics, and high-resolution tiled displays backed by clusters of PCs connected over multi-gigabit networks. The goal of this research is to enhance collaboration among distantly located teams of experts gathered to intensively solve problems.

Human factors study over ACEs is intended to understand interaction among distributed teams working in the display-rich environments. An exploratory design study was conducted to evaluate how small groups in distributed Continuum spaces perform information discovery and knowledge crystallization tasks using varying technology configurations. The goal of the design study was to explore design issues for enhancing the quality of cooperative work in ACEs and to provide guidance to designers and facilitators of ACEs. This dissertation discusses the design concept of ACEs, the findings of the design study, and the analysis of shared workspace model for ACEs.

1. INTRODUCTION

1.1 Motivation

A virtual team refers to a group of geographically separated people sharing knowledge, skills and resources, and working cooperatively to achieve common goals (Mowshowitz, 1997). The notion of virtual team has become popular recently with the trend in globalization and outsourcing. Major corporations launch global virtual teams to address multifaceted challenges of global competition, global markets, and global coordination. In modern science and engineering research, large-scale, distributed, and multidisciplinary collaboration across laboratories around the country becomes more common to produce discoveries by sharing of computational resources, scientific instruments and massive data with researchers who are working together from remote locations. A few examples are the Network for Earthquake Engineering Simulations (NEES), the Grid Physics Network (GriPhyN), Earthscope for gathering high resolution seismometer data in the entire US, and Biomedical Informatics Research Network (BIRN) (Finholt and Olson, 1997). It is believed that there will be growing needs towards higher level of collaboration in the communities of science and engineering research to approach scientific problems from a broader and deeper systems perspective. The trend in the collaborative nature of research and tremendous improvements of computer and network technologies suggest an opportunity to update and elaborate the original collaborate laboratory concept.

Amplified Collaboration Environments (ACEs) aim to provide a future generation of collaboratorium for scientific investigation by augmenting the traditional concept of the war room with advanced technologies (Leigh et al. 2002). Prior research in war rooms has shown to have significantly enhanced performance in co-located teams (Covi et al, 1998, Teasley et al. 2000, Olson and Olson, 2000). Tightly coupled work is often considered as a feature of traditional co-located teamwork, but now it is possible to realize an affordable environment for supporting intensive work between distributed teams. The goal of ACEs is to enhance collaboration among distributed teams of experts gathered to intensively solve problems.

The Continuum is an ACE that provides integrated ubiquitous tools and environments to support collaborative scientific investigation using advanced computation and visualization technologies (Leigh et al. 2002; Park et al. 2003). The Continuum adapts information to be optimally displayed using a variety of technologies such as multi-site video conferencing, interactive stereoscopic computer graphics, and high-resolution tiled displays backed by clusters of PCs connected over multi-gigabit networks. This dissertation focuses on a human factors study over ACE exploring the design issues to enhance intensive cooperative work among distributed teams.

1.2 Problem Statement

The design and development of content sharing is one of the most difficult problems in ACEs since it requires understanding of shared workspace models that accommodate interaction of distributed groups using multiple information technologies. First of all, the design issues posed by shared workspaces are significantly different from a single user application. In particular, interaction modes must address multiple users' interactions, different paradigms for display organization must be supported, and the management of the users' interactions must address the group perspective.

Most synchronous collaboration systems have been developed to help interaction among co-located users in a meeting room or distributed users at separated desktop computers. They have discussed designs of different shared workspace systems to support a variety of specific collaborative tasks for distributed users. While these systems are valuable, it is difficult to apply their designs directly to the development of ACE content sharing because they are designed for desktop users whereas ACEs aim to support interaction among distributed teams with a lot of information artifacts over multiple display and input technologies.

In addition, ACEs focus on supporting collaboration among engineers and scientists who need to view, query, and discuss large-scale datasets for the analysis – not just simple text or drawing. Therefore, it is important to understand what display and interaction techniques would be appropriate for ACE users, in order to ensure the successful design of the ACE shared workspace model. The design of collaboration system must be properly matched with the needs of a group's tasks, and often the tools have developed without a full understanding of how to best support those needs (Espinosa et al., 2000).

In this research, a user-centered iterative design strategy was used to determine which tools would be appropriate for teams tackling scientific problems over ACEs. The design study was conducted to iteratively evaluate the system configurations of the Continuum technologies to identify design issues and group's needs on a variety of collaborative tasks, to improve the design of the Continuum shared workspace model, and to provide new design perspectives for developing and deploying ACEs that support information-rich intense collaborative work among distributed teams.

Some fundamental questions asked in this research are: how to analyze the shared workspace model for previous CSCW collaboration systems, how to design the appropriate technologies and user interfaces for the ACE shared workspace to enhance collaboration among distributed teams, and how to design the Continuum technologies configurable to support a variety of collaborative tasks. This will require an understanding of patterns of group working in ACEs on a variety of scientific tasks and on a variety of arrangements of the technology.

1.3 Shared Workspace Models

First, this research has undertaken a classification of some typical collaborative work patterns over shared visual workspaces found in previous CSCW studies into the two dimensions of visibility and controllability. The dimension of visibility concerns the extent to which users share view of information artifacts with others. The dimension of controllability concerns the extent to which users share control of information artifacts with others. The dimensions are divided into three categories: public (always shared by the group), private (always no sharing), and mixed (can be shared by the group publicly or individuals privately) during the collaborative work session.

Public visibility refers to information artifacts that are fully visible to all group members, whereas private visibility refers to information artifacts that are only visible to their owners and not visible to the others. Mixed visibility refers to information artifacts that can be viewed to public or private only. Public controllability refers to information artifacts that are fully controlled by the group (so, individual controls are not allowed on these artifacts), whereas private controllability refers to information artifacts that are only controlled by their owners and not by the group (so, it only allows private individual control on these artifacts). Mixed controllability refers to information artifacts that can be controlled publicly (by the group) or privately (by individuals).

The communication only model (such as text chat or Media Space) in the previous CSCW studies, for example, belongs to private visibility and private controllability since it does not support content sharing. That is, information artifacts are kept in private such that it is neither visible to others nor controllable by others. On the other hand, the war room model belongs to public visibility where all information artifacts are remained visible at a glance. In the ACE design study, a number of different shared workspace models were evaluated to understand which model would work better for the ACEs.

1.4 Summary

This chapter presents the subject of Amplified Collaboration Environments and the shared workspace models for ACEs motivated the need for research in this area. Chapter two presents shared workspace models for synchronous collaborative work. Chapter three describes the design concepts of the Continuum Amplified Collaboration Environment and its hardware and software technologies. Chapter four discusses the initial use of the Continuum. Chapter five continues to discuss the iterative design studies of evaluating how small groups of distributed participants interact over the Continuum spaces with variations of the technologies. Chapter six discusses the design issues explored in this design study and the analysis of shared workspace models. Chapter seven describes the important design issues for the ACEs and also ideas for future direction.

2. SHARED WORKSPACE MODELS

This chapter reviews several models, which cover some of the most important shared workspaces found in the CSCW related literature over the past two decades. The scope of survey is limited to synchronous collaborative work (where multiple users work together in real-time) using the shared visual workspaces (where group members share information using collaboration technologies, such as whiteboard or group editing tool). The shared workspace models are summarized into Table I at the end of the chapter.

2.1 Co-located Users' Synchronous Collaborative Work

In the co-located users' synchronous collaborative work, all group members are in the same physical location, such as a meeting room or lecture room. Co-workers have access to common spaces for group interactions and generally have mutual access to significant shared artifacts such as displays, files, models, and whatever they are using in their work.

2.1.1 Collaborative Work Side-by-Side Model

Twidale (Twidale et al., 1995) discussed a spontaneous co-located synchronous collaboration in a physical library. A group of two to four students worked around a single terminal, discussing their ideas and planning their next actions. Another group of two to three students worked on two to three adjacent terminals discussing what they are doing, comparing results, and sometimes seemingly competing to find the information. Individuals who worked at adjacent terminals occasionally leaned over and asked their neighbor for help, while individuals who worked at separate terminals monitored the

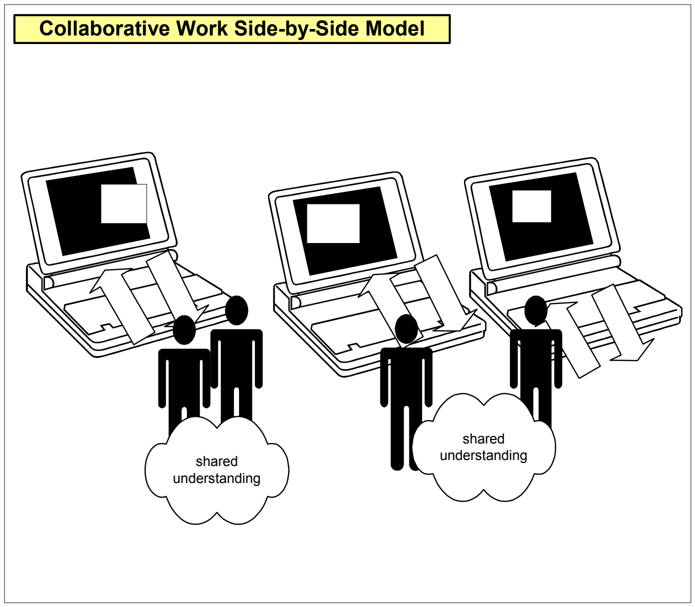


Figure 1. Collaborative work side-by-side model

activity of others. When a group of users worked side-by-side using multiple individual terminals, they were able to share information contents by leaning or glancing over at the others' terminals. They can share the input control by handing one's input control to the other, but typically input control is owned by individuals.

2.1.2 Extreme Programming Model

Williams (Williams and Kessler, 2000) described extreme programming, as a practice in which two programmers work side-by-side at one computer while continuously collaborating on the same design, algorithm, code or test. The initial study results indicated that paired programming made fewer errors and might be more productive than

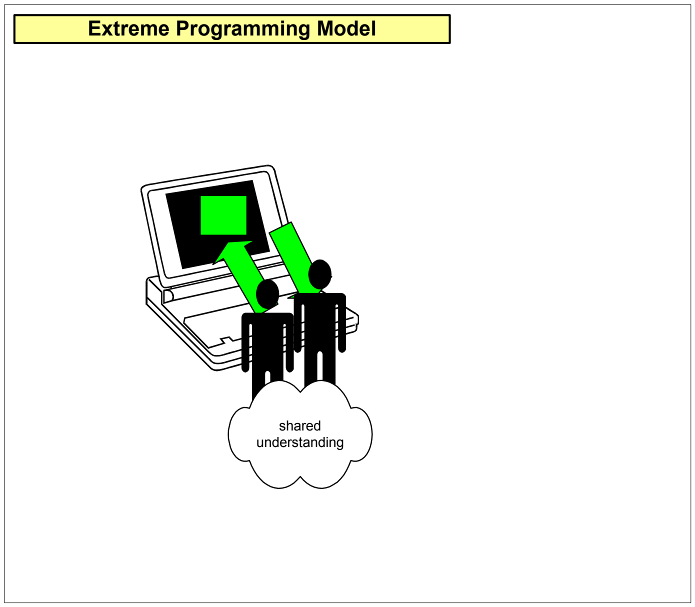


Figure 2. Extreme programming model

working alone. This practice required the use of collective code ownership whereby both partners own the code, the work patterns of continuous code review by the person not typing the code, and the continuous availability of help and peer learning. One key element in this approach was that everything was fully shared between two programmers such as shared working objects, i.e. code, as well as one shared input/output control.

2.1.3 <u>War Room Model</u>

Recently researchers at University of Michigan conducted fieldwork and interviews at several corporate sites and observed the work of people who are maximally co-located in dedicated project rooms often called war-rooms (Covi et al, 1998, Teasley et al. 2000,

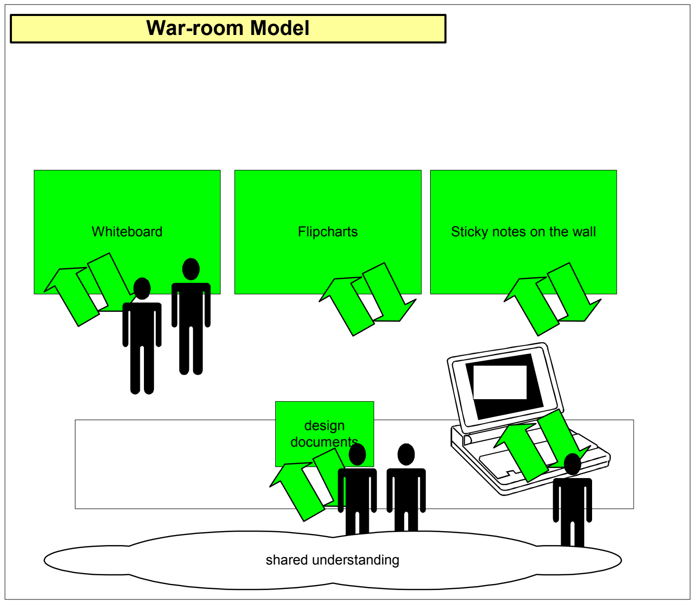


Figure 3. War room model

Olson and Olson, 2000). In a war-room, a group of people is co-located over a period of several days to months in order to solve a problem together. The room consists of numerous shared information tools such as a whiteboard, flipcharts, and a corkboard in which the members of the group may deposit information for the duration of the project. The artifacts are kept persistent so that members can refer back to them from time to time. In some of the cases, war-rooms led to increased learning, coordination, and productivity as compared to the corporate average (Teasley et al. 2000). Some of the key characteristics were:

- *Persistence of rich information*. Project rooms allowed for the depositing of diverse informational artifacts such as notes that were written on flipcharts in addition to drawings, schematics, and printouts that were pinned to a wall. These notes were present every day of the collaboration. Collaborators were able to spontaneously and simultaneously modify these artifacts by writing over them or moving them.

- *Spatiality of human interaction and deictic reference*. In a project room, because the whiteboards, flipcharts, and corkboards are arranged around the room, collaborators had a special memory of where the artifacts were located and could quickly refer to them by pointing at them or by glancing in their direction that everyone could immediately interpret.

- *Group awareness*. Even if several members were simultaneously posting new information, the fact that the information was on the public display, where it was fully visible to all members, allowed them to keep constant awareness of the overall state of the project meeting. Also, they could overhear others' conversations and see what someone was working on and be aware of how long they had worked on it with or without progress.

- *Continuously available help*. Since the collaborators were all present in the room, questions could be answered immediately. Furthermore participants could form

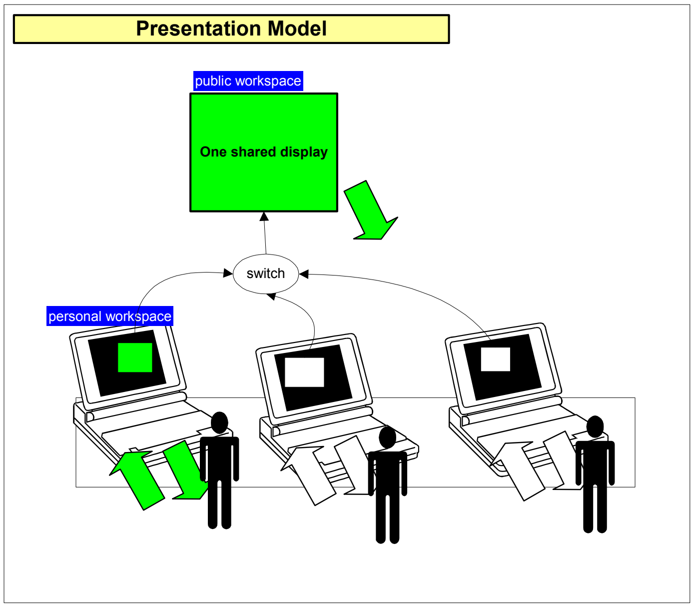


Figure 4. Presentation model

multiple subgroups to attack sub problems once a good partitioning of an overall problem had been established.

TeamX at NASA Jet Propulsion Laboratory (JPL) is an example of war-rooms augmented with information technologies for designing space mission proposals (Mark, 2002). In this room, engineers use a variety of computer technologies such as public displays, databases of past space mission equipment and measures, an orbit visualization program, a configuration graphics program, and a publish-subscribe system of networked spreadsheets.

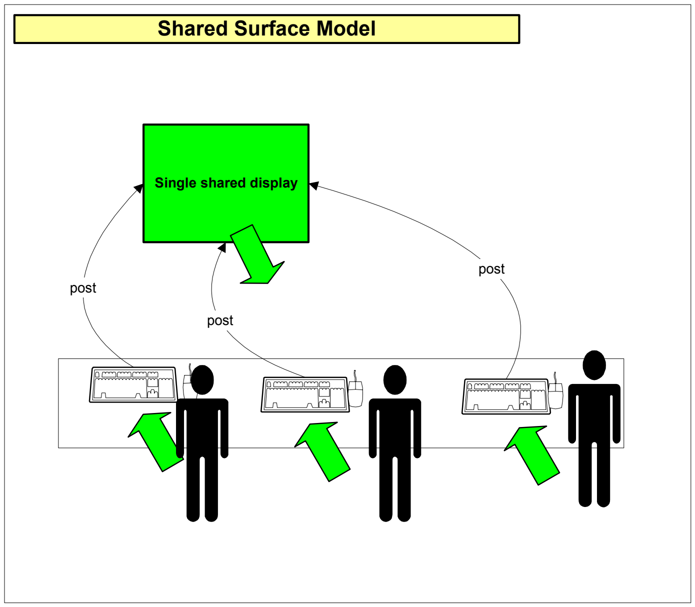


Figure 5. Shared surface model

2.1.4 Presentation Model

In today's meeting rooms, typically there is a large public display, such as projector or plasma panel, in which the speaker can easily hook up his/her laptop computer to give a presentation. This is called a display pushing model in which a user pushes information from a private workspace (e.g. laptop computer) to the public display (e.g. a large projection display). During the presentations, all meeting attendees share information contents projected on this public display, but the presenter owns the input control on his/her private workspace.

2.1.5 Shared Surface Model

Some earlier CSCW studies investigated a small group's face-to-face design session using a shared drawing surface (Bly, 1988; Tang, 1991; Pedersen et al., 1993). In this session, the designers worked together around a shared drawing surface like a large sheet of paper or a whiteboard, and each designer had a pen for pointing or drawing. The general conclusions from these studies were that the shared surface supported a common view for designers, that the designers used the drawing surface extensively as part of the collaborative design process, and that the drawing activities, such as each designer's drawings and gestures, were also important and independent of the drawing artifacts created.

Stewart and his colleagues studied the effects of using Single Display Groupware (SDG) on small co-located group's collaborative work (Stewart et al., 1998; Stewart et al., 1999). SDG focused on the use of one shared public display and several input devices for users (one input per user). The characteristics of SDG applications were shared screen space, a shared user interface that can handle multiple simultaneous inputs from users, shared feedback, coupled navigation, and shoulder-to-shoulder interaction. Earlier SDG studies of comparing collaborative work using SDG with using single user application at one workstation revealed significant hindrances of single user application. The results were following: a passive user often pointed at the screen, users fought for input control, most conversations were from a passive user issuing order, a passive user had less engagement and more frustration by not being an equal participant in the collaborative effort, and there were increased potentials for peer teaching/learning when using SDG. A recent study further discussed and examined design interfaces that encouraged collaboration when using SDG (Benford et al., 2000). An example of such interfaces is combination of actions taken by multiple SDG users.

There were some approaches using multiple PDAs (Personal Digital Assistants) or tablet PCs as portable personal input devices in SDG. The Pebbles project investigated the use of PDAs as a remote commander to allow users to send input simultaneously from PDAs to the same PC display as if they were using the PC's mouse and keyboard (Myers et al., 1998). Rekimoto's multiple device approach demonstrated multiple users with tablets that acted as a personal tool palette to control a shared digital whiteboard in a collaborative setting. Users worked on a personal tablet and then moved the data onto a shared public computer, such as a digital whiteboard, using the Pick and Drop protocol (Rekimoto, 1998).

2.1.6 CoLab Model

CoLab (Collaboration Laboratory) is an electronic meeting room developed by XeroxPARC in the late 1980s to help face-to-face meeting collaboration (Stefik et al., 1987). CoLab provided users with networked desktop computers for personal work and a large display at the front of the room for group work. It allowed users to create public windows and private windows on their workstations, where public windows were used

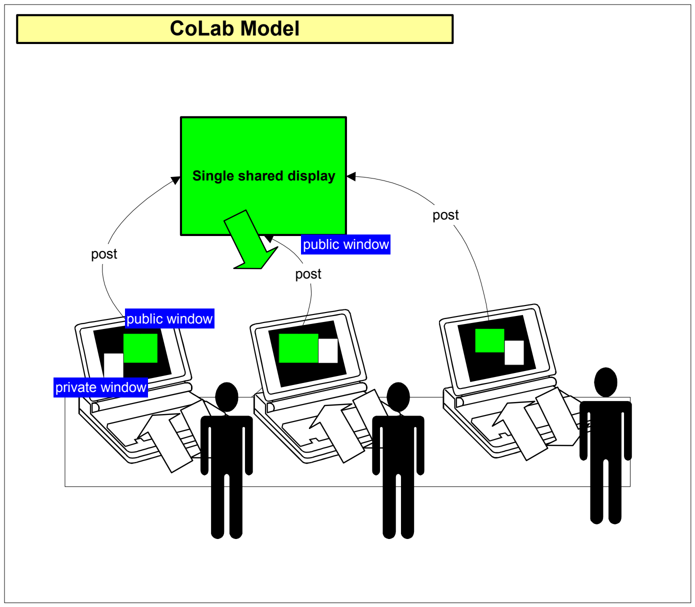


Figure 6. CoLab model

for sharing information with others. The public windows allowed anyone to write or edit in a public window. Private windows were used for a personal notepad. Similarly, CTS (Collaboration Technology Suite) was an electronic meeting room that consisted of a large wall-sized public display and several networked workstations (Olson et al., 1993).

2.1.7 <u>Smart Meeting Room Model</u>

By the inspiration of ubiquitous computing (Weiser, 1992; Weiser, 1993; Want, 1995), recently researchers have explored possibilities of people working together in a technology-rich smart meeting room. This room consists of a wide range of computing and interaction devices such as tiled wall displays, a table display, workstations, laptop computers, tablets, and PDAs. The main challenge in this research is integrating multi-users and multi-devices within the room which requires the development of a new architecture and interface that make it easy to create and add new display and input devices, to move work from one computing device to another, and to support and facilitate group interactions. The few prototypes of smart meeting rooms are Active Environment by Anderson Consulting (Lange, 1998), Augmented Surface by SONY (Rekimoto, 1999), DARPA's Command Post of the Future (DARPA), Future Computing Environment by Georgia Technology Institute (Abowd, 1999), I-LAND by GMD (Streitz, 1999), and Interactive Workspace Project by Stanford University (Winograd 1999; Fox 2000).

2.2 Distributed Users' Synchronous Collaborative Work

While the shared workspace models for co-located users' synchronous collaborative work are generally the meeting room model, the shared workspace models for today's distance work are mostly the extension of communication model. These systems include teleconferencing, desktop video audio conferencing, meeting room video conferencing, text-based chat rooms, file/data sharing, application/desktop sharing, and collaborative virtual environments.

2.2.1 Text-based Communication Model

MUD (Multi-User Dungeons) developed by researchers at Xerox and elsewhere provides a text-based virtual environment in which remotely located people can meet and interact with each other based on which rooms they have entered. When a user enters, leaves, or joins a conference, messages are printed on the screens of other users in the room.

Instant messaging (e.g. ICQ and MSN Messenger) also provides text-based chat session. It is perhaps the most well-known collaboration system supporting casual interaction where one can select their friends or close collaborators, see if they are online, and then easily enter into a text chat conversation.

2.2.2 Media Space Model

XeroxPARC Media Space provides an always-on video portal between distant locations to support shared awareness and to increase casual interaction (Bly et al., 1993). Media Space allows users to walk to distantly located rooms. Authorized participants can ask the server to bring up the images of remote rooms on their workstations thereby becoming aware of their activities. In Media Space, people gather awareness through the video channel and use the same channel to move into communication.

The Portholes is a quasi-dynamic Media Space emphasized on the role of shared awareness in the support for informal interactions within distributed work groups (Dourish and Bly, 1992). The concept of Portholes shows that there is an intermediate ground between static images and dynamic video. Instead of sending images continuously, Portholes sends images every few minutes.

Bellcore's Cruiser is a system to support social browsing by touring through various offices and public spaces (Fish et al, 1993). EuroPARC's RAVE is a system to enhance peripheral awareness of ongoing activity and also to establish long term working relationship (Gaver et al., 1992). The CAVECAT project at University of Toronto connects distant users via desktop videoconferencing as well as shared drawing, writing, and programming software (Mantei et al., 1991).

2.2.3 Collaborative Virtual Environment Model

Collaborative Virtual Environments (CVEs) are multi-user virtual reality systems where participants navigate in 3D space and see, meet, and interact with each other and object in a shared virtual environment. Tele-immersion is the integration of collaborative virtual environments (CVEs) with audio and video conferencing, in addition to the access of supercomputing resources and massive data stores that are connected over high-speed nationwide or worldwide networks (Leigh et al., 1997; Park et al., 2000). In tele-immersive environments, collaborators work together on 3D artifacts such as the design of new car or the visualization of multi-dimensional datasets. The presence of users is depicted by life-like representation of themselves called avatars.

Some researchers claimed that CVEs may support collaboration and interactivity, especially geographically distributed collaboration, in ways which go beyond what is possible by using more familiar meeting room or teleconferencing technologies (Benford et al., 1995). CVEs may provide a shared spatial environment where, in principle, people can employ communicative resources, which are unavailable to them in other technical systems. For example, participants can have a degree of control over what they view in a CVE, which is not generally possible with Media Space, with the support of a fixed camera and monitor system. Furthermore, users in a CVE are all embodied in the environment so that their location and orientation can be represented, and hence, a degree of mutual awareness of each other's activity may arise or be readily supported.

2.2.4 Web-hosted Shared Repository Model

The BSCW (Basic Support for Cooperative Work) system supports cooperation among distributed working groups through "shared workspaces", i.e. web-based shared repositories where project partners can deposit and retrieve information (Bentley et al., 1995). A shared workspace contains different kinds of information such as documents, pictures, URL links to other web pages, threaded discussions, member contact information, and more. The contents of each workspace are represented as information objects arranged in a folder hierarchy. The ScienceDesk (Keller, 2002) supports distributed science teams with information sharing tools. Its primary tool is ScienceOrganizer, a centralized, web-based digital project library of heterogeneous scientific information, including datasets, documents, images, and field and lab records. ScienceOrganizer combines the functionality of a database, a document management system, and a hypermedia information space. The Collaboratory of space physicists is another example of scientific collaboration over the web-based community resource.

Their Collaboratory focuses on the simultaneous access to real-time data from instruments around the world, thereby allowing senior and junior scientists to talk about phenomena.

While the systems above are mainly used for laboratory studies, online user communities such as Yahoo® Groups have been growing and widely available to public. In this community, anyone can come in, register a few email addresses, and begin a group. These sites have some powerful community features which include the following: file sharing, threaded discussion board, group mailing list and e-mail notification, real-time text chat, audio/video conferencing, group calendars for shared resource reservation, file annotation, active user monitoring (e.g. the list of currently joined users), and tracking awareness information about which users have done what activities.

2.2.5 Distributed Presentation Model

There has been a growing interest in using computer technologies that broadcast lectures over the Internet for distance education. Students can take college-level courses at home by downloading course materials from the Internet and viewing video streams of lectures. For example, in early 2001 MIT began broadcasting all its undergraduate lectures on the Internet. Perhaps the earliest effort for interactive live-broadcasting presentations was Forum, a computer technology developed at Sun for supporting presentations to large distributed audiences (Isaacs et al., 1994). Forum allowed each audience member to view a video of the speaker as well as speaker's slides and slide

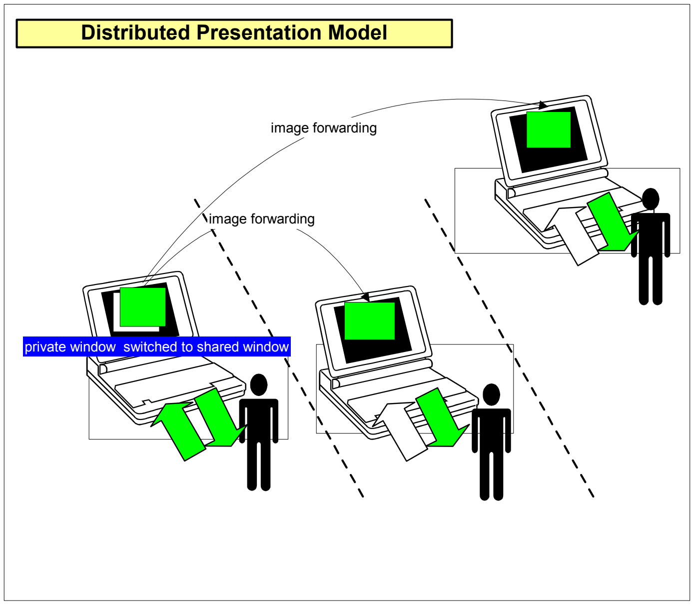


Figure 7. Distributed presentation model

annotations. Audience members could press a button to raise their hands to ask questions, and the speaker saw the names of those who had raised their hands. The lecturer could call on one of these users to speak and a stored image of the student would be displayed to the speaker as well as for all other audience members. Students could also vote in response to a poll, and the results of the poll were shown to all users. They could also mail private comments to the speaker and other students.

Web-hosted conferencing systems such as WebEx (WebEx), TeamWave Workplace (TeamWave), eRoom (eRoom), NetPodium (NetPodium), and PlaceWare (PlaceWare) are, basically similar to, online meeting rooms. Unlike videoconferencing, which requires expensive hardware and relatively demanding software for quality results, online meeting rooms typically ask for nothing but a web browser and an ordinary telephone.

With document and application sharing, attendees can see everything that happens on the presenter's screen. Microsoft NetMeeting® is electronic meeting room software that allows audio and video conferencing, application and desktop sharing, shared whiteboard, file transfer, and text-based chat. The software works across the Internet and over LANs but does not involve browser. Recently researchers studied four distributed groups' routine uses of NetMeeting for their project meeting at Boeing. These groups included scientific teams, technical working group, virtual staff, best-practice team (Mark et al., 1999). These research and commercial products are systems targeted for desktop-to-desktop presentations in which all the viewers are remote and the speaker is without a local audience usually in an office or recording studio. Recently other researchers have explored technologies focusing on presentations with mixed live local and remote audiences. The TELEP project attempted to provide speakers and local audiences with greater awareness of remote viewers and to provide remote viewers with a means to interact with speakers and other remote viewers (Jancke et al., 2000).

The main features of these online presentation systems is, in essence, pushing of one's desktop computer display to a remote collaborators' desktop computer in order to share the contents (e.g. the presentation slides or lecture notes) in the presenter's screen with remote participants (e.g. meeting attendees or students). These systems, therefore,

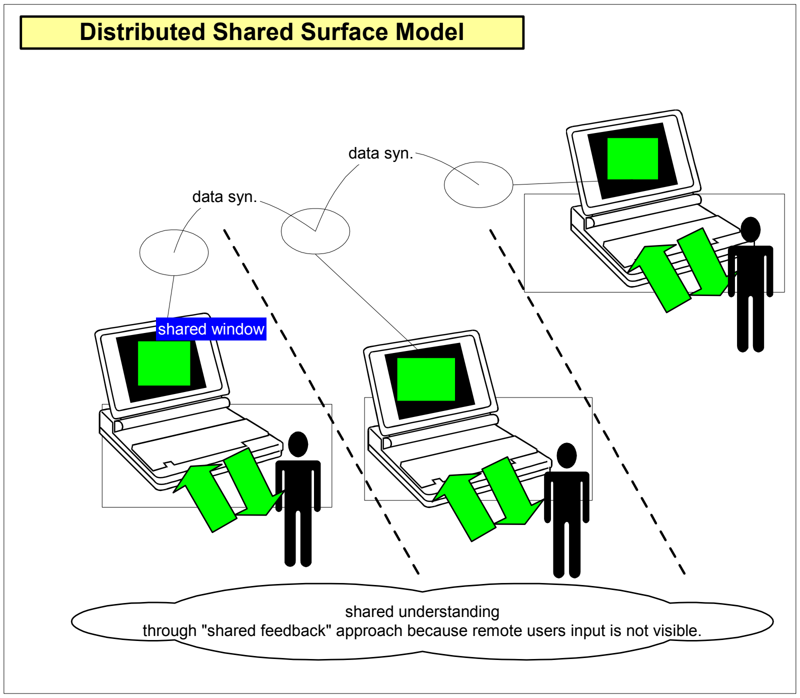


Figure 8. Distributed shared surface model

are not appropriate for the high-resolution contents distribution from multiple computers to remote sites.

2.2.6 <u>Distributed Shared Surface Model</u>

Distributed shared surface tools were developed based on the studies about collaborative work activities of co-located users using a shared drawing surface. These tools focused on supporting distributed designers to have the ability to share a drawing surface and to engage in many of the interactions available in conventional face-to-face situations. The main characteristic of these tools is that it provides all distributed participants with the ability to share a common view of the work surface, while it allows simultaneous access from all users and supports ways to convey gestures to remote viewers, such as tele-pointers.

Commune, for example, provides a shared drawing surface and a pointing device for each distributed user (Bly and Minneman, 1990). The drawing surface is a digitalizing table in horizontal position and is connected to the user workstation. All users have the same view on their screens as they are working together, and the cursor gestures are visible simultaneously to all users. GroupSketch is a group drawing tool supporting real-time remote design activities (Greenberg et al. 1992). It is implemented based on Tang's design principles (Tang, 1991). GroupSketch is able to do the following: display identical images of the sketch window on the screens of all participants, display cursors of all participants in each of these windows, let any user enter any command at any time, immediately broadcasts all actions to all users, and support modelessness. In addition, it provides special support for gestures. A cursor, or tele-pointer, movement can be used as a gesture. For this reason, cursors are made larger than their normal size. Four gesture types are supported that include: pointing, writing, erasing, and directing attention. Each gesture type has its own cursor shape and a cursor is labeled with the name of its user. ClearBoard is a shared drawing space where two distributed users can collaborate though screens displaying overlaid images of computer-generated graphics, drawings made by both user, and a video image of the other user (Ishii and Kobayashi, 1992).

2.2.7 Distributed Meeting Room Model

Some researchers pointed out the needs of "virtual meetings" by extending the physical boundaries of one meeting room while, at the same time, allowing face-to-face meetings within the room (Haake and Streitz, 1995). This allows the coupling of several meeting rooms and remote offices as well as integrating them into "virtual meetings". Unlike other synchronous distributed groupware systems where most of them are desktop to desktop based tools that focus on individual communication, the pattern of this model can be described as multi-users, multi-devices, room-to-room interaction. Such interactions are different from and more complex that desktop to desktop interactions.

2.3 Visibility and Controllability of Shared Workspace Models

Figure 9 depicts previous CSCW shared workspace models that can be classified according to the dimensions of visibility and controllability. The dimension of visibility concerns the extent to which users share the view of information artifacts with others. The dimension of controllability concerns the extent to which users share the control of information artifacts with others. The dimensions are categorized into public, private, and mixed. Public refers to visibility or controllability that is always fully shared with others. Private refers to visibility or controllability that is always not shared with others. Mixed refers to visibility or controllability that can be shared with others or not during the collaborative work session.

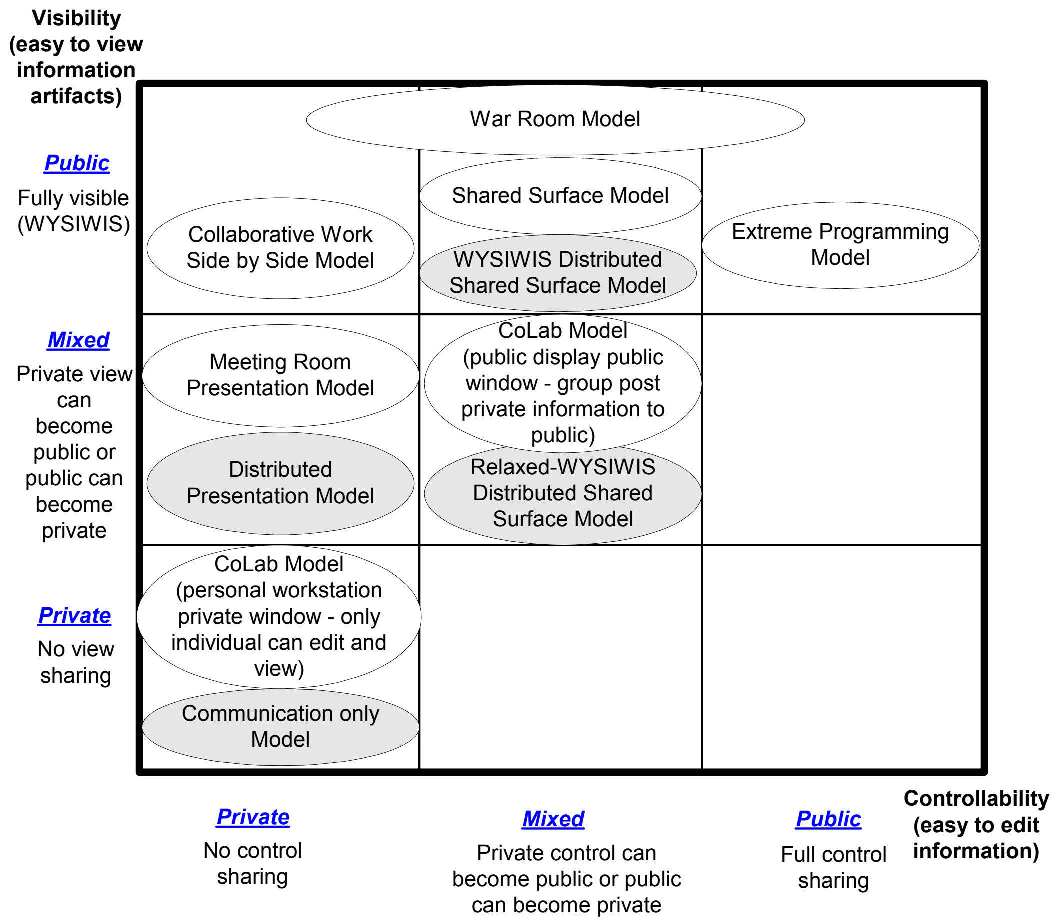


Figure 9. Previous CSCW shared workspace models

In public visibility and private controllability, information is visible to all group members but controlled by its owner. Collaborative work side-by-side model belongs to this category since information artifacts can be visible to other by glancing but typically input control is not shared. In public visibility and mixed controllability, information is visible to all group members and controlled by multiple users simultaneously where public control on information can become private by locking or private control can become public by releasing. The models under this category are war room model, shared surface model, and WYSIWIS distributed shared surface model. In public visibility and public controllability, information is visible to all group members and controlled by the group. Extreme programming model belongs to this category since view and control of information artifacts are fully shared by two co-workers.

In mixed visibility and private controllability, private information can become visible to public or publicly visible information can become private, but information is only controlled by its owner. Presentation model and distributed presentation model belong to this category since meeting participants bring their private information artifacts then display them onto the public display to share with others. In mixed visibility and mixed controllability, private information can become visible to public or publicly visible information can become private, and information is editable by multiple users' simultaneous control where public control can become private by locking or private control can become public by releasing. The example includes a large public display in CoLab model showing public window where group members can post information from private windows to public windows and multiple users can edit information simultaneously on the public windows. Also, relaxed-WYSIWIS distributed shared surface model belongs to this category since it supports users to have public view or private view.

In private visibility and private controllability, information is always not visible to others and controlled by only its owner. The example is no content sharing model, such as communication-only model and personal workstations in CoLab model showing private window, in which information is not shared with others and only viewed and controlled by its owner.

TABLE I

SUMMARY OF SHARED WORKSPACE MODELS

Models	Descriptions	# of people	# of inputs	# of outputs	Input shared	Output shared	Input simultaneous
Collaborative work side-by-side	Multiple co-located users' spontaneous collaboration (on multiple workstations)	2-4	1 per user	1 per user	Shared by handing	Shared by glancing	Yes - on different terminals
Extreme Programming	Paired programmers' collaborative work using one computer	2	1	1	Fully shared	Fully shared	No
War-room	Multiple co-located users' collaborative work in a dedicated project room using multiple public information tools (e.g. whiteboard, flipcharts)	5-7	5-10	5-10	Fully shared - turn taking by social protocol	Fully shared	Yes - on different displays
Presentation	PowerPoint presentations (from laptop) plugged into a public display (e.g. projector)	5-7	1 per user	1 - on a public display	Individual input	Shared public display (by turn taking)	No - by turn taking
Shared Surface	Multiple co-located users' collaborative work using single shared display (e.g. a large sheet of paper or whiteboard)	3-4	1 per user	1	Individual input	Fully shared	Yes
CoLab	Multiple co-located users' collaborative work in the electronic meeting room that consists of a large public display and PCs	3-6	1 per user	2 per user	Shared - editable on public windows	Shared - viewable on public windows	Yes - on public windows
Smart Meeting Room	Multiple co-located users' collaborative work using multiple displays and input devices	5-7	5-10	5-10	Shared	Shared	Yes
Distributed Presentation	Multiple *distributed* users' collaborative work using an online presentation tool (e.g. NetMeeting application sharing); Each user using a workstation	2-4 sites (1 user in each site)	1 per user	1 per user	Individual input	Shared - on shared windows by turn taking	No - by turn taking
Distributed Shared Surface	Multiple *distributed* users' collaborative work using a shared group workspace (e.g. shared whiteboard); Each user on workstation	2-4 sites (1 user in each site)	1 per user	1 per user	Individual input	Fully shared (WYSIWIS) or relaxed	Yes
Distributed Meeting Room	*Distributed* teams' (both co-located and distributed users) collaborative work using multiple information devices; a group of users using multiple displays in a room	5-7 (2 or 3 sites with 2 or 3 users)	5-10	5-10			

3. THE CONTINUUM

An Amplified Collaboration Environment (ACE) is a distributed extension of a war-room or dedicated project room (Leigh et al., 2002). ACE is motivated by prior research in war rooms which has shown that in some cases productivity can be enhanced far beyond the corporate average. Tightly coupled work is often considered as a feature of traditional co-located teamwork, but it is now possible to realize an affordable environment for supporting intensive work between distributed teams. The goal of ACE is to provide a future-generation collaboratorium by augmenting the traditional concept of the war-room with technologies that permit distributed teams to make use of its problem solving benefits.

The Continuum is an Amplified Collaboration Environment specifically targeted for supporting collaborative scientific investigation over high-speed networks that are connected to high-performance computation and data resources (Leigh et al., 2002). Current off-the-shelf collaboration tools such as NetMeeting cannot support the kind of interaction that occurs in real science campaigns. Scientists want more than just being able to video conference and share spreadsheets with each other. They want to be able to collaboratively query, mine, view, and discuss visualizations of enormous data sets in real time. The data sets that scientists routinely work with are on the order of terabytes. The visualization systems that are capable of displaying data sets of this size require more than desktop PCs.

Figure 10. The Continuum Amplified Collaboration Environment

Figure 10 shows a fully constructed Continuum space at Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago. Top left is a passive stereo display for showing immersive 3-dimensional contents; next to it are vertically stacked plasma screens that are used for Access Grid; to the right of this is the plasma touch screen. The small screens in front of the students form a tiled display that can be mounted in a 2 X 2 matrix. Two Continuum spaces are built at EVL to develop the technology and to facilitate human factors research experiments needed to support distributed collaborative project rooms. Another one is also operational at the Technology Research Education and Commercialization Center (TRECC) in DuPage County, Illinois.

The Continuum consists of a number of modular technologies: Access Grid multi-site video conferencing to support group-to-group communication, interactive stereoscopic computer graphics and high resolution tiled displays for content sharing, plasma touch screens to support shared flipcharts, and wireless mobile interaction – such as using laptops, PDAs and tablet PCs – for remote access to the numerous displays.

3.1 Conferencing

The Access Grid (AG) is a collection of resources that enables collaboration over the grid (Childers et al., 2000). It consists of high-quality multi-channel digital video and audio, a large-format display, presentation, and interaction software environments. The Access Grid is designed to support group-to-group collaboration in which it allows a group of people at different locations to see and talk with people at other locations simultaneously. The Access Grid has been used for meetings, brainstorming sessions, distance learning (e.g. seminars, lectures, training, etc.), and informal gathering. Over 100 AG nodes exist worldwide and more are being installed each month.

An AG node has a large tiled projection screen on which remote or local participants and software applications, such as web browsers and distributed power-point presentation slides, are displayed. A typical AG node is driven by four PCs (one for display and navigation, one for video capture, one for audio, and one for controls). An AG node also

Figure 11. The Access Grid at EVL

has four pan-tilt-zoom cameras that are distributed throughout the meeting room. This configuration affords each site the ability to provide multiple simultaneous viewpoints into a meeting. These viewpoints are important because a single camera simply does not have sufficient resolution and field of view to depict all the meeting attendees.

EVL's Access Grid uses plasma screens rather than projectors (Figure 11). On the left is the distributed Power Point presentation slide that is shared with AG meeting participants at other locations. There are several advantages to this. To ensure that the participants on camera are well lit, studio lights are mounted from the ceiling. The intensity of these lights tends to detract from images that normally come off projectors. Plasma screens, however, are still viewable in a very bright room. One disadvantage of

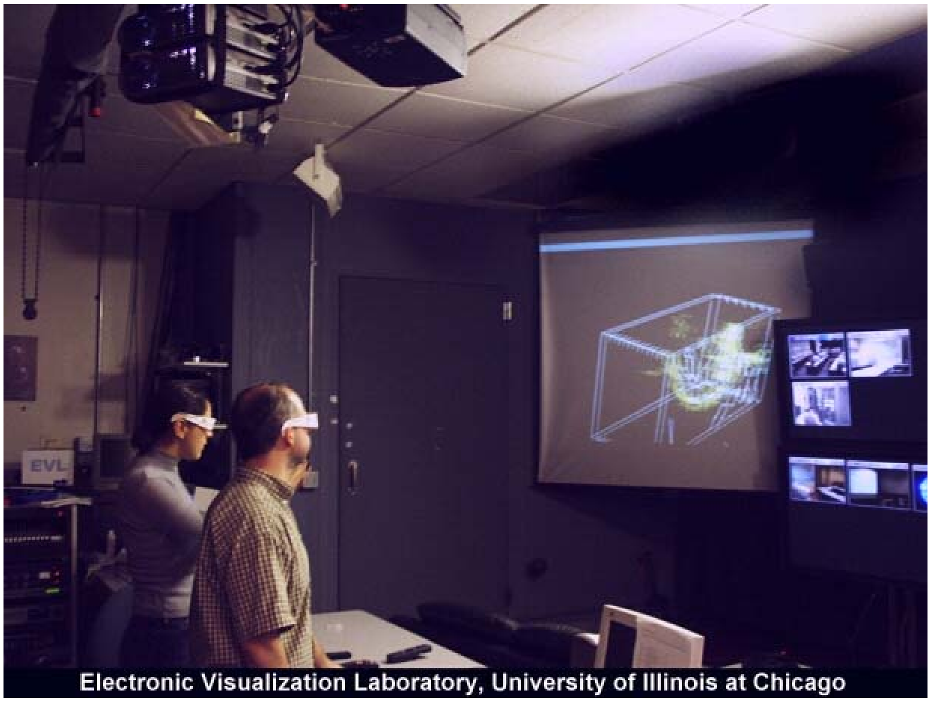


Figure 12. One of GeoWall AGAVE passive stereo displays at EVL

plasma screens is that they are smaller in size than projected images. Hence it is more suitable for small group interactions rather than large audience presentations. An extra projector can be ignited for that purpose.

3.2 Content Sharing

3.2.1 GeoWall AGAVE Passive Stereoscopic Display

GeoWall AGAVE (Access Grid Augmented Virtual Environment) provides passive polarized stereoscopic three-dimensional graphics using two low-cost projectors and a

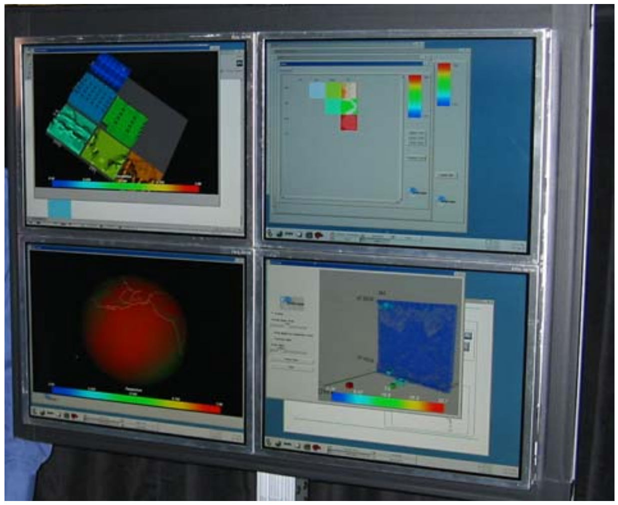


Figure 13. Tiled Display

Linux or Windows PC (Leigh et al., 2001). Circular polarizers are used to project both the left and right eye images simultaneously on the polarization-preserving screen, often called a “silver screen”. The observer wears low-cost polarizing 3D movie glasses to see the stereoscopic effect. As shown in Figure 12, EVL has two versions of the AGAVE; one uses a front-projection screen, while the other uses a rear-projection screen to provide greater contrast and less ghosting than the front projected system. Furthermore rear-projection screens allow users to walk up to the displays without blocking the projected images. AGAVE was designed to augment the Access Grid to allow collaborators to immersively share three dimensional content, such as scientific and engineering data, in conjunction with their two dimensional Access Grid content.

3.2.2 Tiled Display

The tiled displays support shared content views of text documents, web pages, spreadsheets, graphs and charts, and scientific visualizations. Figure 13 presents multiple visualizations of atmospheric datasets. It allows viewers to compare high-resolution visualizations side by side. The ultimate goal is to support users to be able to manipulate remotely located contents collaboratively as if everything is being done locally. With that focus, EVL has developed TeraVision technology to support content sharing on the tiled displays. A scalable LCD tiled display, called the PerspecTile, developed at EVL, supports viewing high resolution visualizations and mosaics of disparate visualizations.

3.2.3 TeraVision

TeraVision is a graphics streaming hardware system that enables scientists to distribute contents from laptops, workstations, or even cluster nodes to remote collaborators over a high-speed network (Leigh et al., 2002). TeraVision is unique in that it does not require any special modification of scientists' software and hardware to share their computer screens. Scientists simply plug the VGA or DVI output of their computer directly into the TeraVision box for remote display. Using multiple TeraVision boxes, scientists can also stream an entire tiled display to multiple remote sites at the same time. Two TeraVision boxes can be connected to the twin-heads of a GeoWall AGAVE system to allow streaming of stereoscopic images.

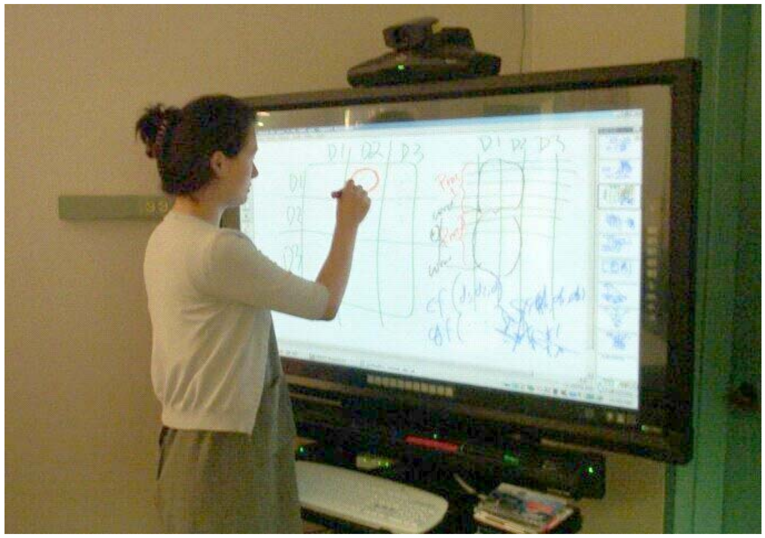


Figure 14. Touch screen whiteboard

A basic TeraVision system consists of a PC server with commodity video capture hardware for grabbing high-resolution VGA or DVI inputs, and a PC client, which can receive these streams and display them at various resolutions. The client does not require any specialized hardware for displaying the incoming video streams.

3.3 Collaborative Annotation

The annotation module serves as a digital whiteboard or flipchart on which collaborators may jot down notes and sketch diagrams. As shown in Figure 14, EVL uses a plasma screen overlaid with the Matisse touch screen, by Smart Technologies (SmartTech). A user can interact with the screen using a passive pen or one's finger as he/she would with traditional dry-erase whiteboards. Touch screen solutions are also available for rear-projected screens, which provide a larger writing surface area. The touch-screen whiteboards between distributed sites are connected via NetMeeting to support shared note-takings during a collaborative work session.

3.4 Wireless Access

There are several ways in which one can use technologies such as wireless PDAs, tablet PCs, and laptops in this environment. One frequent requirement is to have the ability to drag-and-drop a document from one's laptop or PDA and place it on the Continuum's content distribution screens to share with remote collaborators. Once the file has been transferred, the user will want to open the document and begin working with it. A software interface to allow a laptop or tablet PC to navigate across any of the displays on the Continuum was developed in order to encourage users to work on these displays collectively (Chowdhry, 2003).

4. THE INITIAL USE OF THE CONTINUUM

A pilot study was conducted with a group of three students to evaluate the design of task and the initial system configuration of the Continuum technologies. The goal of this initial trial was to ensure that the final procedure for the design study would be easy to understand and that the task could be completed in a reasonable time period.

4.1 Participants

Three students from the CAVERNsoft group at EVL participated in the initial evaluation of the Continuum technologies. All three students were familiar with computer and collaboration technologies such as email, discussion boards, or instant messaging systems. They were all highly motivated and interested in collaborative work. One student had more experience with online meeting systems (such as NetMeeting) and Continuum technologies (such as Access Grid and SmartBoard™ electronic whiteboard). One of them had extensive experience with correlation statistics.

4.2 Experimental Design

The group solved a set of collaborative problems together under two conditions. The first group members were distributed in two sites on the first day (the distributed condition), and then, group members were co-located in the same room on the second day (the co-located condition).

TABLE II

THE PILOT STUDY EXPERIMENTAL DESIGN

Condition	Procedure	
Distributed	60 min	Training
	15 min	Concentration Games
	45 min	Information Search and Retrieval (Cuba)
	60 min	Information Visualization and Exploration (Cereals dataset)
	30 min	Interview
Co-located	15 min	Concentration Games
	45 min	Information Search and Retrieval (University)
	60 min	Information Visualization and Exploration (Boston housing datasets)
	20 min	Brainstorming and Design
	30 min	Interview

The first day consisted of a 1-hour training session to help the participants gain familiarity with the Continuum technologies, tasks, and basic concepts of correlation statistics and multivariate data analysis. After the training session, they were distributed in two Continuum spaces where two participants were in the same room and the third was in the other room. The group was asked to perform a set of collaborative tasks: two concentration games (15 minutes), three questions on the information search and retrieval task (45 minutes), and seven questions on the information visualization and analysis task (60 minutes). The group had a short 10-minute break after the completion of each task, and a 30-minute group interview session after the completion of all three tasks to rate the usability and general effectiveness of the Continuum technologies.

On the second day, all three participants were located in the same room. The tasks given to the group were the same as on the first day, but the questions were more ambiguous, and more negotiations were required than on the first day. The task included two concentration games, one decision-making question on the information search and retrieval task, and five questions on the information visualization and exploration task. The second day also included a 20-minute design task where the group was asked to generate design ideas for the improvement of the Continuum technologies. The interview session was followed shortly after the completion of all three tasks.

4.3 Procedure

The first day consisted of a training session to introduce the group to the Continuum technologies and how to use the various software tools provided in Continuum. Then, the group received the task instructions and the basic concepts of correlation statistics and multivariate dataset analysis, such as scatter plot matrix and parallel coordinates, for the information visualization and exploration task. The order of tasks was given from most familiar task, to encourage collaboration, and then increased the complexity.

The group was first asked to perform two concentration games in which the group was given two identical game boards on two tile screens. The concentration game was to match two identical cards in the board (10 by 10 cards) until all the cards were matched. The task was ended when both groups found all the matched pairs.

In the information search and retrieval task, the group was asked to search on web sites using multiple web search engines to find answers to the questions. There were three questions in the Cuba search problem: how much sugar did Cuba export and which country imported it from 1990 to 2001, which were the two top buyers of sugar from 1990 to 2001, and find the trend of Cuban sugar industry from 1990 to 2001. A relevant document was information regarding Cuba's sugar trade. Sugar production statistics were not relevant unless exports were mentioned explicitly. On the other hand, there was one big question in the University search problem: given personal statistics of a high school student, the group should decide which university is best for this student and explain the decision.

In the information visualization and exploration task, the group was asked to search for trends in a dataset to verify or refute the questions. First, they briefly scanned the text of the dataset to become familiar with the variables and also to read the hypotheses briefly. Then, they examined the dataset on the information visualization tool, called XmdvTool (Ward), to confirm or deny the hypotheses and wrote up a report of the group findings on the touch screen whiteboard. The group was asked to solve seven focused questions of using the Cereals dataset and five ambiguous questions using the two Boston

Housing datasets. The Boston Housing datasets were grouped by geological or sociological independent variables.

The Cereals dataset had 77 observations and 15 variables: Cereal (bran=0, grain=1, oat=2, wheat=3, others=4), Manufacturer (A=0, G=1, K=2, N=3, P=4, Q=5, R=6), Type (Cold=0, Hot=1), Calories, Protein, Fat, Sodium, Fiber, Carbohydrates, Sugars, Shelf, Potassium, Vitamins, Weight, and Cups. This data was taken from the information visualization course at Georgia Institute of Technology (IV). The Boston Housing dataset had 506 observations and 19 variables divided into two groups: the geological and pollution variable group and the sociological economical variable group. This dataset was taken from the StatLib library at Carnegie Mellon University (StatLib).

After the completion of each task, the group was asked to fill out the post-test survey followed by a short 10-minute break. The 30-minute debriefing interview session was followed at the end of the tasks. The audio and video was recorded using a video camera in each room approximately five feet from the Continuum displays. Access Grid node operators helped in running the AG session between two rooms. Two evaluators in each room recorded group behaviors taken into the observation notes. The activities of the groups, such as the history of visited web sites and XmdvTool usages, were captured into log data files.

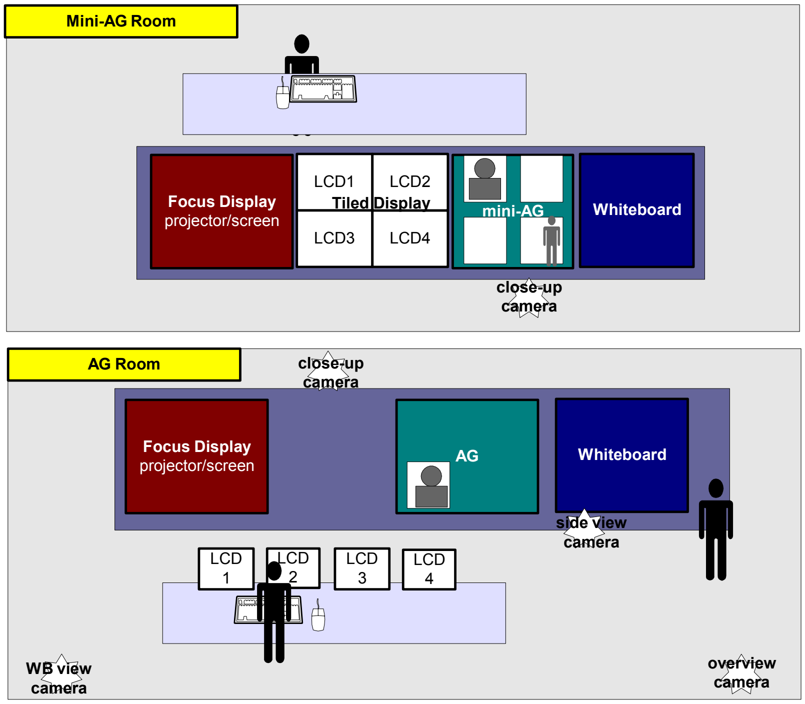


Figure 15. Diagram of system configurations in the distributed condition of the pilot study

4.4 System Configurations

4.4.1 Distributed Condition

Figure 15 shows the diagram for system configuration in the distributed condition. Two members of a group were located in the same room, and the third was alone in an adjacent room. The third participant was chosen to be the one who had some experience with the Continuum technologies in order to encourage active participation during the task. All of the participants could speak to each other via AG. The touch screen

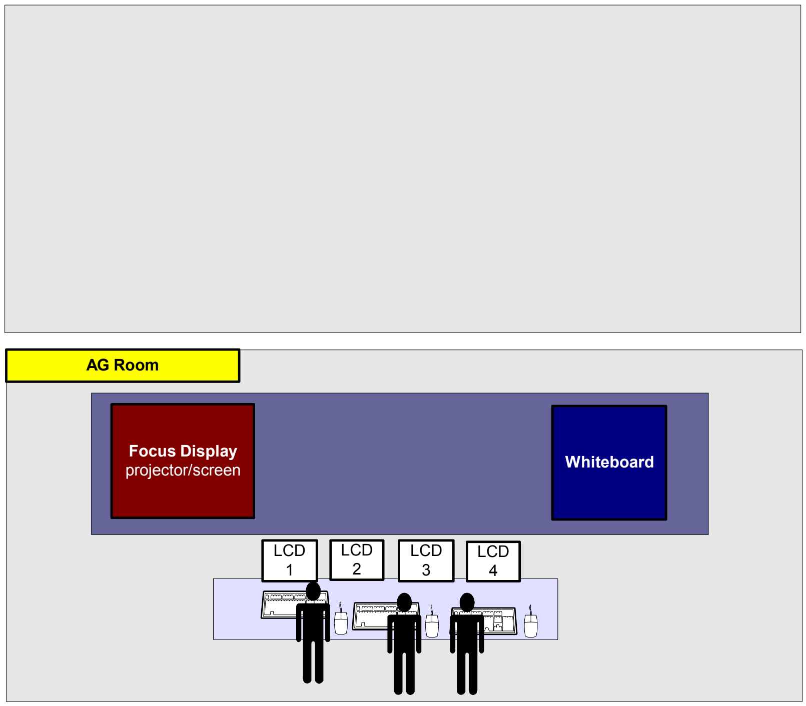


Figure 16. Diagram of system configurations in the co-located condition of the pilot study

whiteboard was connected via NetMeeting for shared note taking. A projection display at both sites showed one of the tiled display screens in a large format.

Only one keyboard and mouse was provided at each site, and hence, the two co-located participants had to share one input control. The tiled displays (1 by 4 table mounted at one site; 2 by 2 wall mounted at the other) were also shared between the two sites. The Switcher program allowed anyone to grab the remote keyboard and mouse control for any of the tiled display screens. The Switcher used a VNC (Virtual Network

Computing) server program on each tiled display cluster node, and a VNC client program on laptops or tablet PCs. This program was configured to allow users to quickly switch the input control from a laptop or tablet PC to any of the tiled display nodes.

4.4.2 Co-located Condition

Figure 16 shows the diagram of system configuration in the co-located condition. All three participants worked side-by-side in front of the tiled displays (1 by 4 table mounted). Since the participants were co-located in the same room, the Access Grid and sharing capability of the touch screen whiteboard were not provided to the group. The group was given three keyboards and mouse input devices on the second day for all tasks, except for the concentration games. During the concentration games, the group was only allowed to use two keyboards and mouse input devices, for the purpose of comparing this case with the group work pattern on the concentration games in the distributed condition. Using Switcher, they could interact with any of the tiled displays.

4.5 Observations

Overall, all students were highly engaged and equally participated in this collaborative problem solving regardless of the condition. There was no one who was left out doing nothing even if one of them did not get a keyboard and mouse control during Day 1 and during the concentration games on Day 2. The person who had no input device acted as a reviewer or a coordinator.

4.5.1 Distributed versus Co-located

It was observed that students used lots of deictic reference words, such as "this/that" or "here/there", which indicated features in their workspaces in both conditions. Since Continuum provided the workspaces that were fully visible to all students, they seemed to understand this deictic reference easily even in the distributed condition. Students did a lot of mouse pointing or finger pointing at the interesting features of a work object (such as a web document or visualization of dataset) to their collaborators especially when they spoke deictic words. In the distributed condition, however, their hand gestures referring to the work object were not transmitted to the remote collaborator(s), and hence, they had to explain more explicitly to indicate the references.

There was no mouse pointing by participants when the two of the co-located students helped the solo remote partner with the concentration games in the distributed condition because the solo student controlled the mouse on his board. Rather, they created a common row/column vocabulary to help the solo partner fill out the board and used the audio announcing the location of items. For example, one student referred to a location by saying "That guy is second column and second row." They could use the mouse pointer more on their own screen to show the solo partner where to click even though they were just relying on the audio and hand-pointing at the solo partner's game board. Often, they had to tell their remote partner more than once to indicate where they were referring to. For example:

Student1 (in room1):	"That one."
Student2 (in room1):	*hand pointing at a card on Student3's screen*
Student2 (in room1):	"More to the left."
Student2 (in room1):	"Keep going down."
Student3 (in room2):	*Moving his mouse pointer down*
Student2 (in room1):	"That one."
Student1&2 (in room1):	"Keep going down till the last row."

The high-quality video conferencing of the Access Grid (AG) supported natural communication and interaction. Students consistently checked the remote collaborators over the AG in order to obtain some forms of deictic reference. The "overhearing" pattern was also observed in the distributed condition, where for example, the solo student entered into to the ongoing conversation of the two co-located students. However, during the post-session interview, all students reported that they felt more comfortable and worked more easily with others when they were located in the same room.

The post-test survey results also revealed that students had to talk more in the distributed condition than in the co-located condition. In the post-test survey of awareness by glancing or talking in the scale of 1 to 4 (1=never, 2=once or twice, 3=regularly, and 4=most of the time), the average of talking is 4 in the distributed condition and 3 in the co-located condition; the average of glancing is 3 in the distributed condition and 2.11 in the co-located condition; and the average of awareness 3.67 in the distributed condition and 3.11 in the co-located condition.

Interestingly, the pattern of casual glancing over at collaborator's workspace was more frequently observed in the distributed condition. The participants in the distributed condition seemed to get some awareness information by looking at other tile screens. In particular, the solo remote student in the distributed condition constantly monitored the others' tile screen(s). For example, on the concentration games, the solo student divided attention to both tiles and sometimes flipped the cards more slowly waiting for a chance to see what the others revealed in order to try to find some useful matches. Interestingly, the solo student still regularly glanced over at the partners' screens throughout the tasks in the co-located condition emulating the same behavior as the day before.

The results in the post-test survey also mirror our qualitative observations – more glancing over in the distributed condition than in the co-located condition (See table). Students also stated that they were well aware of others' activities in both conditions – a little bit higher in the distributed condition than in the co-located condition (See table). This result implied that the distributed participants used more casual glancing to get awareness information, while the co-located participants maintained group awareness via overhearing conversations and nonverbal communication, such as gesturing and hand pointing. In the collocated condition, physical presence of people in front of the display seemed to discourage their casual glancing over.

4.5.2 Work Pattern

4.5.2.1 Concentration game

The work and communication patterns were more clearly distinguished by the task. In the concentration game, the group tended to work individually because speed was a goal in this task. In the distributed condition, one member of the co-located pair controlling the mouse just focused on searching for the matching pairs on the board and looked very little at anything except his tile screen. The other pair of students, who had no mouse control, helped the co-located partner more than the solo remote partner, such as informing the others additional findings. This person did some glancing over at the remote partner's screen mainly to transfer the answer to the remote partner. The solo remote student did glance over at the tiled display, particularly to transfer found matches already made by the pair.

In the co-located condition, two students controlling the mouse concentrated on working on their own board. The one with no mouse control pointed out coincidences between the two screens and helped both students more equally. It was much easier for the student without mouse control to inform the others about the findings when they all worked side-by-side in the same room.

4.5.2.2 Information search and retrieval

In the information search and retrieval task, it was observed that the students worked largely independently while searching on the web to find answers until one notified the finding to the others. They worked together from time to time to verify and converge on their findings. It seemed that the tiled display helped parallelism and reduced collisions of interaction in this task.

In the first day where the group was distributed in two rooms, they often announced findings to the others and referred to each other's screen (e.g. "Look at screen A.") when discussing their findings. The group used three or all four tile screens for different searches, and sometimes the group looked at the two or three screens to compare different search results. In the distributed condition, two co-located students searched the web together, and they switched roles to write notes on the whiteboard as they gathered relevant information.

In the second day where the group was co-located, the group had even more loosely coupled independent searching probably due to the number of input controls provided to the group (1 input per user) even though the question was more ambiguous and required more negotiation. The students divided up the task by one university per person, but constantly informed the others of what they found which led to group discussion. All students opened multiple windows (e.g. browsers, a question page, a text editor for personal note taking) on their tile screens and switched between these windows when they worked on individual searching.

In the post-test survey, the students rated the average task difficulty of 5.0 for the first day questions and 5.3 for the second day questions in the scale of 1 to 10 (1=very easy and 10=very difficult).

4.5.2.3 Information visualization and exploration

In the first day, the group worked closely solving problems together one after another in the distributed condition. One student controlled the mouse, and the other two students gave him comments to adjust the visualization variables. They switched between two windows (e.g. the graph window and the question page) on a single tile screen. Then, suddenly, they used more tiles because the question required a comparison of more data which was easier to do with extra screens. They engaged in lengthier discussions to modify the visualization to see the patterns more easily. All students equally participated in the debates of analysis. In the post-test survey, all students indeed rated that they exchanged the largest amount of information in the second day involving information visualization and exploration task (average=4=large amount) as compared to other tasks in both conditions (the average range of 3 to 3.33).

In the second day, the group worked together for the first two questions and then divided the remaining three questions by assigning one question to each student. All questions required the linking of two or three visualizations from two datasets in order to get correct answers. The group worked together to solve two questions using one tile at first and then used multiple tile screens – This included one tile for looking at the visualization and the raw data text, one tile for question page, and one tile for writing notes on the text editor). The group members looked at the visualization on the tile screen rather than on the projection display, which would have made it easier for them to see.

Then, the group members divided the work (one question per user) and worked individually on their respective tile screens, and two or all of them worked together if someone asked for help. The group performance in the second day was not as good as that of the first day probably because the question was more focused in the first day, whereas it was more ambiguous in the second day.

In the post-test survey, the students rated the average task difficulty of 5.67 for the first day questions and 5.57 for the second day questions in the scale of 1 to 10 (1=very easy and 10=very difficult).

4.5.3 Usage Pattern

4.5.3.1 Access Grid conferencing

When the students started to talk with remote collaborators for discussion or to inform others of findings, they first directed their attention to the video window of collaborator's view in the AG display. It seemed that they looked at AG to see if the remote collaborator could be interrupted. When the students talked over AG, they often looked at the collaborator's view of AG display wherever they were in the room (i.e. eye gaze towards the remote collaborators). Some interesting behaviors included one student raised his hand to get the remote partner's attention and one student gestured in the direction of the AG camera to "offer the pen to remote partner" in front of the whiteboard, in the first day information visualization task.

4.5.3.2 <u>Distributed corkboard</u>

The students seemed to have a sense of ownership over the tile screens. The pilot study configuration allowed users to use any of the tile screens at any time, and it allowed multiple users to interact on the same tile screen by social turn-taking protocols. However, students tended to find and use their own workspaces and not the others' workspace. That is, all students had visual access to all the workspaces, but input access was not shared and only controlled by its owner. This ownership pattern seemed to help reduce collisions between multiple users on the same screen.

The tiled display provided multiple individual workspaces while maintaining necessary awareness between distributed participants by the fully visible shared workspaces. This fact was demonstrated on the first day of the information search and retrieval task where the group showed mix-focused collaboration that involved frequent switching between individual search and group discussion. For example, the solo remote student looked at the others' search on the tiled display and then started to discuss the following information with them.

Student1 (in room1):	"Look at screen C. Go to sugar. .. 93-94."
Student3 (in room2):	"Give me a URL?"
Student1 (in room1):	"www.cia..."
Student3 (in room2):	"cia?" *then typing URL on his screen*
Student3 (in room2):	*looking at screen C; then pointing at the chart with his hand*
Student3 (in room2):	"Sugar production is half."

Another example was that the solo remote student overheard the others' conversation, and then he quickly looked at the tiled display to see what they were discussing, jumped into their ongoing conversation, and informed them of his findings in which he remembered that he had already been searching.

Student1&2 (in room1):	*local discussion for new search*
Student3 (in room2):	*looking at screen D, in order to know what they are talking about*
Student3 (in room2):	"We are talking about the first question"
Student1&2&3:	*more discussion over AG*
Student3 (in room2):	"Have a look at this summary on screen A" *then highlighting those portions of text.*
Student3 (in room2):	"They are talking about 90-98."

The tiled display was also useful for visualizing multiple views and side by side comparison. For example, all tiles were used for different purposes – such as displaying raw data, scatter plot, question, and notepad – at some time in the second day of the information visualization and exploration task. Students also used all four tiles to combine information to answer the third question in the first day of the information search and retrieval task where the question asked about finding the general trends.

4.5.3.3 Projection display

The projection display was used only once or twice in the information visualization task when students wanted to examine the patterns of dataset in a bigger format. The reason for under utilization of the projection display might be because the tiles were sufficiently viewable.

4.5.3.4 Shared whiteboard

Similarly, the shared touch screen whiteboard was used only for recording the answers as it was required. It seemed the shared whiteboard would have been more useful for the collaborative brainstorming task. In the second day, all students started using a text editor program to take notes on their tile screens during the task rather than physically moving to the whiteboard to take notes.

4.5.3.5 Wireless access control

It is observed that the group tended to work more independently on the information search and retrieval task. However, in the distributed condition, two co-located users wanted more keyboard and mouse controls in order to work in parallel. One of them even attempted to open up a web browser on the whiteboard. During the information search task in the first day, the group wanted to work in parallel, but two co-located students were forced to work together because they had to share one input control. It seemed that task parallelism was blocked by multiple users' sharing one input control.

4.6 Discussion

The pilot study was conducted to evaluate the initial design of task and system configurations of the Continuum technologies. Although the study focused on evaluating the variables of locations (distributed vs. co-located), task questions (focused vs. unguided), and system configurations (one input per site vs. one input per user), the initial user experiences with the Continuum invoked a wide range of design issues of user interaction over multiple display technologies in distance or co-located collaboration.

4.6.1 Design Issues for Task

The purpose of testing concentration games was to see if users were passively aware of the other's work where they would get the benefits of accidentally looking at flipped cards on both game boards. However, the result showed that the students concentrated on their own work because speed was important in this task. Only the coordinator, who had no mouse control in the co-located condition, seemed to have the benefits of glancing over at both screens on the tiled display.

The group in this pilot study did not show a pattern of "query triggering" discussed in (Romano, N. et al., 1999). Query triggering is the idea triggering in the collaborative information retrieval process where one user builds a new query from those of other users and hence, finds additional information that might have been missed if each member of the team had searched individually. It seemed that the group shared findings or answers by informing one another more than search process during the web search task; otherwise, it might have been difficult to measure this pattern.

It seemed the difficulty of the information search task and the information visualization task was similar between the first day and the second day as shown in the post-test survey results, and yet it seemed that the questions were too unguided in the second day which might have been resulted in poor group performance.

The shared touch screen whiteboard was used only for recording the answers as it was required. It might have been more useful for the collaborative brainstorming task.

4.6.2 Design Issues for Technology

In the pilot study, the tiled display was configured as a large distributed corkboard to provide the ability for users to pin up information artifacts for all users to see. This configuration of the tiled display was designed to encourage users to casually glance over at other's work activities. It was clearly observed that the tiled display helped group awareness for remote collaborative work, and it was also useful for side-by-side comparison and linking multiple information sources.

It was obvious that the students tended to see various display technologies provided in the Continuum as one big continuous screen. For example, they expressed the desire to move data from one display to another (e.g. cut-and-paste text). This implies that Continuum should provide a virtual desktop over distributed computers to make displays seamlessly connect together. In fact, students often informed one another to transfer information (e.g. URL, findings, notes) between the tiled display and the whiteboard.

In addition, instead of providing the projection display separately next to the tiled display, it might be useful to have a flexible and configurable tiled display that can project up to a single large high-resolution visualization for easy transition between individual work and group discussion. There were occasions that the group wanted to explore the data visualization at a size greater than that of a LCD display in order to read the pattern of data more easily. Originally, the projection display was provided for this purpose, but it was not used much even if all three students looked at one tile screen together on the second day.

In the distributed condition, the solo student wrote notes on the whiteboard, but he did not announce it to the others in the other room. Additionally, those two co-located students did not seem to be aware that the solo student had written some notes. Also, when one of the two co-located students pointed at something on the whiteboard, the solo student looked at the student over the AG to get some form of deictic reference. These examples indicate that the system should provide a way to indicate who is writing on the whiteboard and where he/she is pointing.

The initial system configuration of Continuum followed the shared surface model of one input control per site, but this approach seemed to block task parallelism. This fact was found in the information search and retrieval task because two students in the same room had to share one input control. Therefore, the system configuration in the second day was modified to provide one input control per user.

5. THE ITERATIVE DESIGN STUDY

This chapter describes the overall method and results of the four iterative design studies. The studies are iterative improvements of the two networked Continuum spaces to better support intensive collaborative work among distributed teams. In each design study, the system configurations were varied and the patterns of group behaviors were observed to determine which parts of the Continuum typically get used in a variety of tasks, to find out which technologies work or not, and to get user feedback on how to reconfigure the system configuration of the Continuum technologies.

5.1 Method

5.1.1 Participants

Sixteen students participated as volunteers in the studies. The subjects were recruited mainly from computer science graduate students from EVL in order to minimize the individual difference. All subjects had a high level of experience with computers and collaboration technologies, such as e-mail and instant messaging. Some of them had used NetMeeting or other commercial or research online meeting room systems. Some had experience with an information visualization tools, but none of them had used XmdvTool before. The subjects expressed fairly high interests in using the Continuum technologies and working as a team.

TABLE III

THE ITERATIVE STUDY EXPERIMENTAL DESIGN

	Group A	*Group B*
Study 1: Evaluation of Seamless Distributed Corkboard	*Group 1* Training Information query and gathering (Cuba) Information analysis and pattern detection (Data2.okc) Collaborative brainstorming and design (Improvement)	*Group 2* Training Information query and gathering (University) Information analysis and pattern detection (Data1-1.okc & Data1-2.okc) Collaborative brainstorming and design (Improvement)
Study 2: Evaluation of Seamless Distributed Corkboard with Personal Displays	*Group 3* Training Information query and gathering (University) Information analysis and pattern detection (Data1-1.okc & Data1-2.okc) Collaborative brainstorming and design (Improvement)	*Group 4* Training Information query and gathering (Cuba) Information analysis and pattern detection (Data2.okc) Collaborative brainstorming and design (Improvement)
Study 3: Evaluation of Discrete Flexible Tiled Display with Personal Displays	*Group 5* Information query and gathering (University) Information analysis and pattern detection (Data1-1.okc & Data1-2.okc) Collaborative brainstorming and design (Suggestion)	*Group 6* Information query and gathering (Cuba) Information analysis and pattern detection (Data2.okc) Collaborative brainstorming and design (Suggestion)
Study 4: Evaluation of Presentation-model Display with Personal Displays	*Group 7* Information query and gathering (Cuba) Information analysis and pattern detection (Data2.okc) Collaborative brainstorming and design (Suggestion)	*Group 8* Information query and gathering (University) Information analysis and pattern detection (Data1-1.okc & Data1-2.okc) Collaborative brainstorming and design (Suggestion)

5.1.2 Experimental Design

Table III describes the experimental design protocol showing the task and the group that was assigned for each iterative study. This is a two-tiered user study – i.e. all students participated in two design studies and solved two different problem sets with other group members. Two groups of four students performed the collaborative tasks in each iterative design study, and the groups received one of two different question sets for the tasks, Cuba or University for the information query and gathering task (see Appendix G), Data2 dataset or Data1-1and Data1-2 datasets for the information analysis and pattern detection task (see Appendix H), and Improvement or Suggestion for the collaborative brainstorming and design task (see Appendix I). All students participated in two design studies: first in the first and second design study, and the second in the third and fourth design study. The studies were conducted over three weeks intervals due to time required to re-configure the systems for the next study.

In the iterative design studies, the system configurations were the main independent variables and other possible variables – such as group size, technology size, individual or group differences, and learning effects – were fixed as much as possible. The group size was fixed into a group of four users. The number of technologies and setting were as much as identical between two Continuum spaces. To reduce individual and group differences, participants were given the pre-test survey to gather demographic information, such as technology familiarity, comfort, interest, and domain knowledge, and they received the brief introduction about the technologies as well as some basic knowledge required to solve the tasks. Since the students participated in two design studies, they were asked to solve two different question sets which had the similar task difficulty rather than being asked the same question. The different question sets were given to students to reduce the learning effects that might have been happened if they were asked the same question.

5.1.3 Tasks

The group was placed in the adjacent Continuum spaces at EVL and asked to perform a variety of information discovery and knowledge crystallization tasks using the Continuum technologies. The tasks were an information query and gathering, an information analysis and pattern detection, and a collaborative brainstorming and design task.

5.1.3.1 Information query and gathering

In the information query and gathering task (see Appendix G), a group was asked to search and gather information on the web to answer the questions. The questions consisted of two focus questions where group members would gather as many as findings on the web simultaneously in order to answer the question quickly and one overall trend question where they would make a conclusion based on their collective and combined findings.

Similar to the information search and retrieval task in the pilot study, the question sets were either the Cuba sugar industry problem or the University search problem. The University search problem was modified to include two questions of gathering information from five given universities, e.g. admission requirements and expenses such as tuitions and fees, and then making a group decision to find the best university in order to counsel a perspective high school graduate.

5.1.3.2 Information analysis and pattern detection

In the information analysis and pattern detection (see Appendix H), a group was asked to perform exploratory data analysis on a dataset using the XmdvTool information visualization system to answer the questions. The questions consisted of five focused questions where a group would find evidence to verify or refute any of the hypotheses and two overall trend questions where they would search for trends or patterns in the datasets.

The group received either the questions of using the Data2.okc dataset or the questions of using the Data1-1.okc and Data1-2.okc datasets. The Data2.okc dataset had 77 observations and 15 variables (A, B, C, D, E, F, G, H, I, J, K, L, M, N, and O), and this dataset was created based on the Cereals dataset used in the pilot study. The Data1-1.okc dataset had 506 observations and 10 variables (A, B, C, D, E, F, G, H, I, and J) while the Data1-2.okc dataset had 506 observations and 13 variables (A, B, C, D, K, L, M, N, O, P, Q, R, and S). These datasets were created based on the two Boston Housing datasets used in the pilot study. Some of the questions of using Data1-1.okc and Data1-2.okc required the comparison or linking of these two datasets. The datasets and questions were modified for the iterative design studies such that it could not be easily answered by participant's common knowledge.

5.1.3.3 **Collaborative brainstorming and design**

In the collaborative brainstorming and design task (see Appendix I), a group was asked to brainstorm, prioritize, and summarize design ideas for the Continuum technologies. Given their experience with the Continuum, the groups were asked to generate ideas for either the improvement of the Continuum designs or the suggestions for the future Continuum users. They were asked to group the brainstormed design ideas and sort the ideas in terms of "most important" first and then summarize the group conclusion to the evaluator.

5.1.4 **Procedure**

In the first and second design study, the groups gathered in the same room and received a 1-hour training prior to the tasks (see Appendix F). The training consisted of a description of the Continuum hardware and software technologies, followed by task instructions and basic concepts of correlation statistics and multivariate data analysis, such as scatter plot matrix and parallel coordinates, for the information analysis and pattern detection task. After the training, the two pairs of participants were distributed between the two Continuum spaces and then asked to perform three collaborative tasks:

an information query and gathering task, an information analysis and pattern detection task, and a collaborative brainstorming and design task. The subjects had a short break at the completion of each task, and they were asked to answer the post-test questions to give feedback about the usability of the Continuum technologies.

In the third and fourth design study, the groups were re-organized so that new groups were created with two people from the two groups who previously participated in the first and second study. For example, Group 5 was formed with two people from the Group 1 participants and two from the Group 4 participants. The purpose of re-grouping was to see if the participants broadened their ideas about the best way to use the technologies because it was observed that the groups in the first and second design study used the technologies in very different ways. Since the groups were already familiar with the technologies and the task, they just paired up and each pair went into one of the two Continuum spaces and performed the same set of collaborative tasks in the third and fourth study. Following the end of the tasks was the 30-minute debriefing interview session.

The groups were recorded using a video camera in each room. Access Grid node operators helped in running the AG session between the two rooms. A technical assistant was assigned to each room to resolve any problems that arose during the study. An evaluator in each room recorded group behaviors in the observation notes. The activities of the group on the tiled display cluster nodes, such as the history of visited web sites and XmdvTool usages, were captured into log data files.

5.1.5 System Configurations

The system configuration was the main independent variable in the iterative design studies. The focus of the studies was to iteratively evaluate the system configurations of the Continuum technologies in order to identify the design problems and the group's needs on a variety of collaborative tasks and to improve the design of the Continuum shared workspace model so as not to just document the weaknesses.

Figure 17 shows the initial layout of two Continuum spaces at EVL which was a starting point for prototyping and testing elements in the iterative design studies. In the full-AG room (the top left image) next to Geowall AGAVE passive stereo display on far left is a 2x2 matrix tiled display. Next to it are vertically stacked plasma screens that are used for Access Grid video conferencing. To the right of the stacked plasma screens is the plasma touch-screen used as a shared whiteboard. The mini-AG room (the top right image) has almost identical Continuum technology settings as the full-AG room. The floor plan of this initial layout is shown in the bottom in Figure 1. In this initial layout, the full-AG room has four cameras and two microphones and the mini-AG room has one camera and one microphone in front of the video display.

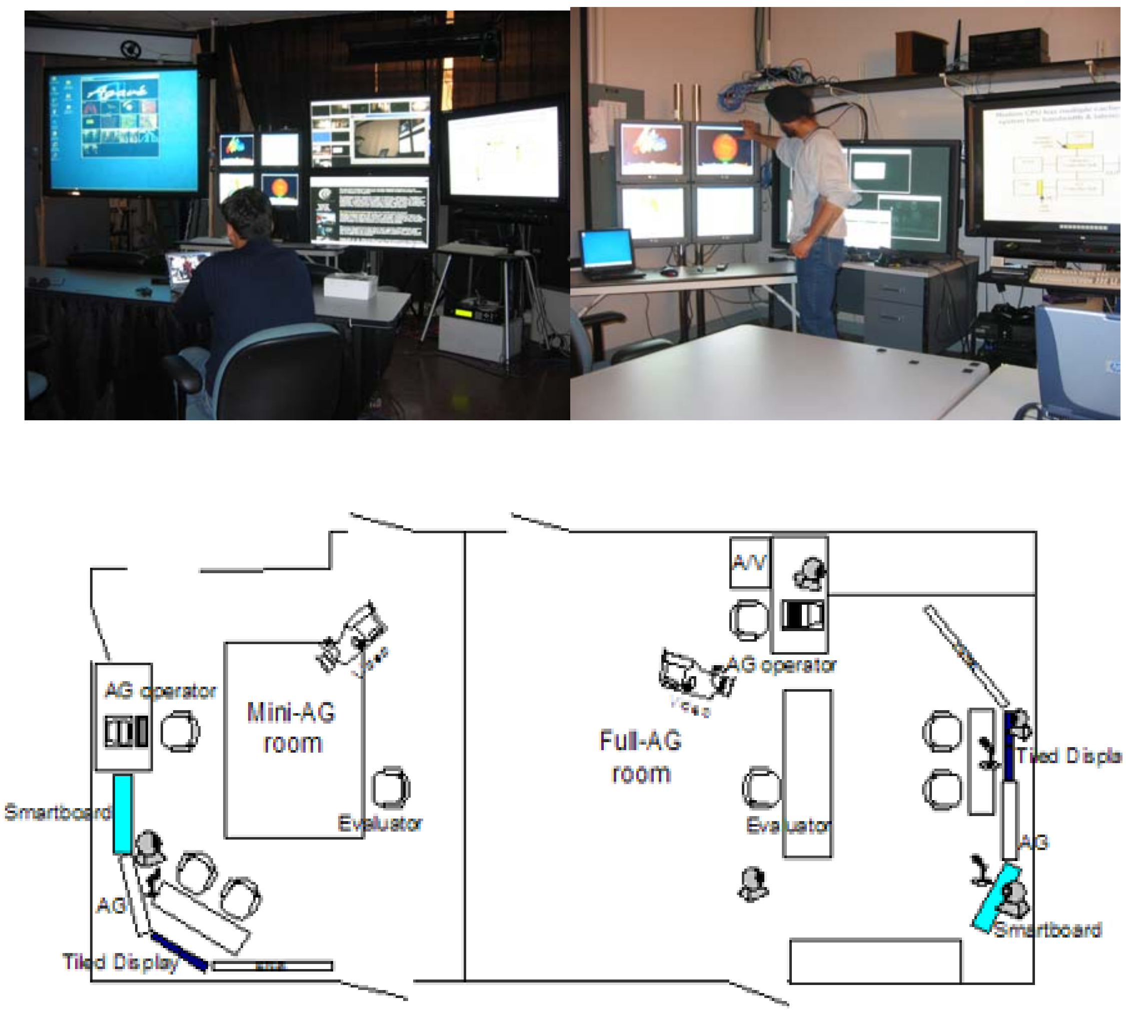


Figure 17. Initial layout of two Continuum spaces

5.1.6 <u>Measures</u>

Sets of dependent measures were collected: survey data and group interviews, performance measures, observations of the group interaction, group activity logs on the tiled display cluster nodes (such as the history of visited web sites and XmdvTool information visualization tool usages), and audio and video recordings (one in each room). In the first and second design study, post-test surveys were used to collect a subjective rating of the group's experiences using the Continuum technologies for their collaborative work practices which included measures for rating group accomplishment, members' contributions in finding the answers, visibility of the workspace, group awareness, and casual glancing over. In the third and fourth design study, the groups had an interview with experimenters after the completion of all tasks.

Measures of task performance included the following: number of problems solved, number of ideas generated, task completion time, members' contributions, quality, work patterns, participation and attendance, awareness and/or attention, number of information exchanges, and many more. Two evaluators (one in each room) observed the group behaviors and recorded them in the notes. Appendix E contains the list of some of the important patterns which would be observed in the iterative design studies, such as engagement, parallel work, shared work, duplicated work, collision, visibility, glance, deictic reference, shared understanding, comparison data, query triggering, and privacy. The groups' activities on the tiled display cluster nodes were captured into log data files. Audio and video of the collaborative work sessions were recorded for detailed post-experiment analysis. Two reviewers studied all the video recordings and noted all interesting patterns in the video, such as hand gesturing and head orienting.

5.2 Evaluation of Seamless Distributed Corkboard: The First Design Study

It was observed that the pilot study participants tended to see the various displays in the Continuum as one big continuous display which was demonstrated by the desire to move data between displays. This pattern led to the development of SpaceGlider which was a software interface that allowed users with laptop or tablet computers to navigate across the boundary of the Continuum's displays (Chowdhry, 2003). SpaceGlider is similar to PointRight developed by Stanford Interactive Workspace Project, which is a pointer and keyboard redirection for use among multiple displays (Johanson et al., 2002).

In the first design study, the system was configured to provide users the illusion of seamless displays. The main technology addition to this study was SpaceGlider for users to navigate across four tile screens. In addition, four keyboards and mice were provided for each user because the production blocking was observed in the first day pilot study where two co-located users had to share one input control even though they wanted to work in parallel during the information search and retrieval task.

Two groups of four students participated in the first design study. First, the groups received one hour training. Then, the group participants were asked to distribute between two separate sites and perform two hours collaborative problem solving tasks consisting of 30 minutes of an information querying and gathering task, 45 minutes of an information analysis and pattern detection task, and 30 minutes of a collaborative brainstorming and design task.

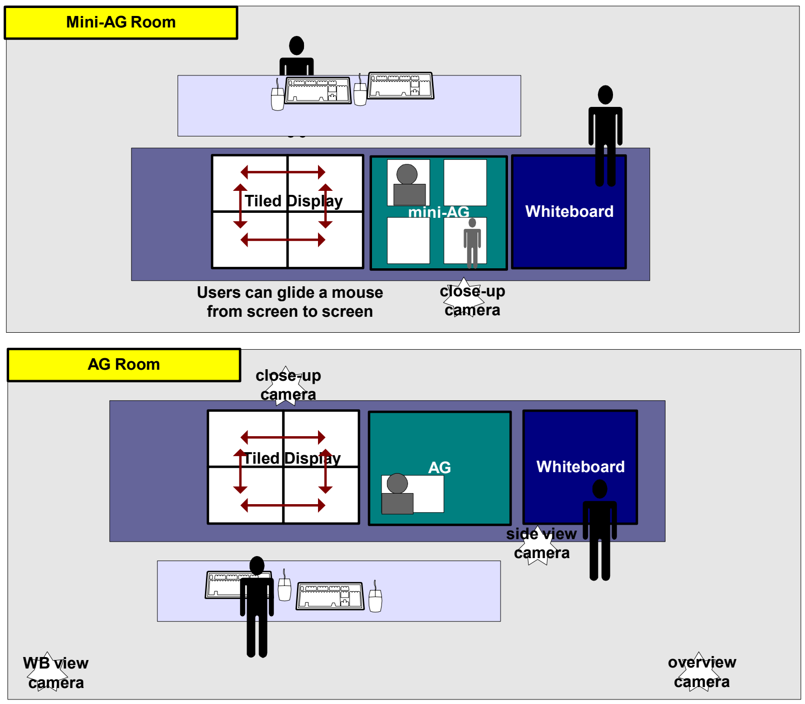


Figure 18. Diagram of system configurations in the first design study

5.2.1 System Configurations

In the first design study (Figure 18), the display setting was replicated as much as possible in both sites which included: the shared LCD tiled display in a 2x2 layout on the left wall, an AG plasma display in the middle with four cameras and two microphones in full AG setting and one camera and one microphone in mini-AG setting, the shared touch-screen whiteboard on the right, four pairs of keyboards and mice with 1 input control pair for each user, and SpaceGlider running on four laptop computers.

SpaceGlider was used to allow users to move their mice across the boundary of the tiled display. The arrow indicates the pointer transition path between tiled displays. The full-sized keyboard and mouse was used rather than a laptop computer to force the participants to look at the tiled display. This was done because one of the study goals was to see if the shared tiled display would help group awareness between distributed participants by allowing them to casually glance over at others' work. The shared touch-screen whiteboard between rooms was connected using the NetMeeting shared whiteboard application. The projection display was not provided in this study because it was underutilized in the pilot study.

The full-AG setting had four cameras and two microphones. The four cameras were located in various positions in the room. The ceiling-mounted camera in back of the room captured the overall view of room display layout and participants. The camera on top of the tiled display captured the collaborators at a close-up view. The camera in front of the SmartBoard™ table captured the tiled display and the side view of the full-AG room participants. The camera on top a shelf next to AG node operator captured the close-up view of the whiteboard area.

The mini-AG setting had one camera located at the corner of the AG display on the table that captured participants from the side. One microphone was located next to the camera. The camera position in the mini-AG setting was changed to face the collaborators more closely for Group 2 because Group 1 participants wanted to see the collaborator's face view rather than the tiled display.

5.2.2 Observations

5.2.2.1 Group versus personal workspace

This configuration of the tiled display offered users one shared group workspace which also allowed multiple users' simultaneous input controls over this group workspace. This affordance allowed group members to share information over the tiled display, and it also allowed them to work in different parts of the group workspace. SpaceGlider supported the ability users to navigate across four tile screens, but it did not support multiple input controls over the same tile screen – i.e. users had to share the mouse control on the same tile screen through a social turn taking protocol. In the pilot study, the group showed the ownership pattern over the distributed corkboard tiled display – for example, the group members grabbed a tile and owned it. This pattern seemed to reduce possible collisions between multiple users on the same screen.

In this study, the groups still showed the ownership pattern over the seamless distributed corkboard although the groups seemed to show slightly different perspectives. Group 1 participants wanted multiple simultaneous individual input controls over the tiled display. For example, they even wanted two members to be able to type in the different sections on the same tile screen. In addition, this group showed its use of the tiled display as partitioned group workspaces in the information analysis and pattern detection task – i.e. each tile screen was used for different purposes, such as the question page, the graph, and the raw data. On the other hand, Group 2 participants assigned individual or subgroup workspaces over the shared group workspaces, and each individual or subgroup owned them. This group disliked SpaceGlider's allowance of an individual's input control to take over another individual's workspaces without notification, and hence, suggested a locking mechanism to resolve this problem.

Group 2 wanted more tile screens and more whiteboards. This was partially because they had experienced conflicts over these displays, but it could be because the group wanted to share some information together. Interestingly, Group 2 participants sometimes looked for the question page from other's screen even though they divided the tiled display into individual workspaces, and they could access to the question page on each tile screen. This result indicated that the group shared common information, and this kind of information should always be visible so that all members could see it even though it was used once in a while.

The shared whiteboard conflict between remote sites came into sight in this study. This pattern involved two remote participants trying to access the shared whiteboard at the same time which resulted in conflicting each other's actions – for example, one tried to move to the next page while the other tried to write down notes. This problem was first observed in Group 2's information query and gathering. In this session, Group 2 showed the divided work pattern where the members divided task by assigning one question to one user and they worked mostly independently on their individual tile screens and combined their answers on the shared whiteboard. Unlike the pilot study group or Group 1 (where one or two members were responsible for whiteboard), all Group 2 participants walked up to the whiteboard to write down their findings as they gathered information. Therefore, the greater amount of whiteboard usages led this group to have the shared whiteboard conflicts.

NetMeeting connecting two touch-screen whiteboards did not seem to update the remote screen promptly and allow multiple simultaneous inputs from both sites. This problem occurred six times repeatedly (6 out of 31 whiteboard uses). Interestingly though, they did not seem to pay much attention to the remote collaborators over the AG video even after they had had this problem, and hence it took a while for them to figure out the problem. Obviously, this problem did not happen between two local collaborators.

5.2.2.2 Visibility

The distributed corkboard tiled display supported high visibility of all participants' work activities. The participants could see what the others were doing by glancing at each other's tile screens and thereby easily refer to the contents on the screens. Three of Group 1 participants reported that they shared searching strategies and built new strategies from those of other group members during the information query and gathering task. The methods of sharing strategies were mainly done through talking and by looking at the others' work over the tiled display.

Visibility was particularly important in group focused work. For example, Group 1 participants worked together to solve problems one after another most of the time during the information analysis and pattern detection task. In this session, one participant controlled graph manipulation on one tile screen, while the others added their insights into the analysis through informing variable selection and brushing, performing small hypothesis testing, and contributing in other ways to find the answers. The example below showed how distributed participants focused on a single item of interest over the visible shared tile screen.

User2 (in room1):	"Alright. Number 5?"
User3 (in room2):	"Now, we go to O column."
User4 (in room2):	"Yeah, only with O."
User2 (in room1):	*manipulating the graph*
User4 (in room2):	"Let's go up a little bit?"
User3 (in room2):	"Scroll up please?"
User4 (in room2):	"Up.. Up.."
User3 (in room2):	"Alright, so.. no.. no.. no.. no.." *pointing at the screen with his index finger and reading the graph for verifying the variables*

Later in this session, Group 1 used two to three tile screens for displaying multiple information items – for example, the upper-left screen for the question page, the upper-right screen for the graph, and the lower-left screen for another graph – and all members moved their focus together from one item to another. Group 1 used two tile screens for comparing two graphs side-by-side which involved one participant spitting from the group to investigate raw data for the sixth question, while the other three kept on working on the seventh question.

Visibility was less important in loosely coupled work. For example, Group 2 divided the task per individual by assigning one user to search for one university and then shared the findings over the whiteboard in the information query and gathering task. The participants worked independently most of the time and the interaction over the AG was limited to sharing task progress or asking some help, but this did not seem to need visibility. In the information analysis and pattern detection task, Group 2 divided the task per site by assigning one site to solve three to four problems. In this session, Group 2 divided the task and divided the workspaces by upper screens and lower screens. Then two local users worked together to solve the assigned problems. Similarly, the interaction over AG was limited to sharing task progress or clarifying some questions.

5.2.2.3 Awareness

Some participants benefited from using the tiled display to maintain group awareness. The group members seemed to use various channels to become aware of their partner's activities. In the post-test survey, the participants stated that they gained awareness by listening to discussion, asking what people were doing, looking at the AG video, and also looking at the tile screens. The frequency of casual glancing over at collaborator's work over the tiled display was distinguished by the groups. The post-test survey result showed more casual glancing over by Group 1 than Group 2. In the post-test survey of awareness in the scale of 1 to 5 (1=not at all, 2=a little aware, 3=somewhat aware, and 4=fairly aware, and 5=very aware), the average of awareness rated by Group 1 is 3.75 with the search task and 4.75 with the dataset task; and the average of awareness rated by Group2 is 4 with the search task and 3.75 with the dataset task. In the post-test survey of glancing in the scale of 1 to 4 (1=never, 2=rarely, 3=frequently, and 4=always and almost always), the average of glancing rated by Group 1 is 3 with the search task and 3.75 with the dataset analysis task; and the average of glancing rated by Group2 is 2.5 with the search task and 1.75 with the dataset task. The result also corresponded to the group behavior shown during the work sessions: Group 1 shared information by glancing other's work over the tiled display during individual searching whereas Group 2 shared more answers over the whiteboard. Group 1 participants reported that their casual glancing over at others' screen helped them understand how to change their search strategy during information query and gathering.

While the tiled display supported overall group awareness, the participants often checked task progress over the AG while they worked independently. That is 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 more frequently in the information query and gathering task than in the two other collaborative tasks. Group 1 seemed to have fully shared understanding on task progress since they worked together most of the time to solve problems one after another in the collaborative information analysis and pattern detection task.

In contrast, Group 2 clearly divided work at the beginning of the information analysis and pattern detection task. Two local pairs worked together concurrently in each room to solve assigned problems. As a result, the synchronization pattern was observed only three times when pairs in one room finished their work and reported that to the remote collaborators.

5.2.2.4 Privacy concerns

Mainly, Group 2 brought up privacy concerns for focusing on their own work. The group suggested a mechanism for providing private workspaces where collaborators needed to request permission to use the things owned by the other members. Group 2 was also concerned with the privacy of workspace visibility specifically for the case in which they did not want to share documents with others.

5.2.2.5 Seamless display

This technology configuration seemed to introduce users to feel more continuity of tiled display. For example, Group 1 participants even tried to move the windows (e.g. Netscape web browser) from one tile screen to another. There were three occasions of users' attempting to move their window between tile screens. The example below illustrated a Group 1 participant, User 3, trying to move a Netscape window to the remote collaborator's screen to assist her during information query and gathering.

User2 (in room1):	"I'm having a serious problem with number 1, you guys."
User3 (in room2):	"Oh, you are?"
User2 (in room1):	"Yes."
User3 (in room2):	"Here. You take this one here." *trying to move his window down to Janet's screen.*
User2 (in room2):	"Can I move this window or not?"
Technical Assistant (in room2):	"No."
User3 (in room2):	"Alright. Why don't you copy the URL here? Take it up."

This pattern was also observed during Group 2's information analysis and pattern detection. In addition, both groups suggested providing seamless display, such as moving windows across tile screens and whiteboard, in the collaborative brainstorming and design task.

While SpaceGlider gave users the illusion that the tiled display was one big continuous display, the participants had troubles identifying each individual's mouse pointer. They also had conflicts between multiple mouse pointers presented in the same screen which made the individual mouse identification more difficult. Sometimes, users accidentally moved the mouse pointer to the adjacent collaborator's screen, for example, when they tried to adjust the window size at the screen corner.

Group 1 had a severe problem with identifying their individual mouse pointers in the information query and gathering task. They had tackled this identification problem for about one third of task time in this session (10 minutes out of 30 minutes). Almost one third of the conversations over AG consisted of "Where is my mouse?", "Is this your mouse or my mouse?", "Ok. I got my mouse control. Which mouse is yours?", and "Where are you?" This ownership pattern in mouse controls and displays indicated a need to support *identification over group workspace*.

Group 2 also faced the mouse identification problem at the beginning of the information query and gathering task, but the problem was reduced by assigning each tile screen for each user. Instead, Group 2 had more troubles in losing the controls by accidentally entering their mouse into a collaborator's workspace. When this happened, they tended to immediately come back to their own tile screen.

For this problem, Group 1 suggested *multiple independent mouse pointers* to support simultaneous access to displays. Group 2 suggested a solution of providing *awareness tools* (i.e. distinguishable mouse pointers for indicating who owns a certain screen) and *locking mechanism* where another mouse could not enter the workspace owned by other members.

5.2.2.6 Data transfer between displays

It was clearly noticed that the Continuum needed to support data transfer between displays, such as a universal notepad to copy and paste texts or images and even programs. In the information query and gathering task, a Group 1 participant asked the remote collaborator to copy and paste URLs between their tile screens, but the only way to transfer this was through looking at the tiled display.

In this configuration, participants had to physically move between their tiles and the whiteboard to write down their findings on the whiteboard. This pattern led to change system configuration of the following design study to include SpaceGlider connecting between tile screens as well as the whiteboard.

Some participants showed read-and-write collaboration pattern, i.e. *the collaboration between two participants to transfer data between displays via voice channel.* That is, one person read texts (e.g. answers) from the tiled display while the other wrote down on the whiteboard or a paper. Both Group 1 and Group 2 showed one read-and-write collaboration pattern between local users during the information query and gathering task. Group 2 had shown seven additional read-and-write collaborations during the information analysis and pattern detection task.

The pen and paper was also used for data transfer between displays. For example, Group 2 participants wrote notes on scratch paper and then brought the paper with them to write down the final answers on the whiteboard.

5.2.2.7 Resolution, display size, proximity to display, and layout

The proximity to display is found to be an important factor in the design of display-rich environments. Those participants who were assigned to use the upper tile screens happened to stand up for the close investigation sometime during the task because the location of the upper tiles made them difficult to interact with. Group 1 showed this pattern during the information analysis and pattern detection task because they used the upper-right tile screen for manipulating a graph. Group 2 also demonstrated this pattern during the information search and gathering task, while two of them worked for searching in their upper tile screens. This is more problematic when the tiled display is scaled to a bigger size, such as PerspecTile (5x3 tiled displays). This result indicated the need for close-up view for the tiled display, such as laptop computer.

5.2.2.8 Communication

An immediate response from the groups was the improvement of mini-AG setting. In the pilot study a solo user in the mini-AG room mostly stayed in front of table next to the microphone whereas in this study participants talked to remote collaborators at various places in the room (e.g. next to whiteboard). In particular, Group 1 participants expressed communication difficulty and wanted more microphones and cameras in mini-AG setting to communicate better with remote collaborators. Few instances of dangling interaction, in which someone's questions were not answered or simply ignored, were observed in Group 1's collaborative work sessions. Group 1 also showed frequent numbers of repetitively asking the same question over the AG because the question was not answered.

On the other hand, Group 2 participants showed relatively few interactions over the AG – Group 2 showed much greater interactions between two local participants than between remote participants. Therefore, Group 2 participants did not need much audio support for their collaborative work sessions. In the information query and gathering task, discourses over the AG mainly occurred at the beginning of the task to divide the work, toward the end to combine their results to make a group decision, and occasionally, when they needed help from remote collaborators, such as to understand the questions or to get instruction of how to use XmdvTool during information analysis and pattern detection.

Nonetheless, both groups wanted remote control for other site's cameras although it was a low priority in the list of the Continuum design improvement ideas. The remote site camera control allowed users to directly control positioning remote site's cameras to their point of interest. This result indicated that the camera position and the angle were not properly arranged in this study. Due to the limited number of cameras in the mini-AG setting, the camera was placed in front of the AG screen to capture the side and upper torso view of the participants. The purpose of this design was to capture user's hand gestures and eye gaze over the tiled display to convey visual cues of which workspaces were being addressed by whom. However, the participants in the full-AG setting requested changing the remote camera position to address the collaborators' face more directly.

The participants were more concerned about the position and the angle of the remote cameras than the number of cameras. They stated that the remote collaborator's close-up face view was the most important one among four different camera views. In fact, the participants often gazed at the video windows when they discussed over the AG.

5.2.3 **User's Design Suggestions**

The groups generated a prioritized list of design ideas for the improvement of the Continuum design in the collaborative design and brainstorming task. Both groups spent about 20 minutes to discuss design improvements of the Continuum's software, hardware, and physical layouts. Table III shows the ideas that the first design study groups generated. Note that the asterisk (*) indicates the most critical points that the groups identified for the improvements.

TABLE IV

USER'S DESIGN SUGGESTION IN THE FIRST STUDY

		Group 1 (20 min)	Group 2 (20 min)
Video Conferencing	Audio	More microphones in the mini-AG setting*	
	Camera	More cameras for the mini-AG setting (to get cohesive feeling for the remote participant environment)*; Control for remote sites' cameras	Control for remote sites' cameras (zoom in and turn to the speaker to see the speaker's body language)
Tiled Display	Displays	Seamless display allowing moving windows from one screen to another	More tile screens for additional workspaces
	Controls	Mouse delay problem; Multiple simultaneous mouse controls for the tiled display; Should be no mouse control conflicts among multiple users	Mouse pointer delay when moving a mouse across one tile to another; Distinguished cursor for indicating different users
	Advanced Features	Touch-screen tiled display to convey gestures	
Whiteboard			Whiteboard sharing problem and a bigger screen (dividing into two parts so that two remote groups will not conflict)*
Data Transfer between Displays		Moving windows from one screen to another	Moving windows across the tile screens and other displays (such as whiteboard)
Physical Layouts		Semi-sphere display layout and interface	
Other issues			Display control panel for privacy and resource locking (such as an option to share or not with others visually or controllability)

5.3 Evaluation of Seamless Distributed Corkboard with Personal Displays and Enhanced Video Conferencing: The Second Design Study

The first study showed that users with SpaceGlider seemed to feel more continuity between the displays. The participants even attempted to move windows (e.g. Netscape web browser) from one screen to another. However, the first study also revealed design problems with SpaceGlider, all concerning mouse sharing and identification.

In the second design study, the system configuration was changed to improve the mini-AG settings and introduce Tablet PC for individual input control. In the mini-AG setting, one more microphone was added next to the whiteboard and the other was in front of the tiled display. Also, one more camera was added in the mini-AG room to capture the overview of room display layout, and a magnifying filter was put on the close-up collaborators' view camera to capture a wider field of view. Tablet PC supplanted a full-sized keyboard and mouse.

Two groups went through the same procedure as the first study. The questions given to the two groups were the same as the first study, but in reversed order.

5.3.1 System Configurations

In the second design study (Figure 19), an additional microphone and video camera were added to the mini-AG setting. Also, a magnifying filter was placed on the close-up camera to capture wide-angle field of view. SpaceGlider was modified so that it disabled the alt-tab key (for switching windows on a Microsoft Windows platform) and reduced

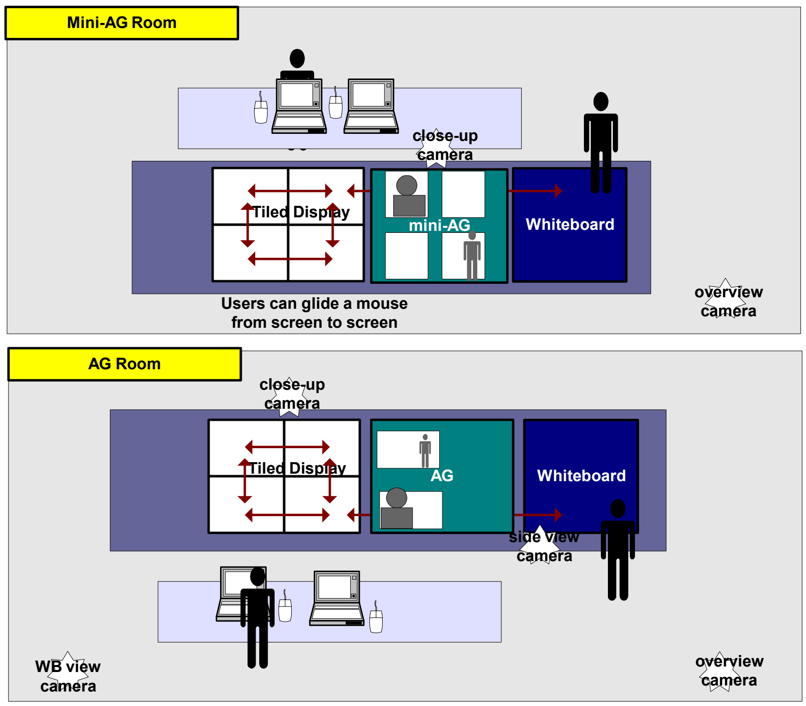


Figure 19. Diagram of system configurations in the second design study

the lag when a user moved a mouse across the boundary of the screens. In addition, SpaceGlider connected the 4-node tiled display screens and the whiteboard. Because of the mouse identification problem observed in the first study, 'Xeyes' and the bigger mouse cursor were added on each tile screen to encourage the easy identification of mouse pointers. A tablet PC was given to each user for the individual input control.

Group 3 participants were given Tablet PCs without screen echo, as a substitute for a regular keyboard and mouse. The reason for the disabling of screen echo on TabletPC was to force the participants to look at the shared tiled display so that it might encourage casual glancing over at others' work. The configuration of SpaceGlider in both rooms was the same, and SpaceGlider connected the lower right tile screen to the whiteboard.

The screen echo was enabled on Tablet PC for Group 4 participants where each Tablet PC mirrored one of the 4-node tiled displays because Group 3 participants wanted to look at the individual's Tablet PC screen, particularly those who used the upper tile screens. To reduce mouse conflicts on the lower right screen observed by Group 3, the configuration of SpaceGlider was changed to connect the upper right tile screen to the whiteboard in the mini-AG room and to connect the lower right tile screen to the whiteboard in the full-AG room.

5.3.2 Observations

5.3.2.1 Group versus personal workspace

The presence of a Tablet PC with screen echo seemed to encourage users to work more on Tablet PCs than on the tiled display. It was much more convenient for users to focus on doing their own work with close-up personal displays. A Tablet PC was used as an individual workspace for focus work whereas the tiled display was used as shared group workspace for group discussion. The tiled display was mainly used for remote collaboration.

Similar to the first design study, the participants looked at the question page once in a while. In the information analysis and pattern detection task, interestingly, Group 3 assigned the upper left tile screen for the question page so that all members could look at it at any time, and by doing that, one of the group members had to give up using a personal tile screen which made this person have to work with the co-located partner on the other tile screen. This result implied the need for more tile screens to make the persistent information visible for the group co-reference.

In the second design study, both groups showed mixed-focus collaboration work pattern (i.e. frequent transition between individual work and group work) and moderate amount of whiteboard usages during the collaborative work sessions. The groups had a couple of chances to use the whiteboard at the same time between remote sites but avoided a conflict by monitoring remote collaborators via the video and actively talking over the AG to decide the whiteboard turn taking.

Another interesting resource sharing pattern was observed over a tile screen during Group 4's information query and gathering. This happened while one member accessed the remote collaborator's screen on other person's tablet, to collect information from the collaborator's screen to transfer this information to the whiteboard. This did not create a mouse conflict as shown in Group 1 because the members agreed on sharing the screen prior to use. However, it created another source of frustration by making someone have to wait for the other person to finish using his screen because the system affordance only allowed one user to grab the mouse control on one screen at a time. This seemed to create a production blocking effect by allowing others to access to one's screen.

The following segments showed resource sharing pattern over the tile screen and the whiteboard intermingled together in five-minute conversation between Group 4 members during the information query and gathering task:

User1 and User2 (in room1):	*Showing read-and-write collaboration pattern – User1 read from User3's 'gedit' notes using User1's Tablet while User2 wrote down on the whiteboard.*
User3 (in room2):	"Can you get out of here (User3's screen)?"
User1 and User2 (in room1):	"No, Wait."
User1 (in room1):	"I'm going to copy.."
User2 (in room1):	"the link (URL link)."
User3 (in room2):	"the link."
User1 (in room1):	"the link.."
User2 (in room1):	"Did you finish, <User4>?" *asking if User2 could use the whiteboard*
User4 (in room2):	"Yes, I put the web site there (on the whiteboard)"
User1 (in room1):	"Ready, <User3>."
…	*Other conversations to discuss findings…*
User1 and User2 (in room1):	*Showing read-and-write collaboration pattern – User1 read User3's 'gedit' notes on User1's Tablet while User2 wrote URLs down on the whiteboard.*
User3	"Hey, can I use my window?" *asking if User3 could use his screen.*

5.3.2.2 <u>Visibility</u>

It was observed that visibility became more important as the groups showed increased interaction and collaboration between remote participants. Visibility was useful for remote instruction, and remote instruction would have been much easier if hand gestures over the tiled display were also transmitted to remote collaborator during the course of instruction. The example below illustrated how Group4 participant helped the remote collaborator start a 'gedit' text editor program. However, it was somewhat difficult to explain this remote instruction verbally, and it was easier when she gestured mouse over the window to indicate what she referred to:

User (in room2):	"You are writing in notepad?"
User (in room1):	".. Writing in gedit. Look here." *hand pointing at gedit icon*
User (in room2):	"What is it?"
User (in room1):	"That is below."
User (in room2):	"What is it?"
	…. long conversation to explain 'gedit'…
User (in room1):	"Not in the touch screen. In the tiled display. Here."
User (in room2):	"eeeh."
User (in room1):	"In the bottom right I have the window open. Look here." *moving her 'gedit' window on her screen (the lower right tile screen)*
User (in room2):	"Ahh."

In this study, the groups showed mixed focus collaboration where group members worked largely independently on their individual workspaces and then worked together from time to time on one of their individual workspaces. Visibility was useful for transition between individual work and group work because one of their individual works could become group focus work. There were a lot of "look at" or "see (my screen)" patterns to share information with group members (See Table XI). This pattern was more observed in this study partially due to the increased number of remote collaboration and interaction. The participants often asked the others to take a look at one of their screens to point at something on the screen during group discussion, and they also used this pattern to grab others' attention to show someone's finding so that it could lead to group discussion.

5.3.2.3 Awareness

The presence of Tablet PC with screen echo seemed to encourage users to work more on Tablet PCs than on the tiled display. The fact that the participants tended to work on personal displays for individual focus work seemed to result in reducing the number of casual glancing over at the other's work over the tiled display.

In the post-test survey, the participants indicated that they became aware of remote partner's activities by looking at the tiled display, talking, and looking at the video, whereas they got a sense of local partner's activities by talking and looking at the partner's tablet or the tiled display. Even though there were variations in the frequency of casual glancing over at remote collaborator's work over the tiled display, the overall result indicated the participants seemed to check the others' work once in a while.

Similar to the first design study, the groups often checked task progress via asking or informing the others of the status, i.e. asking the remote collaborators which question they were working on, or informed about what they had done and what they were going to do next. This pattern of synchronization occurred more frequently when the group showed the mixed-focus collaboration work pattern. Group3 participants divided task to search for one university per person, and they often informed others about their findings and search strategy or called out to look at the screen to discuss findings together with others.

In the post-test survey of awareness in the scale of 1 to 5 (1=not at all, 2=a little aware, 3=somewhat aware, and 4=fairly aware, and 5=very aware), the average of awareness rated by Group 3 is 3.6 with the search task and 4.75 with the dataset task; and the average of awareness rated by Group 4 is 3 with the search task and 4.25 with the dataset task. In the post-test survey of glancing in the scale of 1 to 4 (1=never, 2=rarely, 3=frequently, and 4=always and almost always), the average of glancing rated by Group 3 is 2.25 with the search task and 2.75 with the dataset analysis task; and the average of glancing rated by Group 4 is 3.25 with the search task and 2.25 with the dataset task. The result also corresponded to the group behavior shown during the work sessions: Group 1 shared information by glancing other's work over the tiled display during individual searching whereas Group 2 shared more answers over the whiteboard. Group 1 participants reported that their casual glancing over at others' screen helped them understand how to change their search strategy during information query and gathering.

5.3.2.4 Privacy concerns

While most of participants in the second design study stated no privacy concerns, one or two users from each group said they wanted to work privately. The main reason for that was to focus on assigned individual work.

5.3.2.5 Seamless display

Similar to the first design study, the groups also wanted to move windows from one screen to another. However, with SpaceGlider connecting the tiled display and the whiteboard, both groups said they felt no continuity of the workspace because of the location of the AG plasma display. The groups suggested swapping the location of the tiled display and the AG display, to make more continuity of the displays when moving a mouse across the displays (between the tile display and the whiteboard).

Similar to the first design study, the groups also had mouse sharing and identification problems due to SpaceGlider, but the number of group discussion regarding mouse sharing problems was reduced to at most two times. Both groups stated that SpaceGlider was intrusive due to blocking one's work by accidental mouse conflicts. For example, when they maximized or moved windows on their individual tile screens, by mistake they were entered in a neighbor's screen. The average total number of SpaceGliding was occurred 22 times in the first design study and 64.25 times in the second design study

With SpaceGlider connecting the tiled display and the whiteboard, the participants moved a mouse across the tiles to go to the whiteboard rather than physically moving to the whiteboard. This, however, created another problem – i.e. the participants had to pass collaborator's workspaces that disturbed collaborators. Group 3 was more problematic because the system was configured to the whiteboard connected only through the lower right tile screen. Group 3 participant's attempts to move a mouse across the tiles to go to the whiteboard and back to their own screens resulted in mouse conflicts at the lower right tile screen. For this accidental intrusion problem, Group 3 suggested a blocking mechanism to prevent others from entering the screen already taken by someone.

Group 3 also brought up screen identification issue. They suggested using different colored or name-tagged mouse controls for easy identification of individual mouse pointers, and they also suggested providing indicators showing who was using which display for easy identification of individual's workspace.

5.3.2.6 Data transfer between displays

The groups expressed a strong desire to copy-and-paste texts between displays during information query and gathering, especially to transfer URL links from the tile to the whiteboard. Group 3 suggested the use of text chat to share URL links between tile screens. Also, Group 3 used a web browser on the touch-screen machine to copy and paste texts directly from the browser to the shared whiteboard. In Group 4's information query and gathering, two remote users tried to copy and paste links and notes from a tile screen to the whiteboard, but the only way to do this was through looking at the tiled display or read-and-write collaboration.

The groups showed greater number of read-and-write collaboration between local users. Interestingly, the groups also showed read-and-write collaboration over the AG between remote users. Group 3 showed four read-and-write collaborations between local users during information query and gathering and four read-and-write collaborations between local users during information analysis and pattern detection where the group showed mixed-focus collaboration. Group 3 also showed two read-and-write collaborations between remote users during information analysis and pattern detection. Group 4 showed five read-and-write collaborations between local users during information query and gathering.

Similar to Group 2 using pen/paper to move data between displays, Group 4 used the tablet to move to the whiteboard, than physically moved between the tiled display and the whiteboard. A participant took a tablet to the whiteboard to help transfer ‘gedit’ notes from the tiled display to the whiteboard. She moved her mouse to different tile screens to bring up ‘gedit’ notes on her tablet and to read ‘gedit’ notes to her collaborator so that her collaborator could write them on the whiteboard.

5.3.2.7 Resolution, display size, proximity to display, and layout

Group 3 participants (those who used the upper tile screens) stated that the tiled display was not at their eye level, and hence, they had to stand up in order to interact with upper tile screens. Group 3 participants wanted to have screen echo on the Tablet PC that mirrored one of the tiles onto their tablet screens, because their immediate tendency was to interact with their tablet screens rather than the tiled display. This proximity to display problem was also observed with the groups in the first design study. Therefore, the screen echo was enabled on Tablet PC for Group 4 where each Tablet PC mirrored one of the 4-node tiled displays.

This screen echo on the Tablet PCs helped resolve proximity to display issue but raised size problem. Group 4 participants raised the issue of distance between the user and the displays. They thought perhaps farther away from the tiled display would help them focus on monitoring all the displays, but the fonts had to be big enough to read at a distance. Group 4 also suggested maximizing the window to fill all screens of the tiled display to help their group discussion. Their comment was that it was too difficult to see the patterns on a small screen when they all worked together in solving one particular problem in the information analysis and pattern detection task.

By connecting SpaceGlider to the whiteboard, the participants tended to write texts on the shared whiteboard using Tablet's pen or keyboard rather than physically move to whiteboard. But, the default text which appeared on the whiteboard was observed to be too small to read at a distance.

5.3.2.8 Communication

The additional camera and microphone in the mini-AG setting seemed to help increase remote interaction. It could be possibly due to group characteristics, but both groups showed a lot of group discussion over the AG with no hindrance and more overhearing patterns than the groups in the first design study. The read and write collaboration (for moving data between displays) was also observed between two distributed participants over the AG.

Interestingly though, both groups suggested reducing the video sources to mainly the collaborator's face view. However, it was observed that the participants used the whiteboard view or the overall view to identify or resolve the shared whiteboard conflicts (one or two times). For example, the participant who intended to use the whiteboard first checked video to see if it was occupied and used the whiteboard if no one was using it. Both groups pointed out that it would be useful to remove a video of the remote tiled display view, which this camera was often blocked by the person using the whiteboard.

Group 3 had audio problems toward the end of the information query and gathering task, and they tried to resolve this problem by using text chat. For about one third of task time (17 minutes out of 55 minutes), they tried to communicate with remote collaborators by using various text chat media, such as MSN messenger on their Tablet PCs, "vi" text editor, or "talk" program on a UNIX terminal on the tiled display, and even writing notes on the shared whiteboard. This audio problem was not easily solved by adopting text communication, and as a result, the session ceased after some trouble shootings.

5.3.3 User's Design Suggestions

Group 3 performed 35-minute and Group 4 performed 55-minute of generating prioritized design ideas for the improvement of the Continuum design in the collaborative design and brainstorming task. The table shows the ideas that the groups generated. Note that the asterisk (*) indicates the most critical points that the groups identified for the improvements.

TABLE V

USER'S DESIGN SUGGESTION IN THE SECOND STUDY

		Group 3 (35 min)	Group 4 (55 min)
Video Conferencing	Audio	Audio should work*	
	Camera	Reduce video sources	Video overload (a video of the remote tiled display doesn't help; just a video of the collaborators is fine)
Tiled Display	Displays	Indicator for who is using which display; Locking workspaces	Personal vs. Public space (some sections are for personal and group work)
	Controls	SpaceGlider is too slow; Different color pointers for mouse identification; Direct access to a screen; Mouse pointer is too big	SpaceGlider is too slow, not too stable, crashes too often
	Other features	Tiled display is not at my eye level	Distance between user and displays (farther away from the tiled display would help to focus on the whole setup, but with bigger font)
Tablet PC		TabletPC are too slow; Training about TabletPC; Use TabletPC to look at the whiteboard contents (by screen updates on Tablet)	Difficult to concentrate on something, overwhelming amount of information in the periphery. Select subset of the displays users need.
Data Transfer between Displays		Need a chat tool	Integration (copy and paste between displays); Cannot drag a window from one display to another
Physical Layouts		Change layout –move tiled display next to whiteboard; Have semi-circular table	AG display between whiteboard display and tiled display – don't feel continuity of space*
Other issues			Linux is uncomfortable for Windows users. Change the tiled display platform to whiteboard OS.

5.4 Evaluation of Discrete Flexible Shared Tiled Display with Personal Displays and Physical Layout Changes: The Third Design Study

In the third design study, the system was configured to support the flexible shared tiled display for easy transition between individual work and group work. It allowed a user to click on the full-screen option icon on a tile screen to maximize the screen over the entire tiled display. The tiled display, by default, showed four individual screens (i.e. the full screen option is off), and distinct background colors were allotted to these screens for easy identification of individual workspace. Each Tablet PC (for each user) also showed one of the tiled display screens. In addition, Switcher was provided for users to access the tiled display. Two groups formed from the first and second study participants and performed the same set of collaborative tasks but different question sets.

5.4.1 System Configurations

In the third study (Figure 20), the tiled display was modified to allow the group 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 allow his/her workspace to be maximized over the entire tiled display) at any time. This flexible tiled display was implemented by using Aura (Renambot and Schaaf, 2002; Schaaf et al., 2002). Each tiled screen had a distinct background color to help users identify individual's workspace.

Since SpaceGlider presented the same mouse sharing problems in the second study, Switcher was provided to the participants in the third design study. Switcher allowed

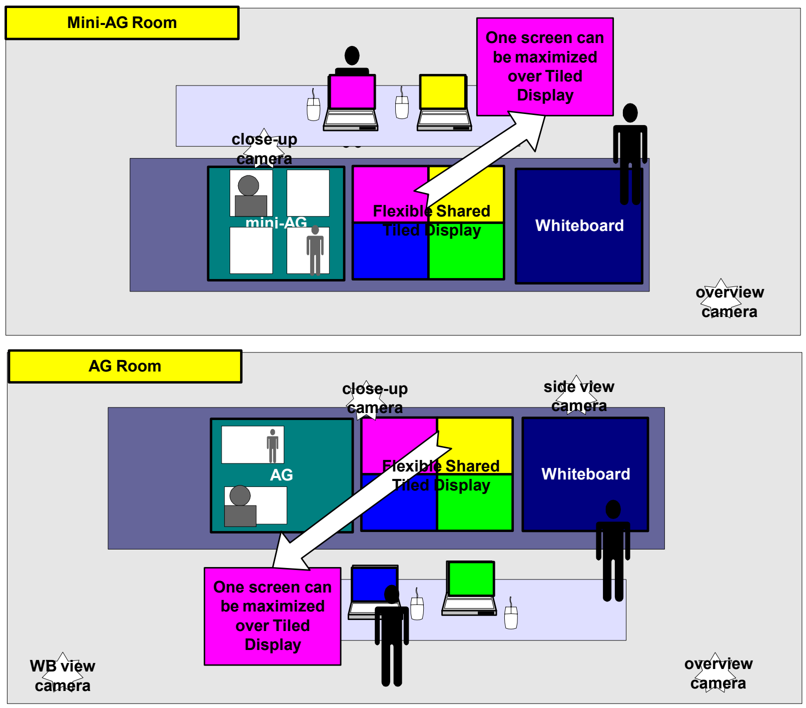


Figure 20. Diagram of system configurations in the third design study

users to jump to any of the tiled display and the whiteboard. The display layout was also changed to swap the location of AG display and the tiled display so that the tiled display was centered and next to the whiteboard.

5.4.2 Observations

5.4.2.1 Group versus personal workspace

Similar to the second design study, Tablet PC was used as individual workspace and the tiled display was used as group shared workspace. The full screen was provided to support easy transition between individual work and group work. In fact, it was used for group discussion, such as presenting one's finding during Group 6's information query and gathering. In this session, all Group 6 participants tried to read texts and trends in the graphs from one individual's finding presented on the full screen tiled display.

The full screen was also used for personal uses, such as to make the scatter plot graph bigger during Group 6's information analysis and pattern detection. However, this full screen tiled display for personal use did not interfere with other member's work since other members could still work on their Tablet PCs. The groups indicated that the full screen was useful for grabbing the other's attention. Group 5 did not use the full screen option mainly due to the thick border of the tiled display.

The typical pattern of technology usage was that the group members first assigned their individual workspaces onto their Tablet PCs and used them. Then, they shared their individual workspace with collaborators when it was needed. For example, three of Group 6 participants used one individual workspace together to solve her problem.

A more recurring pattern observed in this study was that the participants looked for the question page sometime during the task and asked for posting the question where it could be visible all the time. This evidence clearly shows the need for more workspaces to post persistent information visible on one of the tile for group co-reference.

As compared to the first and second design study, the groups showed increased amount of whiteboard usages overall. In the information query and gathering, Group 5 showed work pattern similar to Group 2, and the group had one conflict over the shared whiteboard between remote sites because of large amount of attempts to use the whiteboard by all members but less attention to the remote collaborators at first. However, after this conflict, the group quickly adopted to use the AG video to monitor remote collaborators and actively spoke plans out loud to get a turn to use the whiteboard. Due to this fact, Group 5 involved the largest amount of conversations to resolve the whiteboard turn taking, as compared to the groups in the first and second design study.

In the information analysis and pattern detection task, Group 5 also had another conflict over the whiteboard even though the amount of whiteboard use was moderate. This also happened because they did not pay much attention to the actions of the remote collaborators in the video. Group 6 showed a moderate amount of whiteboard use in the collaborative work sessions and had no conflict over the whiteboard because the group used the AG video to monitor the remote collaborators and announced turn taking for the whiteboard to group members.

Group 6 who used the full screen option also showed the resource sharing pattern over the full screen tiled display because the full screen tiled display had to be shared by all group members. It was observed that one of Group 6 members announced to the others the reserving of the full screen tiled display for data transfer between the tiled display and the whiteboard during information query and gathering.

Also, another interesting resource sharing pattern was observed by two local users' sharing one of their tile screens during Group 6's information analysis and gathering. This happened because they worked cooperatively on the same tile screen to solve problems together.

5.4.2.2 Visibility

Similar to the second design study, the groups had a large number of interaction and collaboration between remote participants. Visibility was important since remote collaboration was mediated over the tiled display. It was shown that visibility was useful for remote instruction or grabbing attention in order to bring people into group discussion in the first and the second design study. Visibility also helped implicit peer learning by allowing people to observe how others tackled on the same problem. It supported the immediacy to access to information and experts. For example, useful information or answers could be found from a collaborator's work and one's difficulty could be seen by remote collaborators. The participants commented that they did not pay much attention to the tiled display but it was helpful to have information visible all the time.

5.4.2.3 Awareness

Similar to the second design study, the participants worked mostly on their personal displays and occasionally checked the tiled display to see others' activities. Both groups commented that they looked at other's screens occasionally, but it was helpful, because, when they needed to work together, they could refer to ‘look at’ the particular screen or maximize the screen so all of them could see and discuss.

Similar to the first and the second design study, the groups checked task progress by asking or informing the others of the status – for example, group members asked for who was working on which problems, or which questions were answered, etc.

5.4.2.4 **Privacy concerns**

Group 6 brought up the need for providing private workspaces for long-term use of the Continuum spaces as a war room. The purpose of private workspaces was mainly for personal task, such as email, since it was something that users do not want to show to others. In general, the participants appreciated having a highly visible distributed corkboard for sharing information for the collaborative work. This also implies, for a short-term scheduled distance meeting, it may be undesirable to provide private workspaces which allow users to do personal task.

5.4.2.5 **Discrete display**

In this study, the tiled display was provided as discrete display using Switcher and multiple background colored individual workspaces. This change was made because of collisions by multiple users over the tiled display when it was provided as a seamless display using SpaceGlider and a single background color in the first and the second 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 hence the participants felt this was less intrusive mouse control. In general, the participants grabbed one tile screen onto their personal displays to do individual work while they kept monitoring one another's work over the tiled display.

Both groups preferred Switcher to SpaceGlider because of the responsiveness to the user's action for a display – i.e. when users hit the key, they are there instead of rolling a mouse. Switcher was also limited to one individual workspace and did not allow users to move a mouse to the next workspace accidentally. The participants stated that they remembered the key and the screen so that there was little accidental mouse entering to others' screen. Also, they immediately knew even if they pressed the key accidentally to enter other's workspace. This happened only one or two times during the collaborative work sessions.

Interestingly, with Switcher, Group 6 showed cooperative mouse sharing pattern to help the collaborator more directly by accessing the collaborator's workspace or to work together on the same workspace. There were two occasions of cooperative mouse sharing for remote help and two occasions for working together during information analysis and pattern detection.

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.

5.4.2.6 Data transfer between displays

As a result of providing the discrete tiled display, the desire to move the window from one display to another pattern disappeared. But, there were still requests for copy and paste during information query and gathering – three copy and paste requests from Group 5 and one request from Group 6. This request happened particularly when a participant tried to move fairly large texts from his/her workspace to the whiteboard.

The read-and-write collaboration between local users and between remote users was still observed. Group 5 showed three read-and-write collaborations between local users during information query and gathering when the group worked mixed-focus collaboration, and three read-and-write collaborations between remote users during information analysis and pattern detection where the group members worked tightly together. Group 6 showed two read-and-write collaborations between local users during information analysis and pattern detection where the group showed mixed-focus collaboration, and two read-and-write collaborations between remote users during information query and gathering when the group showed loosely coupled divided work pattern between sites.

5.4.2.7 Resolution, display size, proximity to display, and layout

To address size problem by introducing personal displays in the second design study, the flexible tiled display was provided so that it allowed users to maximize one individual workspace into the entire tiled display to help everyone read text or graph easily. Indeed, Group 6 used this full screen option for group discussion where all members worked together to verify one individual's finding during information query and gathering. The group also used this option for personal use (and subgroup discussion) during information analysis and pattern detection, such as to make a bigger scatter plot graph to see the patterns easier. Group 6 found this full screen option useful because sometimes the image on the tiled display was not big enough.

Aside from copy and paste, trying to get the displays close together seemed to help a user move data between displays. With the changed display layout, the participants also stated that it was easier to move data than the previous display layout when they read texts from the tiled display to write on the whiteboard.

5.4.2.8 Communication

Similar to the second design study, it was observed that group members were involved in frequent group discussions over the AG during information query and gathering. In addition, the groups showed the increased number of read and write collaborations between remote participants as compared to the second design study – 2 read-and-write collaboration over AG (out of 18 total read-and-write collaboration) in the second design study and 5 read-and-write collaboration over AG (out of 10 total read-and-write collaboration) in the third design study. Moreover, the groups showed more casual interaction between distributed participants than the second study groups probably due to their familiarity with the technologies and tasks.

It was observed that both groups' participants used the video of whiteboard view to check if any remote participant already took control of the whiteboard. Group 5 showed a large amount of whiteboard use by all participants which was similar to that of Group 2, but, after a conflict over the whiteboard between remote participants, unlike Group 2, Group 5 participants quickly adopted using the video of whiteboard view to reduce further possible conflicts. Group 6 showed a moderate amount of whiteboard use and sorted out possible whiteboard conflicts by checking the AG video windows and by talking over the AG.

The participants simply preferred to speak out loud to announce their intentions prior to using the whiteboard or their status of being done using the whiteboard. These actions helped resolve possible conflicts, but they were burdensome. This result indicates that there is a need to provide awareness tools to help ease the burden of turn taking within the group over shared resources.

5.4.3 User's Design Suggestions

The groups performed about 30 minutes of generating prioritized design ideas of suggestion to the future user of the Continuum technologies in the collaborative design and brainstorming task. The table shows the ideas that the groups generated. Note that the asterisk (*) indicates the most important item that future users should know.

TABLE VI

USER'S DESIGN SUGGESTION IN THE THIRD STUDY

	Group 5 (25 min)	Group 6 (30 min)
Video Conferencing		Use of audio/video to get aware of remote users
Content Sharing	Useful for sharing applications, viewing images, and zooming into details on a display; Not useful with viewing text; Saves time in debugging and testing applications; Useful for comparing data, images or presentations; Providing a way to keep track of ideas and changes in content	Requires introduction on how to start features such as the remote input control for the displays*; Allows the sharing of a unified desktop as well as dividing the tiled display using icons on the task base; All shared information like the question page and results should go onto the whiteboard display; Ability to reactivate a window or whiteboard after someone has used it; Use the menu to access tasks
Data Transfer between Displays	Integrated workspaces	Moving windows across the tile screens and whiteboard
Applications	Useful for people located in different places who need real-time application interaction*; Improves interpersonal relationships; Beneficial for collaborate networked game playing involving the discussion of strategies in real-time	
Other issues	Practice is the key; Long-term use needed to become familiar with technologies	Divide tasks

5.5 Evaluation of Presentation-model Shared Display with Personal Displays: The Fourth Design Study

The fourth design study was intended to evaluate how a user's awareness of their remote collaborator's work factored into their combined problem solving abilities. The system was configured to embrace the "presentation-model" display. This model provided more private workspaces (information on individual workspace is not visible by default) but allowed users to make their individual workspace public on the tiled display so that everyone in the meeting room could share it. This model supported only one individual workspace to be shared at a certain time on the tiled display. Two groups performed the same set of collaborative tasks with different questions. The system configuration adopted the Presentation model (pushing a private display to the public) thereby selectively showing one individual's workspace at a time.

5.5.1 System Configurations

With this configuration (Figure 21), the group members were assigned to their individual workspace on their tablet PCs, and one could choose to click on a "show" button on his/her workspace to make it appear on the tiled display so that all members could see it. They could show their workspaces on the tiled display as either one large screen (full-screen) or four identical small screens. They also had an option to "hide" their workspace in case they did not want to show it to others. Individual workspaces had the same distinct background colors given as the third study. The group members were

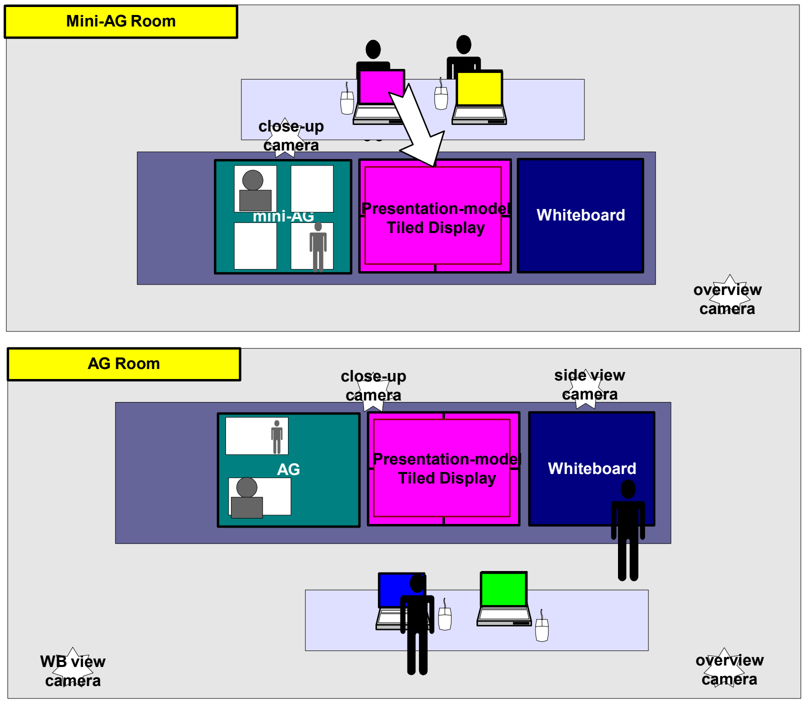


Figure 21. Diagram of system configurations in the fourth design study

only allowed to switch between their own personal workspace and the whiteboard on their tablet PC. The other settings were the same as the third study.

5.5.2 Observations

5.5.2.1 Group versus personal workspace

This presentation-model display provided users with more personal workspaces but allowed one's workspace to be publicly visible over the group shared tiled display. The presentation-model display was provided to support information visibility for group discussion. Thus, a Tablet PC was used as individual workspace, while the tiled display was used as a group workspace shared using turn taking. The pattern of looking for the question page over the tiled display was also observed in the fourth design study as it was shown in the previous studies. This clearly indicated the need for more public workspaces for group co-reference.

As compared to the previous design studies, the groups showed the decreased amount of whiteboard usages overall. In the information query and gathering task, Group 8 showed many attempts to use the whiteboard by using Switcher rather than physically moving to the whiteboard for note taking (25 totals by all members). The group had one conflict over the shared whiteboard between remote sites at the beginning of the task, and, after this conflict, the group members talked to each other for the whiteboard turn taking. Group 8 showed a little use of the whiteboard during information analysis and pattern detection, and overall Group 7 showed a little use of the whiteboard in the collaborative work sessions.

Interestingly, the resource sharing pattern was also observed over the tiled display because the group members had to share this presentation-model shared display by turn taking. The participants reported they tended to hide the screen on the tiled display after presenting information so that the others could use it. This result indicated that the hide screen option was used as a cue to indicate the release of using the presentation-model display. Another important comment from the participants was that they felt the tiled display was the common shared resource because they had to "request" information visible on this resource so that it made them feel as if they were using the shared resources like the whiteboard.

5.5.2.2 Visibility

The presentation-model shared display disallowed a user's casual glancing over at another's work but allowed personal information to be visible by displaying one's workspace to the tiled display so that the group could see it. In the second and the third design study, the participants tended to work mostly on their personal displays and called out to each other for group discussion when it was necessary, and they stated that they only looked at the tiled display once in a while. However, when visibility was reduced in the fourth design study, it was clearly observed the need to have information always visible for collaborative work.

Unlike the groups in the previous studies, the fourth design study groups showed the "show me" pattern. This pattern seemed to be due to less visibility. The "show me" pattern was an explicit request to make information visible – for example, one group member asked the other to show his/her workspace or another offered to show his/her own workspace in order to share information with other group members. This pattern was observed when one wanted to present something to others or to solve the problem together when someone had a problem.

Having had experience with the distributed corkboard, the participants really disliked to go back to classical Power Point Presentation model of collaboration. They wanted to see all of the information and compare to each other. The participants also said 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-model display. This request became a source of delay when the group wanted to share information. The immediacy of access to information seemed to help the group move between individual work and group discussion.

Moreover, the participants indicated that they accidentally found useful information from others' work. Therefore, they wanted information always visible on the tiled display because they did not know ahead of time what useful information would be there. The participants also indicated that they got ideas and learned from others, by observing what they were doing so that they did not even have to ask questions – such as, how to select all variables on XmdvTool during information analysis and pattern detection.

Furthermore, visibility seemed to encourage engagement. Some participants stated that they were more involved with two remote sites and more involved through the distributed corkboard because they could see what the others were doing and what they had done.

5.5.2.3 Awareness

This configuration provided users with more private workspaces that had the limited information sharing capability between group members. It only allowed one member's private workspace to be publicly visible over the tiled display. This configuration also did not allow users' casual glancing over at collaborator's workspaces due to the same constraint.

In fact, the groups tended to have limited interaction between remote participants. Group 7 showed divided work pattern and a large percentage of talking over the AG for task awareness (about 60% in the information query and gathering task; about 88% in the information analysis and pattern detection task). Group 8 showed pattern of working together in the information analysis and pattern detection task, and a fairly large amount of interaction over the AG in this session had shown task awareness or the "show me" pattern.

The participants commented that they did not look at the tiled display much in this study unless they were asked to present because only one individual's workspace was shown on the tiled display. They also commented that they were more aware of remote partners' work by overhearing their conversations.

5.5.2.4 Privacy concerns

The presentation-model display provided more private workspaces where information on personal displays was not visible unless users explicitly showed it to the others for sharing. The groups indicated that a laptop computer or a Tablet PC was enough, and it could be used for personal private task, such as email or instant messaging. In fact, the participants suggested all individual screens should always be shown on the tiled display as it was provided in the distributed corkboard setting unless they wanted to do personal task.

5.5.2.5 Discrete display

Similar to the third design study, the pattern of desire to move windows from one screen to another was not observed 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. However, there were some whiteboard conflicts and resolutions caused by multiple users trying to access the whiteboard on their personal displays. For example, in an extreme case, Group 8 had 25 instances of using the switching feature to access the whiteboard in the information query and gathering task.

Similar to the third design study groups, both groups liked Switcher better than SpaceGlider for the same reasons (i.e. responsiveness and no accidental intrusion), and they preferred SpaceGlider over Switcher if only one user used the tiled display.

5.5.2.6 Data transfer between displays

Similar to all previous studies, the groups still wanted the ability to copy and paste during the information query and gathering task. There were three copy and paste requests by Group 7 and five requests by Group 8. There was one occasion where Group

8 wanted a copy and paste feature between remote users to transfer a URL link, and it was somewhat cumbersome without a glancing capability. The number of read-and-write collaborations were reduced in comparison to all the previous studies and only occurred between local users. This seemed to relate with the decreased number of interactions over the AG.

Another interesting pattern for data transfer was that a Group 7 participant used the presentation-mode display to project his personal workspace and then switched to the whiteboard on his tablet in order to move the URL links from his personal workspace to the whiteboard.

5.5.2.7 Resolution, display size, proximity to display, and layout

Both groups wanted the distributed corkboard tiled display back during the collaborative work sessions so that they could see all of them and compare to each other. In general, the participants reported that this presentation-model tiled display was not useful, and the different background colors did not help them associate which color was indicating which user.

The presentation-model 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 in 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" and then "show you my screen".

Similar to the third design study, the participants liked layout changes where the location of the tiled display was moved next to the whiteboard, and it helped them move text from the tiled display to the whiteboard.

5.5.2.8 Communication

There was no particular audio and video problem that occurred in the fourth design study, but the groups tended to have less interaction over the AG. For example, the read-and-write collaboration over the AG disappeared. The participants indicated that less interaction over the AG was because of less visibility in this study. In the first or the second design study, they were able to see each other's work and talk to each other to ask questions and discuss something together; whereas in the fourth design study, they could only obtain information through overhearing comments.

5.5.3 User's Design Suggestions

The groups performed about 30 minutes of generating prioritized design ideas for the suggestion to future user of the Continuum technologies in the collaborative design and brainstorming task. The table shows the ideas that the groups generated. Note that the asterisk (*) indicates the most important item that future users should know.

TABLE VII

USER'S DESIGN SUGGESTION IN THE FOURTH STUDY

	Group 7 (30 min)	Group 8 (25 min)
Video Conferencing		Talking and discussion*; Pay attention to remote users by looking at remote user video windows
Content Sharing	Know remote control input keys*	Keep notes with the list of commands to prepare for time when something goes wrong
Data Transfer between Displays		Have a chat window (for instance, copy and paste URL links)
Applications	Useful for collaborative brainstorming design; Useful for software engineering code-walk through; Useful for playing games; Useful for presentation or remote administration	Use for design, tutorial tool, distance learning

5.6 Comparison of the Iterative Design Studies

In the first design study, the seamless tiled display using SpaceGlider was provided to create an illusion of one continuous tiled display in the first design study. This seemed to lead users to feel more continuity but caused conflicts for multiple users while the users were trying to move a mouse across the tile screens. Some users brought up privacy concerns due to losing control of their workspaces by collaborator's accidental mouse entering. Those users suggested a locking mechanism to prevent this. In addition, it was observed that the participants had difficulty in interacting with the upper tile screens because the screen was not located at their eye level. As a result of this proximity issue, tablet PCs were provided to the participants in the second design study. In addition, the participants wanted more microphone and cameras in the mini-AG setting to communicate better with remote collaborators. This issue came into sight in the first design study because two participants who were assigned in the mini-AG room tended to move freely in the room to interact with various displays.

In the second design study, additional camera and microphone in the mini-AG setting helped increase the number of casual interaction between remote participants – such as a large amount of conversations, more overhearing, and casual glancing over at the video to be aware of the status of remote participants – but, the participants did suggest reducing video sources. Mirroring of one tile screen to the portable personal display (Tablet PC in the second design study) provided users a close-up view of the tiled display. This resulted in reducing users' casual glancing over at the tiled display, since users worked mostly on the personal displays and used the tiled display mainly for remote collaboration.

In the third design study, discrete display using Switcher reduced collisions between multiple users on the tiled display. The flexible tiled display provided both shared individual workspaces and a group-focused workspace (in the bigger format). The full screen option was used for both group discussion and personal uses to make text/graph bigger. The full screen was used only once or twice, but the participants (those who used full screen) felt that it was very useful for group discussion or for grabbing group attention. Since users worked mostly on their personal displays, the full screen over the tiled display did not block individual's work.

In the fourth design study, users, having experienced the shared tiled display, really disliked going back to classical presentation model of collaboration. They wanted to see one another's work for implicit peer learning – i.e. awareness issue. They also wanted to display more data side-by-side on the tiled display for comparison – i.e. resolution issue. More importantly, group performance was degraded by the extra step required to show individual work to the group on the public presentation-model display.

5.6.1 Visibility and Controllability

In the first and the second design study, the seamless distributed corkboard provided public visibility and public controllability since it allowed users easily to move their mouse across any tile screens. However, this created many mouse conflicts among multiple users by allowing easy mouse movement to adjacent displays.

On the contrary, the discrete distributed corkboard helped preventing this problem since it did not allow accidental mouse entering to adjacent displays and no mouse moving across other displays to go to the destination display. This also helped multiple users effectively share group workspaces by social turn taking protocol, which was shown as the ownership pattern.

In the third design study, the discrete flexible display with personal displays provided public to mixed visibility and mixed controllability. The full screen option made visibility less public because only one's workspace is maximized over the entire tiled display which made others' workspaces became private (i.e. not visible). Since this full screen option had been used for group discussion or personal use for a short period of time, users did not lose much awareness context.

In the fourth design study, the presentation-model display with personal displays provided mixed to private visibility and private controllability. Personal displays provided private visibility and the presentation-model display provided mixed visibility where it allowed one's workspace (i.e. one's tablet) to become visible on the tiled display. In this model, control was not shared with others, and hence there were no mouse conflicts between multiple users. However, this model did not allow direct control of others' workspaces even if users needed – not often but sometimes users do.

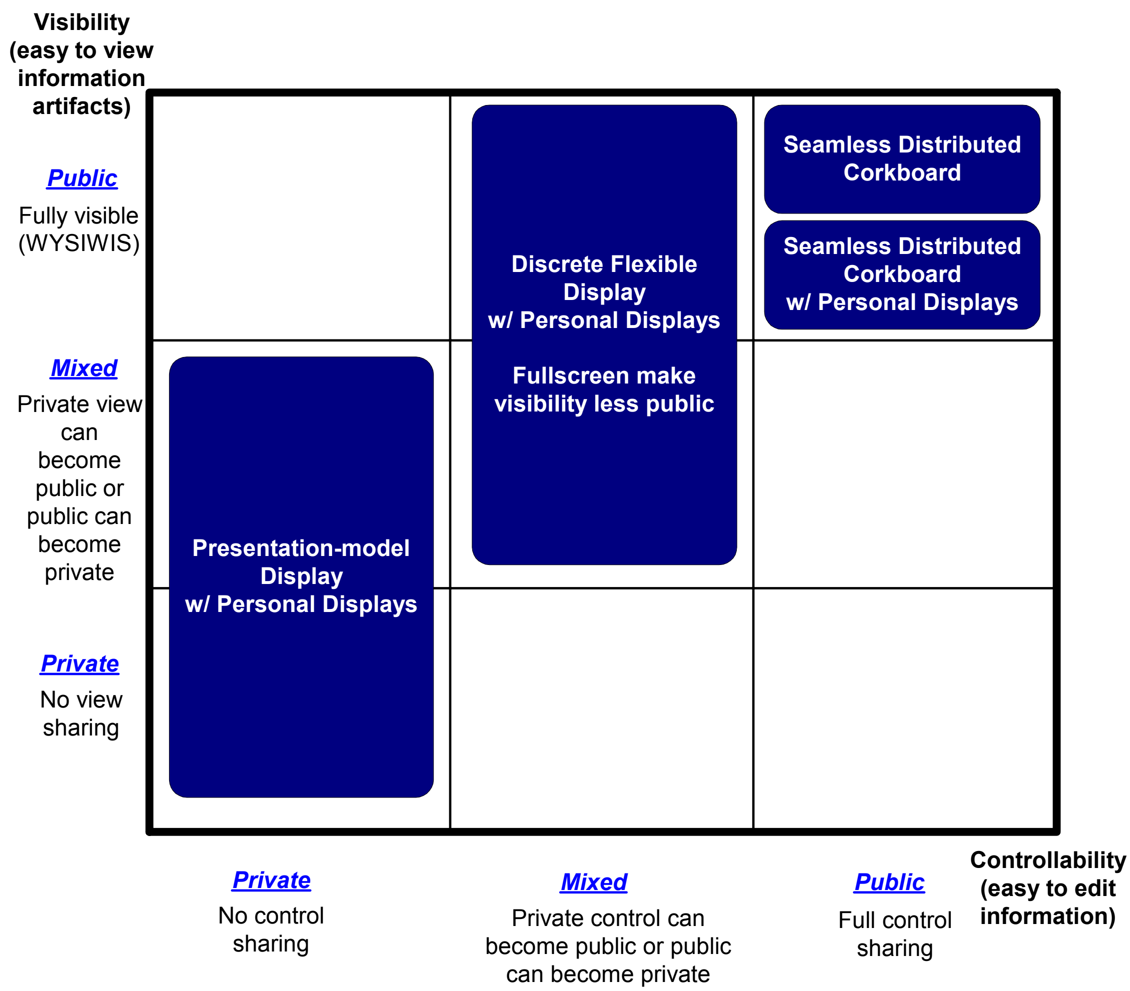


Figure 22. Diagram of the Continuum study shared workspace models

Figure 22 shows the diagram of the shared workspace models explored in the Continuum design study. The study results indicated that public controllability caused control sharing problem whereas private controllability may cause users' desire to control others' workspace more directly. On the other hand, mixed controllability helped effective control sharing over group workspaces while allowing direct control over all group workspaces.

This study also revealed that public visibility helped maintaining group awareness and enabling implicit peer learning by casual glancing. In addition, the presentation-model private to public visibility mechanism caused visibility problem by explicit request to show information, whereas the full screen public to private visibility mechanism did not create such problem since it was mainly used for group discussion where the group members all focused on the single item of interest. Private visibility was proven that it created visibility and awareness problem in the intense collaborative work since it did not allow casual glancing over at other's work.

5.6.2 Performance

As shown in Table VIII, the group performance was widely varied in the first and the second design study. Then, the overall group performance (in terms of completion time and work quality) improved in the third design study but declined in the fourth design study. Note that some groups did not perform task well due to technical difficulties. The group with the Cuba search question in the first design study had mouse sharing problems for about one third of their task completion time. The group with the University search question in the second design study had not reached the final group decision because the group had the AG audio problem for about one third of their task completion time.

5.6.3 Work Pattern

The overall work pattern was more clearly distinguished by group and task; indeed, the work pattern was quite similar from subjects' first participation (in the first and the second design study) to their second participation (in the third and the fourth design study). Table IX shows the overall group work pattern and Appendix K shows group work pattern in the percentage of individual work, discourse between local users, task related discourse between remote users, and technology related discourse between remote users.

In the information query and gathering task, most groups showed mixed-focus collaboration work pattern, where the group members worked largely independently on individual workspaces and shared their findings with the partners from time to time. For the Cuba search question, the group members often informed one another of the findings or asked for help to verify findings that led them to work together for group investigation. Interestingly, the group with the Cuba search question, in the fourth design study, did not share much information between remote participants. For the University search question, typically the groups divided work to search for information from one university per individual. Then, some group members called each other to look at their screens for group investigation. Some group members shared the answers on the whiteboard during independent searching and then discussed them together to reach the final decision of the department and the university researched. Interestingly, the group members with the

University search question in the fourth design study had difficulties in sharing information (such as findings) over the tiled display, and consequently they informed one another about findings, plans, and progress more actively than the other groups in the previous studies.

In the information analysis and pattern detection task, the groups showed one of the three different work patterns. Three groups showed the all members working together pattern where they solved the problems one after another. Three groups showed two local users working together pattern where the group members divided work by assigning three to four problems per each site and sharing the answers on the whiteboard. Two groups showed mixed-focus collaboration work pattern where the group members divided work, and then, from time to time all group members worked together to solve a problem.

5.6.4 Usage Pattern

Table X shows the technology usage pattern by the groups and the tasks. The group had more mouse conflicts between multiple users on the tiled display with SpaceGlider, which was used in the first and second design study, than with Switcher, which was used in the third design study. In the fourth design study, the participants did not have any mouse conflict since they were not allowed to move their mouse to other's workspace. The results also indicated that there were more mouse conflicts in the second design study than the first design study due to increased number of user's tendency to move their mouse between the tiled display and the whiteboard. The number of tile screens used the group was dependent on the task type and the group working style. All groups used all four tile screens during the information query and gathering task. The groups, however, showed different usage patterns over tile screens during the information analysis and pattern detection task. The groups who worked together typically used two to three screens whereas the groups who divided work typically divided workspaces and hence used four screens. The whiteboard conflicts were occurred between remote sites in relation to the amount of whiteboard used by multiple users.

TABLE VIII

TASK COMPLETION TIME AND WORK QUALITY

Task	Question	Study 1	Study 2	Study 3	Study 4
Information query and gathering	Cuba	(30 min)	(55 min)	(32 min)	(35 min)
		0 URL link	6 URL links	2 URL links	1 URL link
		1 (out of 12) sugar export quantity information collected	1 (out of 12) sugar export quantity information collected	7 (out of 12) sugar export quantity information collected	0 (out of 12) sugar export quantity information collected
		2 (out of 2) answers are correct	1 (out of 2) answer is correct	2 (out of 2) answer are correct	1 (out of 2) answer is correct
	University	(55 min)	(55 min)	(32 min)	(53 min)
		15 out of 20 requirement information collected	7 out of 20 requirement information collected	20 out of 20 requirement information collected	10 out of 20 requirement information collected
		UW, Seattle & Medical chemistry	No decision	UC, Berkeley & Agricultural and environment chemistry	No decision
Information analysis and pattern detection	Data2	(42 min)	(65 min)	(27 min)	(25 min)
		5 (out of 7) answers are correct	4 (out of 7) answers are correct	5 (out of 7) answers are correct	3 (out of 7) answers are correct
	Data1-1 & Data1-2	(40 min)	(55 min)	(30 min)	(35 min)
		6 (out of 7) answers are correct	5 (out of 7) answers are correct	5 (out of 7) answers are correct	3 (out of 7) answers are correct

TABLE IX

GROUP WORK PATTERN

Task	Question	Study 1	Study 2	Study 3	Study 4
Information query and gathering	Cuba	Mixed-focus work	Mixed-focus work	Mixed-focus work	Mixed-focus work
	University	Divided work and mixed-focus work	Divided work and mixed-focus work	Divided work and mixed-focus work	Divided work and mixed-focus work
Information analysis and pattern detection	Data2	All members tightly coupled work	Mixed-focus work	Divided work and two local users tightly coupled work	Divided work and two local users tightly coupled work
	Data1-1 & Data1-2	Divided work and two local users tightly coupled work	Mixed-focus work	All members tightly coupled work	All members tightly coupled work

TABLE X

TECHNOLOGY USAGE PATTERN

Task	Question	Study 1	Study 2	Study 3	Study 4
Information query and gathering	Cuba	18 mouse conflicts on tiles	27 mouse conflicts on tiles	2 multiple mice on tiles	0 mouse conflict on tiles
		4 tiles for individual searching	4 tiles for individual searching	4 tiles for individual searching	4 tiles for individual searching
		0 conflict on whiteboard	0 conflict on whiteboard	0 conflict on whiteboard	0 conflict on whiteboard
	University	9 mouse conflicts	22 mouse conflicts	0 multiple mice	0 mouse conflicts
		4 tiles for individual searching	4 tiles for individual searching	4 tiles for individual searching	4 tiles for individual searching
		6 conflict on whiteboard	0 conflict on whiteboard	1 conflict on whiteboard	0 conflict on whiteboard
Information analysis and pattern detection	Data2	7 mouse conflicts	24 mouse conflicts	4 multiple mice	0 mouse conflict
		1 to 3 tiles for group work	4 tiles for individual & subgroup work	4 tiles for 2 subgroup work	2-3 tiles for 2 subgroup work
		0 conflict on whiteboard	0 conflict on whiteboard	0 conflict on whiteboard	0 conflict on whiteboard
	Data1-1 & Data1-2	14 mouse conflicts	18 mouse conflicts	0 multiple mice	0 mouse conflict
		4 tiles for 2 subgroup work	3 tiles for 2 subgroup work and 1 tile used for question	2 to 4 tiles for group work	2 to 3 tiles for group work and one of them shared
		0 conflict on whiteboard	0 conflict on whiteboard	1 conflict on whiteboard	0 conflict on whiteboard

TABLE XI

LOOKAT AND SHOWME PATTERN

Task	Question	Study 1	Study 2	Study 3	Study 4
Information query and gathering	Cuba	2 lookat	9 lookat	3 lookat	4 lookat
		0 showme	0 showme	0 showme	3 showme
	University	4 lookat	5 lookat	3 lookat	9 lookat
		0 showme	0 showme	0 showme	4 showme
Information analysis and pattern detection	Data2	12 lookat	23 lookat	8 lookat	0 lookat
		0 showme	0 showme	0 showme	0 showme
	Data1-1 & Data1-2	1 lookat	15 lookat	5 lookat	1 lookat
		0 showme	0 showme	0 showme	11 showme

TABLE XII

KEY FEATURES OF THE DESIGN STUDY

	Pilot Study (Day 1)	Pilot Study (Day 2)	Study 1	Study 2	Study 3	Study 4
Shared workspace	Group	Group	Group	Mixed	Mixed	More personal workspace
Visibility	Public - by glancing	Public - by glancing	Public - by glancing	Public - by glancing	Less public - by full screen	More private - until presenting
Awareness	Casual glance	Casual glance	Casual glance	Less casual glance	Less casual glance	No casual glance
Moving control across displays	Discrete display - on tiled display	Discrete display - on tiled display	Seamless display - on tiled display	Seamless display - on tiled display & board	Discrete display - on tiled display & board	Discrete display - on tablet & board
Display resolution, size, proximity, and layout			2x2 tiled display	Close up display - tablet as close up personal display	Full screen tiled display; Layout changes	Reduced resolution - on tiled display

TABLE XIII

KEY OBSERVATIONS I

	Pilot Study (Day 1)	Pilot Study (Day 2)	Study 1	Study 2	Study 3	Study 4
Shared workspace	Tiled display for either group or individual work	Tiled display for personal work side by side	Tiled display for either group or individual work	Tiled display for group work & tablets for individual work	Fullscreen for attention & easy transition between individual and group work	Tiled display used for presenting personal workspace visible
Group co-reference			On tiled display	On tiled display	On tiled display	On tiled display
Ownership pattern	Over tiled display	Over tiled display			over tiled display	
Shared resource turn taking pattern	Over input control		Over board	Over a tile screen	Over board and fullscreen	Over presenta-tion model display
Visibility	Good for group focused work (e.g. multiple views side by side)		Good for group focused work; Less useful for group divided work	Good for mixed-focus work by allowing individual work to be group work	Full screen used for group discussion and attention	Not easily visible over this tiled display; Visibility problem due to less visibility
Awareness	Casual glance	More overhear	Casual glance is good for sharing searching strategies	Less casual glance due to users' tendency to look at tablet for individual work	Less casual glance due to users' tendency to look at tablet for individual work	No glancing; Looking tiled display only when presenting; More overhear

TABLE XIV

KEY OBSERVATIONS II

	Pilot Study (Day 1)	Pilot Study (Day 2)	Study 1	Study 2	Study 3	Study 4
Moving control and data across displays	Desire to move a mouse across displays		Users felt more continuity (Desire to move windows from one screen to another); Mouse sharing problem	Users felt more continuity (Desire to move windows from one screen to another); Mouse sharing problem; Increased mouse across the tiled display to board	No desire to move windows from one screen to another; Reduced collision between multiple users ; Peaceful mouse sharing on the same tile screen	No desire to move windows from one screen to another; No mouse conflict by preventing other users' access to personal display
Display resolution, size, proximity, and layout			Need close-up display for proximity to display issue	Close-up display helped proximity issue but raised size issue; Need to change display layout to support continuity (due to seamless display)	Fullscreen tiled display helped size issue; Layout changes (e.g. putting display closer together) helped data transfer	Presentation-model display caused a resolution problem (e.g. desire to display more data side by side)

6. DISCUSSION

This chapter will discuss some of important design issues raised in the iterative design studies.

6.1 <u>Communication</u>

6.1.1 <u>Audio</u>

In the study of war rooms, the researchers believed overhearing one another's conversations and watching one another's activities probably had a lot to do with the productivity gain. The same rule was applied to the Amplified Collaboration Environments. In fact, overhearing pattern was also frequently observed over the distance in this design study – when one member was explaining something to others, remote members could overhear and interject clarifications and corrections. In addition, it was observed that a collaborative work session was halted by audio failure which was not easily repaired by using other mediums such as text chat. Thus, it is necessary to provide sufficient quality of audio conferencing to capture all conversations in ACEs to support overhearing and easy communication over the distance – e.g. perhaps providing microphones next to all displays in ACEs.

6.1.2 <u>Video</u>

Most video conferencing systems provide only one or two views, typically showing collaborators' faces. Other approaches are head-mounted video systems that show views of worker's hands (i.e. camera focusing on active workspace) for collaborative physical tasks (Fussell et al., 2000). An Access Grid conference provides multiple simultaneous views of participants. Most AG nodes have typically four cameras and all cameras are displayed at all nodes participating in a conference. The research questions in ACE's video conferencing are: how many cameras are needed, how to position and angle the pan/tilt cameras, how to arrange multiple video windows on the display, and which video window sizes are affected to user interaction. The result of this design study implies that it is necessary to support one camera view for the participants' close-up view and additional views of shared resources for conveying participants' spatial references over these resources.

In this design study, the full-AG setting cameras captured the overall view of the room display layout and the spatiality of participants in the room, the participants' front and close-up face view, the tiled display area and the participants' side view at the tiled display and their hand gestures over the tiled display, and the close-up view of the whiteboard area. The mini-AG setting camera was, at first, located in front of the AG display and captured the participants' side and upper torso view. This was done in order to convey their hand gestures on the tiled display to the remote participants and to give visual cues of which workspaces were being addressed by whom. However, the immediate response from participants in full-AG setting was a request to change the remote camera position to address the collaborators' face more directly. After this, this camera was moved to the top of the AG display with a magnifying filter to capture the participants' close-up, wide-angle, upper-torso view; also, one additional camera was added in the mini-AG setting to capture the overview of the room display layout.

In fact, participants often gazed at the video image of the remote collaborator's close-up face view during the course of a discussion. This collaborator's face view helped them get some forms of deictic reference or small feedback signal (e.g. nodding, murmuring, or facial expressions from the listener). Thus, it is important to provide this remote collaborator view close to the meeting participants. More life-size video displays of remote collaborators would also encourage natural interaction. According to a study (Olson and Olson, 2000), the size of the video window affected to the interaction between remote participants, and the bigger size made them feel more comfortable.

It was observed that the participants used the whiteboard view or the overview to get attention of remote users to see if any remote user was using the whiteboard. In the first design study, one group had whiteboard conflicts six times repetitively and took longer to identify this problem because the full-AG setting did not provide the video of the whiteboard view and the participants in the mini-AG setting did not pay attention to the video of the whiteboard. After the first design study, the groups showed few whiteboard conflicts (even if there was a large amount of whiteboard usage), and the participants paid more attention to the video of the whiteboard view or the overview – for example, the participants checked this video to see if someone was already using the whiteboard.

Both groups in the second design study suggested removing the view of the tiled display area because this camera was located on the side of the whiteboard and often blocked by the body of person who used the whiteboard during the task. This camera was moved to the top of the whiteboard for the third and the fourth study. Another important user comment from the third and the fourth design study was that each member used one or two video sources, but, the group as a whole used all the video sources.

Even though the participants used various video sources for resolving shared resources sharing, the participants simply preferred to speak out loud about plan or status for using the whiteboard, such as “I’m going to use the whiteboard” or “I’m done using whiteboard”. This kind of discourse was observed largely in this design study. This implies a need to develop the group awareness tool for the shared resources (such as indicator for someone’s using the whiteboard) to reduce the number of possible conflicts over the shared resources and to increase the task-oriented interaction over AG.

6.2 Shared Workspace

6.2.1 Public versus Private

Public displays provided information visible to all group members and enhanced group awareness but no privacy. This design study found that the groups benefited from the ability to see all members’ work over the public tiled display. Indeed, the fully visible public tiled display helped the groups to perform collaborative work much better than those with the presentation-model display.

The mechanism of private information becoming visible on the public display caused visibility problem as was shown in the fourth design study. With the presentation-model display, users had to explicitly show information from the private personal displays to the public group display. This visibility problem was also discussed in the CoLab and Cognoter study (Tartar et al., 1991). In Cognoter, users had to create “item (such as text)” in private item-creation windows, and then present and organize items in public WYSIWIS item-organization windows. This mechanism caused visibility problem – i.e. the important data was not visible to users when they needed it.

With observations of group work in this design study, it is believed that persistent information should always be visible on the public group workspaces for group co-reference. Throughout the iterative design studies, the groups showed the pattern of looking for the question page over the tiled display, even though each group member could access the question page on each tile screen. This pattern was observed once in a while, but the groups usually asked for posting the question page on one of the tile screens, somewhat where it was visible. One group even assigned the upper left tile for the question page so that all members could refer to it at any time. Moreover, the groups with the presentation-model display requested “show me” to see the question page. This result indicates that it is necessary to provide more group shared workspaces to post persistent information for group co-reference.

6.2.2 Group versus Personal

Personal displays are usually available and visible only to one person. Examples are paper and portable personal computers (such as laptop, tablet or PDAs). Some public group displays, such as overhead projector, are used only for displaying information so that it is visible to all people present in the room. Whiteboards and flipcharts serve as public group displays and offer easy to use interfaces. They are large surfaces visible to all people in the room, not just the person who writes or draws. More recently, electronic whiteboards allow users to interact with information on these displays directly using a hand or a pen input device. However, electronic whiteboards have low resolution (only small amount of information can be presented on the screen) and do not allow simultaneous inputs by multiple users.

At first, the tiled display was provided as public group displays and the users sat closer to the displays to interact with them. However, it was found that there was a need to provide personal displays due to the proximity to display issue. This proximity issue is a problem when users interact with the very high resolution tiled display, such as PerspecTile (5x3 tiled displays) – it is much more difficult for users to interact with all screens in the very high resolution tiled display because it is hard to read. By mirroring tiles onto personal displays, it was more convenient for users to focus on their own work. However, the tiled display still served as public group displays for the purpose of viewing all information at a glance, and it was also used for remote collaboration. This result indicates that personal displays are needed for users to easily interact with information while public group displays are needed for users to maintain overview of all information flows.

6.2.3 Multi-users Interaction

The ownership pattern was defined as group members grabbed individual workspaces over the group shared workspaces and owned them. This pattern also indicated that there was no control sharing over individual workspaces. The distributed corkboard tiled display, offered as the group partitioned shared workspaces, allowed any user to interact with any tile screen at any time. However, the groups tended to assign each screen to an individual and not use other members' screen. With the seamless distributed corkboard, the participants were disconcerted by other members' easy access to their own workspaces with no prior permission. The result suggests the need to support a simple locking mechanism for group members to work on their own objects over the group shared workspaces. It would be also useful to provide identification such as nametags for individual mouse pointers and indicators for ownership of the workspaces to help easy reference by group members.

The shared resource turn taking pattern was defined as group members had to wait to get control of shared resources. This pattern was observed over various input and output devices in this design study. It was first observed with input control sharing in the pilot study where two co-located users in the distributed condition had to share one keyboard and mouse control. This pattern occurred most frequently when all group members tried to use the whiteboard, especially when the amount of whiteboard uses increased. The large amount of whiteboard uses also led to conflicts between remote sites and a long delay to get turns for using the whiteboard. In the fourth design study, the group members shared the presentation-model display by turn taking since it allowed them to display only one individual screen at a time. Similarly, in the third design study, the full screen tiled display was shared by the group members by turn taking. In addition, sometimes multiple users shared the same tile screen by turn taking. This turn taking pattern was also observed over the group shared workspaces, particularly between remote participants. The result suggests a need to support awareness tools, such as identification for who is using what group shared workspaces, to show the ownership of the shared resources.

For a multiple users' collaborative session, it would be better to use a "Give" turn taking protocol than a "Take" protocol for the shared resources. In a "Take" protocol, the user without control preemptively acquires control, whereas in a "Give" protocol, the user with control of the shared workspace voluntarily relinquishes control (Inkpen et al., 1997). The distributed corkboard tiled display was offered as group partitioned shared workspaces. It allowed any user to interact with any tile screen at any time and it also allowed multiple users to interact with the same tile screen by social turn taking. The turn taking protocol used in the distributed corkboard was a "Take" protocol. This "Take" protocol, however, seemed to create mouse conflicts when multiple users tried to get control on the same screen at the same time. With a "Take" protocol, users could grab control on the collaborator's screen unexpectedly while they accidentally moved a mouse to that screen. With a "Give" protocol, users could not grab control on the screen already taken by others. Thus, it would help reduce intrusion by someone's accidental entering to one's workspace. However, this protocol could be clumsy when multiple users tried to share control on the same screen by simple control switching; because, they would have to give control every time they want to switch control. In ACEs, there are a large number of group shared workspaces that members can interact with, and hence it would be sufficient to support multiple users' simultaneous input controls by adopting the right turn taking protocol for the group shared workspaces.

6.3 Visibility, Awareness, and Privacy

The value of the ability to see all group members' work at glance was confirmed in this design study. So, how does visibility help group work among distributed participants?

- *Awareness of others' activities*. It helps maintain group awareness of what others are working on.
- Immediacy of access to information and help. It is useful to have information available to all group members so that it helps communication with the others when the group needs to share. Making information visible by request is a source of delay when the group wants to share information.

- *Implicit peer learning*. People learn many things by observing other's work over the shoulder. In this design study, the participants got ideas (e.g. search strategy) from others by glancing and learned how to select all variables on XmdvTool by watching how others were doing, rather than interrupting others to find out this information.
- *Useful information can be found from other's work*. Accidental glancing over at other's work can also result in finding useful information. In this design study, the web site found by remote collaborators for the one question was also applied to the other question that one was trying to answer. Therefore, information is always visible to all members because people do not know ahead of time what useful information will be there.
- *Problem can be found by others*. Accidental glancing over at other's work can also lead to finding the answer for remote collaborator's problem. One's difficulty can be observed by others, and others would offer help.

However, knowing this value of visibility, the participants still wanted private workspaces mainly for personal things (such as email). This result implies privacy also needs to be considered in the design of ACEs, especially for the long term remote collaboration.

6.4 Display-rich Environment User Interface

The design issues for display-rich environment user interface fall into two categories: moving control and moving information between multiple displays.

6.4.1 Seamless versus Discrete

This design study examined two legitimate ways of doing the navigation between displays: SpaceGlider to give users to feel Continuum's displays as if one continuous display, and Switcher to give users to feel as if one discrete virtual desktop display. SpaceGlider has some obvious benefits for a single user and a large number of tiles in an amorphous configuration. However, clearly it did not work in multi-users shared case. The participants using SpaceGlider spent a lot of time either confused with identifying individual's mouse pointers or resolving accidental conflicts between multiple mouse pointers on the same screen. This result indicates that SpaceGlider needs to allow the multiple users' simultaneous input controls on all shared displays, or to provide the awareness tools such as nametags for mouse pointers or indicators for who is owned the particular screen, to help multi-users' collaborative work.

Switcher avoided collisions between multiple users, and due to this fact, all participants preferred Switcher to SpaceGlider. But, Switcher is not scalable to many tiles. Even though Switcher allowed any user to jump from tile to tile at any time, the participants showed the ownership pattern over the discrete tiled display. The pattern seemed to indicate that participants adopted a social turn taking protocol over the group partitioned workspaces. Since the distributed corkboard tiled display was fully visible to all, the participants could see which tile screens were occupied so that they could quickly find other available tiles.

6.4.2 Data Transfer between Displays

The interaction techniques for moving data between displays have been widely discussed in multi-devices and multi-users interface environments. Examples include Interactive Workspace Project's Drag-and-Drop protocol (Fox et al, 2000), i-LAND's Take-and-Put protocol (Streitz et al., 1999), and Rekimoto's Hyperdragging (Rekimoto, 1999) or Pick-and-Drop protocol (Rekimoto, 1998). Hyperdragging is a direct manipulation technique for moving information across the boundary of computers and surfaces. A user can start moving an object on a computer in the normal manner by dragging it with the pointing device. When the cursor reaches the edge of the screen, it jumps to the table surface. The user can also drop an item on a physical object, such as a VCR tape, to make a link between real and virtual objects. Pick-and-Drop protocol allows a user with a pen pointer to transfer between displays by picking up a computer object from one screen and then dropping the object from the pen tip onto the designated screen. Take-and-Put protocol, inspired by Pick-and-Drop technique, allows a user to "take" an object at one position and then walk over to another position at the wall display and "put" it there. Drag-and-Drop protocol allows a user to drag and drop data from any of the devices onto another – for example, users can drag and drop the URLs on the desired screen to view the corresponding web page on that display.

In this design study, there were few occasions when the participants wanted to move a window (such as a Netscape web browser) between tile screens while they wanted to give one's web page to the others. This pattern emerged only with seamless display and disappeared with discrete display. However, the participants consistently requested a copy-and-paste command to move text between displays throughout the design study (from the pilot study to the fourth design study). This request was occurred particularly in the information query and gathering task when the participants needed to move a large text from the web to the whiteboard. Consequently, often the participants physically moved between two displays to write findings from the tiled display to the whiteboard. Also, sometimes, two participants showed read-and-write collaboration – i.e. one read text from the tiled display, while the other wrote it onto the whiteboard. In addition, the participants used various other channels – such as, paper, tablet, or verbal channel – to transfer data between displays. These observed behavioral patterns clearly indicate a need to support a copy and paste command over multiple displays in the ACEs. Aside from copy-and-paste, the study revealed that putting the displays closer together helped user's moving data between displays.

6.5 Resolution, Display Size, Proximity to Display, and Layout

The tiled display screens are small and difficult to read at a distance, but they have a lot of resolution. In the first design study, the 2x2 layout tiled displays created the proximity to display issue – i.e. users had difficulty in interacting with the upper tile screens because those screens were not located at eye level. Because of this result, personal displays were provided to users in the second design study. Mirroring of tile screens to portable personal displays (e.g. tablet PC in this study) provided users a close-up view of the tiled display which helped the proximity issue, but this raised the size issue – the texts entered on tablet appeared to be too small to be read at a distance on the public displays, such as the tiled display and the whiteboard. With the seamless display over the tiled display and the whiteboard, users reported they felt no continuity of the workspaces because the displays were not next to each other. In the third design study, the flexible tiled display provided an additional option to make one screen maximized over the entire tiled display to help the size issue (in the bigger format). The full screen option was used for both group discussion and personal uses to make text/graph bigger. This full screen option also helped easy transition between individual work and group work. Putting the displays closer together helped copy and paste as well. In the fourth design study, the presentation-model display only allowed one screen to be visible at a time, and it raised the resolution issue. Users wanted to see more data side by side over the tiled display for data comparison. The display resolution, size, and proximity issue is also an important factor in the design of ACEs and it can be addressed by providing screen zoom.

The meeting room systems, such as CoLab and Collaboration Technology Suite, were designed to support face to face meetings. The general layout of electronic meeting rooms usually includes a large public display in front of the room, with users positioned towards the public display. In addition, all meeting participants have their own personal displays which can be recessed into the tabletop to reduce the visual effect. In ACEs, however, the layout should be designed in a way that users are surrounded by a number of public displays, in order to help users see all information easily.

6.6 Task Parallelism and Group Awareness

Task parallelism is defined as group members working simultaneously on different parts of the task in the shared workspace (Ellis et al., 1991). In this design study, task parallelism was affected by task types, group working styles, and technological constraints. The groups showed more parallel work pattern in the information query and gathering task than the other two tasks. In the information query and gathering task, all group members immediately started searching on the web to find the relevant information to the questions. On contrast, the groups showed group focus work pattern in the brainstorming and collaborative design task.

The group working style is another factor. Some groups divided work and shared only answers between group members. Hence, these group members worked in parallel on their individual workspaces most of the time, and once in a while, they checked work progress. Some groups showed mixed-focus collaboration where the group divided work per subgroup or individual; and, from time to time, all members worked together to verify or share their findings. Some groups showed all members working together solving one problem after another where one person controlled (acting as a system manipulator) and the rest contributed (acting as reviewers). When the group worked together, the group members simply did not use simultaneous input controls.

The technological constraint was also a hindrance to parallelism. In this design study, the groups had to share various shared resources by turn taking. People were not allowed to work simultaneously over these resources. Some critical examples include the mouse and keyboard sharing by two co-located users due to less number of input controls in the pilot study, the whiteboard sharing, and the presentation-model tiled display sharing.

More importantly, it was observed that awareness was needed when the group worked in parallel. When the group worked together tackling problems sequentially, they had greater awareness of each other and task progress. When the group worked separately but simultaneously, they required extra time to see what others had been doing, to coordinate their progress, such as what had been done and what would be done next.

In the everyday world, people are aware of many things, including not only other people but of the events occurring around them and of the things or artifacts. Yet, maintaining this awareness over the distance has been shown difficult because a lot of this information is not conveyed to remote users with today's technologies. In the group collaborative work, awareness information is always required to coordinate group activities. In this design study, some awareness problems occurred between remote sites, such as the mouse identification and conflict problem, the whiteboard conflict and resolution, and task awareness. Unfortunately, the participants spent a lot of time negotiating these problems and explicitly informing or asking each other about their intentions and activities. The use of multiple video sources helped them be more aware of remote participants and was somewhat useful to resolve these problems. But, such problems can be further reduced by the provision of awareness information and coordination tool – for example, audio and video cues to indicate who is using shared resources and the group activity history tool to manage task progress.

The notion of awareness was defined by (Dourish and Bellotti, 1992) as "an understanding of the activity of others, which provides a context of your own activity." Awareness has been extensively studied in CSCW and identified as a key feature for collaborative systems. 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 and of the tiled display. Glancing over at other's work over the tiled display helped them be aware of what others were doing. Even though the participants said they did not pay much attention to other's work, it was proven that casual glancing helped maintain awareness between distributed participants in collaborative work. When glancing was taken out in the fourth design study, it was obvious to see an awareness problem – i.e. less interaction between remote users and greater degree of explicit notification about findings, plans and task progress. The fact that the participants often used deictic reference such as “that one” or “this” over the tiled display and the fact that remote participants understood this reference, easily also made me believe that the participants were aware of each other’s activities through the tiled display. With the high quality Access Grid conferencing, the participants could overhear when problems arose and they helped each other or worked together over the fully visible tiled display, even though they were remotely located.

7. CONCLUSIONS AND FUTURE WORK

The focus of this research is to explore design issues to enhance interaction and collaboration among distributed teams in the Amplified Collaboration Environments (ACEs). Amplified Collaboration Environments are integrated ubiquitous tools and environments that allow distributed researchers to gather to intensively solve complex problems. The Continuum is an ACE specifically designed to support collaborative scientific investigation using advanced computation and visualization technologies. The purpose of the human factors study over ACE is to understand how a small group of distributed people work in environments which have an active display on every wall.

In this research, an exploratory design study was conducted to determine what tools would be helpful to distributed teams tackling a number of typical scientific tasks in ACEs. The study involved placing group of collaborators in two separate Continuum spaces and asking them to perform a number of typical scientific tasks. Group performance and their use of the available tools were observed to determine which tools assisted them in accomplishing the tasks. The purpose of the design study was to provide design guidance to designers and facilitators of the ACEs who examined methods to improve performance and interaction among distributed teams. The perspectives gained from this research contributed to the body of knowledge about small group interaction involving multiple displays and multiple simultaneous inputs in distance collaboration.

7.1 Design Issues for Amplified Collaboration Environments

The value of the Access Grid is that it enables distributed people to be brought together into common spaces (e.g. virtual venue) for group interaction, whether it is used for scheduled formal meeting (things are set up ahead of time) or dedicated informal use. Through the AG, distributed people can see each other, get a sense of awareness of each other, and overhear each other. Indeed, the AG users often desire workspace docking for ease of information and resource sharing. This research endeavored to answer the following question for the ACE designs: how is information presented and shared by distributed members for effective collaborative work? The findings and lessons learned from the design study could be complied into five key concepts: Persistence of information, spatiality of information, information in the background and the foreground, moving information, and coordination of interaction.

Persistence of information – Work must be always visible at a glance

War rooms consisted of numerous shared visual workspaces, such as whiteboards, flipcharts and corkboards on which the members of the group could post information artifacts. The information artifacts were kept persistent during the course of the meeting so that group members could refer back to them from time to time. The artifacts on these shared visual workspaces provided ready reference to coordination information by a simple glance (Covi et al., 1998; Teaseley et al., 2000; Olson and Olson, 2000).

This design study confirmed the value of having all information artifacts of group member's work visible for collaborative work in ACEs. Indeed, the distributed corkboard tiled display afforded all work visible at a glance, and this feature helped group members be aware of the progress or issues of others. The recent study about systematic comparisons of wall display technologies also found the value of the large high resolution display which allowed users to see everything at once (Olson. et al., 2003). Therefore, having all work visible to others at glance is a good design feature, and it helps group members to understand work more quickly and add their ideas easily.

The mechanism of information from private workspaces to become visible on the public workspace caused visibility problem, such as the presentation-model display in this design study. With the presentation-model display, users had to explicitly show information from private display to public display. On the other hand, making public information to be private on the group display, such as full screen tiled display, caused less problems since users still could work on their personal displays.

Spatiality of information – Keep WYSIWIS (What You See Is What I See) across distributed sites

In war rooms, group members had a special memory of where the artifacts were located and could quickly refer to them by pointing at them or by glancing in their direction so that everyone could immediately interpret (Covi et al., 1998; Teaseley et al., 2000; Olson and Olson, 2000). Although the gesture and eye contact was important in group collaboration, it was hard to convey subtle gesture and nuances over distance. There have been considerable efforts to support this nuance information in remote collaboration, but there was limited success in desktop to desktop interaction (Ishii and Kobayashi, 1991). In this design study, the participants tended to use their finger index to point at interests and gesture their hands over the display rather than using their tele-mouse pointer. It is interesting to study how (or whether) nuances make the group interaction seamless and natural over many displays in ACEs.

More importantly, information artifacts have to be distributed and organized in the same way across the ACEs. In the face to face communication, people use lots of deictic references (such as “here”, “there”) knowing that listeners have access to the same information in the periphery. This simple WYSIWIS (What You See Is What I See) is an important design concept for shared understanding among group members, but it may be difficult to apply to ACEs because the size of technologies and rooms can be widely varied. The challenge is how to organize information in a way that all members can interpret easily, even with different ACE configurations – something like, tool that manages the chuck of related information artifacts presented in ACEs. The key concept is that information has to be located in fixed periphery so that group members can understand joint reference to artifacts more easily. The persistent information (such as the question page in this design study) should always be visible somewhere in the public group workspaces for group co-reference.

There have been inherent arguments between WYSIWIS and customizability in the design of collaboration technologies. In the WYSIWIS systems, such as group shared drawing tools on networked desktop PCs, the group often felt restrictive by not being able to move freely to various parts of the workspace and operations of the interface were done sequentially. However, in the relaxed-WYSIWIS systems, which allowed working simultaneously on various parts of the workspace, the group often suffered from different views by individuals and required extra time to see what others had been doing; hence, this awareness information had to be gathered through verbal communication (Gutwin and Greenberg, 2001).

Information in the background and the foreground – Need group flexible peripheral display and personal focus display

In war rooms, all team members are co-located and communication overhead is minimal. Information artifacts are present and shared on the walls. These rooms are configured such that the individuals work facing the walls on the periphery and the center of the room contained a table or common work surface for scheduled or impromptu meetings (Covi et al., 1998; Teaseley et al., 2000; Olson and Olson, 2000).

In this design study, the distributed corkboard tiled display was used as either a large single group shared workspace or multiple individual workspaces – in both cases, all workspaces were visually shared by all group members, but input controls were owned both by the group and by members respectively. The group used the distributed corkboard as a large single workspace for group focus work of a single item or for group divided attention to multiple items (such as multiple graphs displayed on different tile screens for side by side comparison). The distributed corkboard was used as multiple individual workspaces for group divided work. It was also used for mixed focus collaboration where one individual workspace became a focus of group attention when the group wanted to work together to share information.

In this design study, the close up personal displays was provided to the participants for proximity to display issue, but it also helped users to focus on their own work. When the distributed corkboard and the personal displays was provided together, the personal display was used as a focus display for individual work while the distributed corkboard tiled display was used as a peripheral display for group awareness and remote collaboration. The participants were still able to see all members' work at a glance over the distributed corkboard tiled display and to collaborate with remote participants. Obviously, the idea of integrating information in the periphery and the context has been received considerable attention in HCI communities (Buxton, 1995; Weiser and Brown, 1995; MacIntyre et al., 2001). In this design study, the value of the distributed corkboard in concert with personal displays was that it allowed users to easily interact with detail information on personal displays while providing the overview of all information of group members' work available on the distributed corkboard.

Moving information – Need copy and paste feature between displays

In war rooms, group members may spontaneously and simultaneously modify the information artifacts by writing over them or moving them. In the war room used for software design, the flip chats are co-authored by the group, and they are clustered, moved, and edited at various times in the production of the software. Individuals moved near their workstations for programming and often referred to the diagrams on the flip chats.

There were two issues of moving information observed in this design study: one was moving information directly between public group displays (e.g. the tiled display and the whiteboard) and the other was moving information between personal display and public group displays (e.g. the public displays and laptop/tablet computers). The copy and paste is one good design feature in which the electronic tools leap over traditional media, and hence it is important to provide the feature across displays in ACEs.

With the current knowledge and experience, it seems discrete (such as i-Land's "Take-and-Put" method) is better than seamless (such as Interactive Workspace's "Drag-and-Drop" method) for multiple users' collaborative work. However, more systematic comparison is needed to understand which one would be better for multiple users or single user in co-located or distributed cases.

Coordination of Interaction – Need awareness information of remote users

Ideally, collaboration technologies should provide multiple users' simultaneous input access over all displays for task parallelism. However, today's collaboration technologies, such as the NetMeeting® and the SmartBoard™, sense only one input control at a time, and people are not allowed to work simultaneously as they would use the traditional whiteboard. Despite this fact, co-located users can effectively coordinate their interaction to share an input control over this shared group workspace since they have greater awareness of collaborators. But then, how do the technologies augment existing social conventions in shared resource turn taking for distributed users? CSCW researchers have suggested the awareness tool to provide distributed users clues about who are using what resources. To be more effective, this awareness information should be provided in the periphery for those who are concerned.

In the design study, the discrete distributed corkboard afforded partitioned shared group workspaces where any user could interact with any tile screen at any time (except for mouse sharing on the same tile screen by multiple users); but, instead, the participants grabbed one screen and owned it. This pattern implied that the participants wanted simple locked individual workspaces over the subset of group shared workspaces for individual focus work. That way the participants could do multiple simultaneous tasks but prevent others' access to their own workspaces. The participants disliked the seamless distributed corkboard because it allowed others to easily access their own individual workspaces without permission – thus, they felt the seamless display was intrusive. This result indicates that it is necessary to provide mixed controllability where control can easily become private or public for supporting effective individual work and group work. It helps coordination of group interaction on group shared information artifacts.

Besides making work visible and editable, the group also needs coordination tools, such as a to-do list, a group activity history list, or a task management tool, for coordinating group activities. This kind of tool helps team members keep track of what they have done individually and what they have to do next to manage task progress.

7.2 Future Directions

Future directions include developing advanced visualization and collaborative technology to support ACEs based on design guidelines explored in this design study and future research on human factors studies exploring following issues:

- long distance collaboration, such as connecting Continuum spaces between EVL and TRECC (Technology Research, Education, and Commercial Center);
- organizational factors, such as a group of peers or multidisciplinary;
- social factors, such as trust or openness;
- coordination of interaction issue such as awareness and attention;
- and video conferencing issue such as camera angle and position, video display factors.

CITED LITERATURE

Abowd, G. D.: Classroom 2000: An experiment with the instrumentation of a living educational environment. IBM Systems Journal 38(4):508-530, 1999.

Abowd, G. D. a. M., E. D.: Charting Past, Present, and Future Research in Ubiquitous Computing. ACM Transactions on Computer-Human Interaction **7**(1):29-58, 2000.

Benford, S., Bederson, B. B., Akesson, K.-P., Bayon, V., Druin, A., Hansson, P., Hourcade, J. P., Ingram, R., Neale, H., O'Malley, C., Simsarian, K. T., Stanton, D., Sundblad, Y. and Taxen, G.: Designing Storytelling Technologies to Encourage Collaboration Between Young Children. In Proceedings of CHI'00, pages 556-563, 2000.

Benford, S., Bowers, J., Fahlen, L. E., Greenhalgh, C. and Snowdon, D.: User Embodiment in Collaborative Virtual Environments. In Proceedings of CHI'95, pages 242-249, 1995.

Bentley, R., Horstmann, T., Sikkel, K. and Trevor, J.: Supporting Collaborative Information Sharing with the World Wide Web: The BSCW Shared Workspace System. The World Wide Web Journal: Proceedings of the 4th International WWW Conference(1):63-74, 1995.

Bly, S.: A Use of Drawing Surfaces in Different Collaborative Settings. In Proceedings of Conference on Computer Supported Cooperative Work, Portland, OR, pages 250-256, 1988.

Bly, S., Harrison, S. R. and Irwin, S.: Media spaces: Bringing people together in a video, audio and computing environment. Communications of the ACM. **36:**28-47, 1993.

Bly, S. A. and Minneman, S. L.: Commune: A Shared Drawing Surface. In Proceedings of Conference on Office Information Systems, Boston, Massachusetts, pages 184-192, 1990.

Buxton, W.: Integrating the Periphery and Context: A New Model of Telematics. In Proceedings of Graphics Interface, pages 239-246, 1995.

Childers, L., Disz, T., Olson, R., Papka, M. and Stevens, R.: Access Grids: Immersive Group-to-Group Collaborative Visualization. In Proceedings of IPT Workshop, 2000.

Chowdhry, V.: SpaceGlider: An intuitive approach for controlling multiple remote computers, M.S. Thesis, University of Illinois at Chicago, 2003.

Covi, L. M., Olson, J. S., Rocco, E., Miller, W. J. and Allie, P.: A Room of Your Own: What do we learn about support of teamwork from assessing teams in dedicated project rooms? Cooperative Buildings. K. K. N. Streitz, and H. J. Burkhardt. Amsterdam, Springer-Verlag**:** 53-65, 1998.

DARPA, Command Post of The Future, http://www.ida.org/DIVISIONS/sctr/cpof/.

Dourish, P. and Bellotti, V.: Awareness and Coordination in Shared Workspaces. In Proceedings of CSCW'92, pages 107-114, 1992.

Dourish, P. and Bly, S.: Portholes: Supporting Awareness in a Distributed Work Group. In Proceedings of CHI'92, Monterey, CA, pages 541-547, 1992.

Ellis, C., Gibbs, S. and Rein, G.: Groupware: Some issues and experiences. Communications of the ACM. 34(1):38-58,1991.

eRoom, http://www.eroom.com/.

Espinosa, A., Cadiz, J., RicoGutierrez, L., Kraut, R., Scherlis, W. and Lautenbacher, G.: Coming to the Wrong Decision Quickly: Why Awareness Tools Must be Matched with Appropriate Tasks. In Proceedings of CHI Letters, pages 392-399, 2000.

Finholt, T. A., and Olson, G. M.: From laboratories to collaboratories: A new organizational form for scientific collaboration. Psychological Science. 8(1):28-35, 1997.

Fish, R. S., Kraut, R. E., Root, R. W. and Rice, R. E.: Video as a technology for informal communication. Communications of the ACM. 36(1):48-61, 1993.

Fox, A., Johanson, B., Hanrahan, P. and Winograd, T.: Integrating Information Appliances into an Interactive Workspace. IEEE Computer Graphics and Applications, 2000.

Fussell, S.R., R.E. Kraut, and J. Siegel: Coordination of Communication: Effects of Shared Visual Context on Collaborative Work. In Proceedings of CSCW'00. pages 21-30, 2000.

FXPAL, Smart Media Spaces, http://www.fxpal.com/smartspaces/index.htm.

Gaver, W., Moran, T., MacLean, A., Lovstrand, L., Dourish, P., Carter, K. and Buxton, W.: Realizing a video environment: Europarc's rave system. In Proceedings of CHI'92, Monterey, CA, pages 27-35,1992.

Greenberg, S., Bohnet, R., Roseman, M. and Webster, D.: GroupSketch. ACM SIGGRAPH Video Review. 87, 1992.

Gutwin, C. and Greenberg, S.: Design for Individuals, Design for Groups: Tradeoffs between power and workspace awareness. In Proceedings of CSCW'98, Seattle, WA, pages 207-216, 1998.

Gutwin, C. and Greenberg, S.: A Descriptive Framework of Workspace Awareness for Real-Time Groupware. Journal of Computer Supported Cooperative Work, 11(3-4):441-446, 2002.

Gutwin, C., Roseman, M. and Greenberg, S.: A Usability Study of Awareness Widgets in a Shared Workspace Groupware System. In Proceedings of CSCW'96, pages 258-267, 1996.

Inkpen, K., McGrenere, J., Booth, K.S., and Klawe, M.: Turn-Taking Protocols for Mouse-Driven Collaborative Environments. In Proceedings of Graphics Interface, pages 138-145, 1997.

Isaacs, E. A., Morris, T. and Rodriguez, T. K.: A forum for supporting interactive presentations to distributed audiences. In Proceedings of Computer Supported Cooperative Work, Chapel Hill, North Carolina, pages 405-416, 1994.

Ishii, H. and Kobayashi, M.: ClearBoard: a seamless medium for shared drawing and conversation with eye contact. In Proceedings of CHI'92, Monterey, CA, pages 525-532, 1992.

IV, http://www.cc.gatech.edu/classes/AY2002/cs7450_spring/a1-cereals.xls.

Jancke, G., Grudin, J. and Gupta, A.: Presenting to local and remote audiences: design and use of the TELEP system. In Proceedings of the CHI'00, The Hague, The Netherlands, pages 384-391, 2000.

Johanson, B., Hutchins, G., Winograd, T., and Stone, M.: PointRight: Experience with Flexible Input Redirection in Interactive Workspaces. In Proceedings of the UIST'02, pages 227-234, 2002.

Keller, R. M.: ScienceOrganizer: A Collaborative Information Management Tool for Scientific Teams. In Proceedings of ISR-NASA Collaborative Software Engineering Tools Workshop, 2002.

Lange, B. M., Jones, M. A., and Meyers, J. L.: Insight Lab: An Immersive Team Environment Linking Paper, Displays, and Data. In Proceedings the CHI'98, pages 550-557, 1998.

Leigh, J., Dawe, G., Talandis, J., He, E., Venkataraman, S., Ge, J., Sandin, D. and DeFanti, T.: AGAVE: Access Grid Augmented Virtual Environment. In Proceedings of AccessGrid Retreat, Argonne, IL, 2001.

Leigh, J., DeFanti, T., Johnson, A., Brown, M. and Sandin, D.: Global Tele-Immersion: Better Than Being There. In Proceedings of 7th International Conference on Artificial Reality and Tele-Existence, Tokyo, Japan, pages 10-17, 1997.

Leigh, J., Girado, J., Singh, R., Johnson, A., Park, K. and DeFanti, T.: TeraVision: a Platform and Software Independent Solution for Real Time Display Distribution in Advanced Collaborative Environments. In Proceedings of Access Grid Retreat, La Jolla, CA, 2002.

Leigh, J., Johnson, A., Park, K., Nayak, A., Singh, R. and Chowdry, V.: Amplified Collaboration Environments. In Proceedings of VR Grid Workshop, Daejun, Korea, pages 77-85, 2002.

MacIntyre, B., Mynatt, E. D., Voida, S., Hansen, K. M., Tullio, J. and Corso, G. M.: Support For Multitasking and Background Awareness Using Interactive Peripheral Displays. In Proceedings of UIST2001, pages 41-50, 2001.

Mantei, M., Baeker, R. M., Sellen, A. J., Buxton, W. A. S., Milligan, T. M. and Wellman, B.: Experiences in the use of a media space. In Proceedings of CHI'91, New Orleans, Louisiana, pages 203-215, 1991.

Mark, G.: Extreme Collaboration. Communications of the ACM. 45(6):89-93, 2002.

Mark, G., Grudin, J. and Poltrock, S. E.: Meeting at the Desktop: An Empirical Study of Virtually Collocated Teams. In Proceedings of ECSCW'99, pages 159-178, 1999.

Mark, G., K. Carpenter, and A. Kobsa.: A Model of Synchronous Collaborative Information Visualization. In Proceedings of the IEEE International Conference on Information Visualization (IV'03), 2003.

Microsoft NetMeeting, http://www.microsoft.com/windows/netmeeting/.

Mowshowitz, A.: Virtual Organization. Communications of the ACM. 40(9):30-37, 1997.

Myers, B. A., Stiel, H. and Gargiulo, R.: Collaboration Using Multiple PDAs Connected to a PC. In Proceedings of CSCW'98, pages 285-294, 1998.

Nayak, A., Scharver, C., Chowdrhry, V., Leigh, J. and Johnson, A. Immersaview, http://www.evl.uic.edu/cavern/agave/immersaview/.

NetPodium, http://www.netpodium.com/.

Olson, J., Bos, N., Olson, G. M., Brinck, T. and Huang, W.: Writing on the Wall: What do we really need an electronic whiteboard to do?, 2003.

Olson, G. M. and Olson, J. S.: Distance Matters. Human-computer Interaction 15(2&3):139-179, 2000.

Olson, J., Olson, G., Storrosten, M. and Carter, M.: Groupware close up: A comparison of the group design process with and without a simple group editor. Special Issue on CSCW of ACM TOIS. N. S. T. Malone. 11(4):321-348, 1993.

Park, K. S., Cho, Y., Krishnaprasad, N., Scharver, C., Lewis, M. and Leigh, J.: CAVERNsoft G2: A Toolkit for High Performance Tele-Immersive Collaboration. In Proceedings of the ACM Symposium on Virtual Reality Software and Technology, Seoul, Korea, pages 8-15, 2000.

Park, K. S., Kapoor, A., and Leigh, J.: Lessons Learned from Employing Multiple Perspectives In a Collaborative Virtual Environment for Visualizing Scientific Data. In Proceedings of the ACM Collaborative Virtual Environments, San Francisco, CA, pages 73-82, 2000.

Pedersen, E. R., McCall, K., Moran, T. P. and Halasz, F. G.: Tivoli: An Electronic Whiteboard for Informal Workgroup Meetings. In Proceedings of INTERCHI'93, pages 391-398, 1993.

PlaceWare, http://www.placeware.com/.

Renambot, L. and Schaaf, T.V.D.: Enabling Tiled Displays for Education. In Workshop on Commodity-Based Visualization Clusters, in conjunction with IEEE Visualization, 2002.

Rekimoto, J.: A Multiple Device Approach for Supporting Whiteboard-based Interactions. In Proceedings of CHI'98, pages 344-351, 1998.

Rekimoto, J. a. S., M.: Augmented surfaces: a spatially continuous work space for hybrid computing environments. In Proceedings of CHI'99, Pittsburgh, PA USA, pages 378-385, 1999.

Romano, N. C., Roussinov, D., Nunamaker, J.F., and Chen, Hsinshun: Collaborative Information Retrieval Environment: Integrating of Information Retrieval with Group Support Systems. In Proceedings of the 32nd Hawaii International Conference on System Sciences, 1999.

Schaaf, T.v.d., Renambot, L., Germans, D., Spoelder, H., and Bal, H.: Retained Mode Parallel Rendering for Scalable Tiled Displays. In Proceedings of the 6th annual Immersive Projection Technology (IPT) Symposium. Orlando, FL, 2002.

SmartTech, Matisse, http://www.smarttech.com/products/plasma/index.asp.

StatLib-Datasets Archive, http://lib.stat.cmu.edu/datasets/.

Stefik, M., Bobrow, D. G., Foster, G., Lanning, S. and Tatar, D.: WYSIWIS Revised: Early Experience with Multiuser Interfaces. ACM Transactions on Office Information Systems, 5(2): 147-167, 1987.

Stefik, M., Foster, G., Bobrow, D., Khan, K., Lanning, S. and Suchman, L.: Beyond the chalkboard: Computer support for collaboration and problem solving in meetings, Communications of the ACM **30**(1): 32-47, 1987.

Stewart, J., Bederson, B. B. and Druin, A.: Single Display Groupware: A Model for Co-present Collaboration. In Proceedings of CHI'99, pages 286-293, 1999.

Stewart, J., Raybourn, E. M., Bederson, B. B. and Druin, A.: When Two Hands Are Better Than One: Enhancing Collaboration Using Single Display Groupware. In Proceedings of CHI'98 Summary, pages 287-288, 1998.

Streitz, N., Geißler, J., Holmer, T., Konomi, S., Müller-Tomfelde, C., Reischl, W., Rexroth, P., Seitz, P., and Steinmetz, R.: i-LAND: an interactive landscape for creativity and innovation. In Proceedings of CHI'99, Pittsburgh, PA USA, pages120-127, 1999.

Streitz, N. A., Rexroth, P. and Holmer, T.: Does "roomware" matter? Investigating the role of personal and public information devices and their combination in meeting room collaboration. In Proceedings of European Computer Supported Cooperative Works 1997, pages 297-312, 1997.

Tang, J.: Findings from observational studies of collaborative work. International Journal of Man-Machine Studies, 34(2):143-160, 1991.

Tatar, D., Foster, G. and Bobrow, D. G.: Design for Conversation: lessons from Cognoter. International Journal of Man-Machine Studies, 34(2): 185-210, 1991.

TeamWave, http://www.markroseman.com/teamwave/workplace.html.

Teasley, S., Covi, L., Krishnan, M. S. and Olson, J.: How does radical collocation help a team succeed?, In Proceedings of CSCW2000, Philadelphia, PA, pages 339-347, 2000.

Teasley, S. and Wolinsky, S.: Scientific collaborations at a distance. Science. 292(5525):2254-2255, 2001.

Twidale, M. B., Nichols, D. M., Smith, G. and Trevor, J.: Supporting Collaborative Learning during Information Searching. In Proceedings of Computer Support for Collaborative Learning 1995 (CSCL'95), Bloomington, IN, pages 367-374, 1995.

Want, R., Fishkin, K. P., Gujar, A., and Harrison, B. L.: Bridging Physical and Virtual Worlds with Electronic Tags. In Proceeding of CHI'99, pages 370-377, 1999.

Want, R., Hopper, A., Falcao, V., and Gibbons, J.: The active badge location system. ACM Transactions on Inf. Syst. 10(1): 91-102, 1992.

Want, R., Schilit, B. N., Adams, N. I., Gold, R., Petersen, K., Goldberg, D., Ellis, J. R., and Weiser, M.: The PARCTab Ubiquitous Computing Experiment, Technical Report CSL-95-1, Xerox Palo Alto Research Center, 1995.

Ward, M. O., XmdvTool: http://davis.wpi.edu/~xmdv/.

WebEx, http://www.webex.com/.

Weiser, M.: The Computer for the 21st Century. Scientific American, 265(3):94-104, 1991.

Weiser, M.: Some computer science issues in ubiquitous computing. Communications of ACM, 36(7):75-84, 1993.

Williams, L. A. and Kessler, R. R.: All I really need to know about pair programming I learned in kindergarten. Communications of the ACM. 43(5):108-114, 2000.

APPENDICES

Appendix A

Pre-test Survey

Subject ID: ____________________

1. How many hours per day, on average, do you use a computer?

2. Do you own a Tablet PC? If so, how many hours a day, on average, do you use it?

3. Do you own a Palm Pilot or Pocket PC? If so, how many hours a day, on average, do you use it?

4. Do you own a cellular phone? If so, how many minutes a day, on average, do you use it?

5. How many hours per week, on average, do you surf the Internet (e.g. web browsing)? For what purpose do you use the Internet web browsing?

6. Do you play networked or online video games? If so, how many hours a day, on average, do you play them?

7. How much experience do you have with the collaboration technologies (e.g. email, instant messaging, web, etc)?

__ None
__ Used once
__ Several times
__ A lot
__ Don't know about these technologies

Appendix A (continued)

8. How much experience do you have with the computer supported collaborative work tools (e.g. NetMeeting, Teamwave, WebEx, or shared whiteboard tool)?

__ None
__ Used once
__ Several times
__ A lot
__ Don't know about these technologies

9. How much experience do you have with Access Grid video conferencing?

__ None
__ Used once
__ Several times
__ A lot
__ Don't know about AccessGrid

10. How much experience do you have with the electronic whiteboard technology (e.g. Smartboard, LiveBoard)?

__ None
__ Used once
__ Several times
__ A lot
__ Don't know about the digital whiteboard technology

11. How much experience do you have with the tiled display technology (e.g. PerspecTile)?

__ None
__ Used once
__ Several times
__ A lot
__ Don't know about the tiled display technology

12. How many displays (e.g. monitors) do you use in your work?

__ Single screen on a computer (Skip the question below)
__ Dual screens on a computer
__ Two computers
__ Three screens or greater

Please explain how you use each screen (e.g. for what purposes).

____

Appendix A (continued)

13. How much experience do you have with the information visualization technology (e.g. Tele-Immersive Data Explorer, IBM Data Explorer, AVS, Spotfire)?
__ None
__ Used once
__ Several times
__ A lot
__ Don't know about the information visualization technology

14. How much experience do you have with XmdvTool information visualization technology?
__ None
__ Used once
__ Several times
__ A lot
__ Don't know about XmdvTool

15. Prior to this experience, how much do you know about "correlation" statistics?
__ None
__ Very little
__ Moderate
__ Very well

16. Please rate which technology you are more comfortable with. (5 extremely comfortable, 4. fairly comfortable, 3. somewhat comfortable, 2. not comfortable, 1. don't know or never used)
- Access Grid __
- Tiled display __
- Touch screen whiteboard __
- TabletPC __

17. How many displays (e.g. monitors) do you use in your work?
__ Single screen on a computer (Skip the question below)
__ Dual screens on a computer
__ Two computers
__ Three screens or greater

Please explain how you use each screen (e.g. for what purposes).
____

Appendix A (continued)

18. How many are you interested in working as a team?
__ Not interested
__ Somewhat interested
__ Fairly interested
__ Extremely interested
__ Don’t know

19. What is your current educational standing?
__ Undergraduate
__ Graduate
__ Post-Graduate
__ Others

20. What is your major?

21. How old are you?

22. Are you male or female?
__ Male
__ Female

Appendix B

Post-test Survey

Subject ID: ____________________

Task: _________________________

1. How would you rate your group's accomplishments?

__ Excellent
__ Good
__ Fairly good
__ Poor
__ Don't know

2. How would you rate your contribution in finding the answers compared to your partner's contribution in 1 to 10 scales? (1=I did all the work, 10=My partner did all the work)

3. Please briefly summarize the answers that you discovered and the answers your partner(s) discovered.

4. How often did you and your LOCAL partner work together (during this collaborative work session)?

__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Please explain in what situation you worked together with your LOCAL partner in a coordinated fashion.

____

5. How often did you and your REMOTE partner(s) work together?

__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Appendix B (continued)

Please explain in what situation you worked together with your REMOTE partner(s) in a coordinated fashion.

____

6. How often did you work independently?

__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Please explain in what situation you worked independently.

____

7. How often did you shift between independent work and shared group work?

__ Always or almost always
__ Frequently
__ Rarely
__ Never

8. How often did you and your (LOCAL or REMOTE) partners divide the work?

__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Please explain what works were divided into whom.

____

9. How often did you and your (LOCAL or REMOTE) partners duplicate work by accident?

__ Often
__ Several times
__ Once or twice
__ Never (skip the question below)

Please explain what works were duplicated and why you think it happened.

____

Appendix B (continued)

10. How often did you feel you wanted to work privately?
__ Often
__ Several times
__ Once or twice
__ Never (skip the question below)

Please explain in what type of work you wanted privacy.

___

11. How often were you frustrated or confused?
__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Please explain the source of your frustration or confusion (e.g. program crash).

___

12. How much were you aware of what your LOCAL partner was doing?
__ Very aware
__ Fairly aware
__ Somewhat aware
__ A little aware
__ Not at all (skip the question below)

Please explain how you were aware of your LOCAL partner activities (e.g. by looking at the tiled display's screen).

___

13. How much were you aware of what your REMOTE partners were doing?
__ Very aware
__ Fairly aware
__ Somewhat aware
__ A little aware
__ Not at all (skip the question below)

Please explain how you were aware of your REMOTE partner activities (e.g. by looking at the tiled display's screen).

___

Appendix B (continued)

14. How often did you monitor or casually glance over at your LOCAL partner's screen?
__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Did glancing over at your LOCAL partner's screen help your work? Please explain how.

---

15. How often did you monitor or casually glance over at your REMOTE partner's screen?
__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Did glancing over at your REMOTE partner's screen help your work? Please explain how.

---

16. How often did a new idea come to you by looking over at your partner's screen?
__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Please explain what (from your partner's screen) made you trigger the new idea.

---

17. How often did you talk to your LOCAL partner about findings, ideas, and work progress?
__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Appendix B (continued)

Please explain what you have discussed with your LOCAL partner.

____

18. How often did you talk over Access Grid (or inform to your REMOTE partner) about findings, ideas, and work progress?

__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Please explain what you have discussed with your REMOTE partner.

____

19. How often did you and your (LOCAL or REMOTE) partners help each other and learn from each other?

__ Always or almost always
__ Frequently
__ Rarely
__ Never (skip the question below)

Please explain what you helped each other or what you learned from each other.

____

20. How many tiled display screens did you use for this collaborative work?

__ I used 4 screens
__ I used 3 screens
__ I used 2 screens
__ I used 1 screen
__ I used none

Please explain how you used each screen for what purposes.

____

21. How would you rate your attention level during this collaborative work session in 1 to 10 scales? (1=I focused only on my screen, 10=I watched what my partner did the entire time)

Appendix B (continued)

22. Rank how important each of these technology was in assuring the completion of your work. (10=most important, 1=least important)

__ Access Grid
__ Tiled display
__ Touch screen whiteboard
__ Tablet PC

23. Rank how much each of these technologies helped your group coordinate parallel activities (10=most helpful, 1=least helpful).

__ Access Grid
__ Tiled display
__ Touch screen whiteboard
__ Tablet PC

24. When given the chance to use a number of displays (e.g. Access Grid, Tiled display, Touch screen whiteboard, and TabletPC), rank how much you used the tiled display (10=used the most, 1=used the least).

25. Please describe any difficulty or inconvenience you may have experienced while working with your partner(s) using these technologies. What could be improved to overcome this problem?

Appendix C

Post-test Interview Questions

Subject ID: ____________________

1. Overall, which technology did you feel more comfortable (5=extremely comfortable, 4=fairly comfortable, 3=somewhat comfortable, 2=a little comfortable, 1=not at all)? Why or why not?

- o Access Grid __
- o Tiled display __
- o Touch screen whiteboard __
- o TabletPC __

2. Overall, which technology did you find more interesting (5=extremely interested, 4=fairly interested, 3=somewhat interested, 2=a little interested, 1=not at all)? Put a check mark next to the technology you have used before.

Used before

- o Access Grid __ __
- o Tiled display __ __
- o Touch screen whiteboard __ __
- o TabletPC __

3. Overall, which technology did you find more useful for your collaborative work activities (5=extremely useful, 4=fairly useful, 3=somewhat useful, 2=a little useful, 1=not at all)? Please explain how you found them useful.

- o Access Grid __
- o Tiled display __
- o Touch screen whiteboard __
- o TabletPC __

4. If you have prior experience with other collaboration technologies (e.g. NetMeeting, Teamwave, WebEx), please compare and contrast your prior experience with the experience you had in this study.

5. Please provide us with any general feedback about your experience - for example, can you tell us what worked, what didn't, and what should be done to improved the way technology was used in the collaborative work session for future users?

Appendix D

Post-test Group Interview Questions

Group ID: ____________________

1. First study experience vs. Second study experience

2. SpaceGlider (continuous workspace) vs. Switcher (discrete workspace)

3. Full-screen (Why did or didn't you use full screen option?)

4. Display Pushing (When/Why did you tend to push your desktop to Tiled Display?)

5. Privacy concerns (When/Why did you tend to hide your desktop? Do you want a private workspace for this collaborative work session?)

6. Query triggering in search task? (a user builds a new query from those of other users (and hence, finds additional information that might have been missed if each member of the team had searched individually – via Tiled Display or via overhearing)

7. Glance (When/Why did you tend to glance over at other's screen? – via Tiled Display or via looking at TabletPC)

8. TD vs. TabletPC (When did you tend to use TD? When did you just use TabletPC?)

9. Enough vs. overwhelming vs. not enough information

10. Given NetMeeting vs. Continuum, Which one to use when you are given? And Why?

Appendix E

Observation Note

Observer: ____________________

Group: ______________________

Task: _______________________

Patterns:

1. **No Engagement** – a user is left out doing nothing – Why?
2. **Parallel/Partitioned Works** – two or three users work on different tiles (screen) at the same time (e.g. user1 works on tile1 for scatter plot, user2 works on tile2 for parallel coordinates, user3 works on whiteboard)
3. **Shared Works** – two or three users work on one focused item together – For what item?
4. **Duplicated Works** – two or three users work on a duplicated thing (e.g. user1 and user2 have done a redundant work) – When?
5. **Collision/Conflicts** – a user is distracted by his/her partner's action (due to no shared feedback) – When?
6. **No Visibility** – a user is verbally explaining information to his/her partner(s) because the information is not visible to his/her partner(s) – What information is not visible?
7. **Glance** – a user is glancing over at his/her partner's workspace (e.g. TabletPC, local partner's tiled display screen, remote partner's tiled display screen, etc)
8. **Deictic Reference (hand or mouse pointing, "this" & "that")** – a user is pointing at any item/action on his/her tile(s) or his/her partner's tile(s)
9. **Shared Understanding (synchronization)** – two or three users talk about what has been done, what is left, what is going to do next
10. **Side-by-side Comparison** – two or three users try to compare the different views in side-by-side (e.g. my analysis vs. your analysis)
11. **Query Triggering** – a user builds a new query from those of other users (and hence, finds additional information that might have been missed if each member of the team had searched individually)
12. **Privacy Concerns** – a user is complaining about privacy – What kinds of privacy?

Appendix F

Training

Instruction:

In the training session, you will receive a brief explanation about the Continuum hardware/software technologies and tools. Then, you will receive the task instructions and basic concepts of correlation statistics and multivariate dataset analysis; such as scatter plot matrix and parallel coordinates. You will spend approximately 30~40 minutes for the training session and you may spend longer if you wish to become more familiar with the system.

1. Continuum
   - Access Grid
   - Tiled Display
   - Shared Touchscreen Whiteboard
   - Wireless Access
2. Task instruction
   - Information query and gathering
     - Sample questions & answers
   - Information analysis and pattern detection
     - Sample questions & answers
   - Collaborative design
3. Correlation statistics and multivariate dataset analysis
   - Scatter plot matrix
   - Parallel coordinates
   - XmdvTool overview
   - Multivariate dataset analysis using XmdvTool

Appendix F (continued)

Continuum:

In the Continuum, an Amplified Collaboration Environment, top left is a AGAVE passive stereo display for showing immersive 3D content; next to it is a 2x2 matrix tiled display; next to it are vertically stacked plasma screens that are used for Access Grid video conferencing; to the right of this is the plasma touch-screen that is used for shared white boarding.

- Access Grid - a multi-party video conferencing that supports group to group communication: 4 camera views in the AG room and 1 camera view in the ICE conference room.
- Shared touch-screen whiteboard - your notes writing on this board are shared with your collaborators in the other room through NetMeeting. To create a new page in NetMeeting, press "Insert New Page" icon at the right bottom corner.
- Tiled display - shared workspaces that users can work in any of these workspaces.
- SpaceGlider - a software interface that allows users with laptop or tablet PC to navigate across any of the tiled display screens & the shared whiteboard.

Sample Questions and Answers (Information Query and Gathering Task):

Question:

1. What are the symptoms of Parkinson's Diseases?
2. What are the treatments of Parkinson's Diseases?
3. What segments of the population have this disease?
4. What are the recent clinical research findings on prevention?

Description:
Documents discussing research projects and funding for research projects were considered relevant only when clinical trials were included. Documents regarding legislation, which discussed funding, and programs were considered irrelevant.

Search (list the relevant web sites that you found):

1. http://www.holisticonline.com/Remedies/Parkinson/pd_home.htm (pointer to symptoms and various treatments)
2. http://www.holisticonline.com/Remedies/Parkinson/symptoms.htm (symptoms)
3. http://www.holisticonline.com/Remedies/Parkinson/pd_treatments.htm (treatments)

Appendix F (continued)

4. http://www.aafp.org/assembly/2001/lectures/parkinsons/parkinsons_slides bw.pdf (population, symptoms, treatments)
5. http://ucneurology.uchicago.edu/Neurological_Disorders/Parkinsons/parkinsons.html
6. http://www.pdf.org/aboutdisease/overview/index.html
7. http://www.pdf.org/aboutdisease/overview/symptoms.html
8. http://www.pdf.org/aboutdisease/overview/treatments.html
9. http://www.emedicine.com/neuro/topic573.htm (surgical approached to the treatment of PD)
10. http://www.yourhealthbase.com/parkinsons.html (symptoms, treatment, recent research on prevention)
11. http://www.ninds.nih.gov/about_ninds/nihparkinsons_agenda.htm
12. http://www.ninds.nih.gov/health_and_medical/pubs/parkinson_disease_htr.htm (pointer to symptoms and treatments and research and population)
    - http://www.healingwell.com/library/parkinsons/info1.asp
13. http://www.boehringer-ingelheim.ca/ethical/parkin_diag.htm (population)
14. http://www.boehringer-ingelheim.ca/ethical/parkin_treat.htm
15. http://www.angelfire.com/oh2/fountainofyouth/parkinsons.html
16. http://mhsource.com/hy/parkinson.html
17. http://www.parkinsonsdisease.com/pcp/PCP13.HTM

Summary:

1. Symptoms
    a. The major symptoms were originally described in 1817 by an English physician, Dr. James Parkinson, who called it “Shaking Palsy.”
    b. Major symptoms are
        i. Tremor (shaking/trembling in the hands, arms, legs, jaw, and face)
        ii. Rigidity (stiffness or resistance of the limbs and trunk)
        iii. Bradykinesia (slowness of movement)
        iv. Postural instability (poor balance and coordination)
    c. Other symptoms are
        i. Depression
        ii. Emotional changes
        iii. Difficulty in swallowing and chewing
        iv. Speech changes
        v. Urinary problems
        vi. Skin problems

Appendix F (continued)

vii. Sleep problems
viii. Shuffling gait, stooped posture, difficulty with fine coordinated movements, and micrographia (small handwriting)
ix. Dementia syndrome

2. Treatments
   a. Drugs
      i. Anticholineargics (Benztropine, Biperiden, Dephenhydramine, Procyclidine, Trihexyphenidyl)
      ii. Amantadine
      iii. Levodopa
      iv. Carbidopa/Levodopa
      v. COMT (Catechol-O-methytransferase) inhibitors (Tolcapone, Entacapone)
      vi. Dopamine Agonists (Bromocriptine, Pergolide, Ropinirole, Pramipexole and Cabergoline)
      vii. Selegiline
      viii. MAO-B (Monamine oxidase-B) inhibitor
   b. Surgery
      i. Thalamotomy and Pallidotomy (has become increasing popular in the past several years)
      ii. Deep Brain Stimulation
      iii. Neural Tissue Transplantation
   c. Diet and exercise
      i. 7:1 plan-for the ratio of carbohydrates to proteins-is designed for patients taking levodopa (proteins reduce the drug's effectiveness).
   d. Potential treatment in research
      i. Neurotrophic proteins
      ii. Neuroprotective agents
      iii. Neural tissue transplants
      iv. Genetic engineering
3. Population
   a. Affects about 1% of population (1 in every 100 people) aged 65 years and older and about 0.4% of population (1 in every 250 people) aged 40 years and older.
   b. Strikes men and women in almost equal numbers (though, one web site says, slightly more often than women). No social, economic, or geographic boundaries.

Appendix F (continued)

c. Age correlates with the onset of symptoms, usually affecting people over the age of 50. The average age of onset is 60 years. Some have estimated that 5 to 10% of patients are under the age of 40.
d. PD may appear at any age, but it is uncommon in people younger than 30, and the risk of developing it increases with age.
e. PD is not inherited, however some studies have shown that it can occur in families.
f. American Parkinson Disease Association estimates that one million Americans are affected by the disease. The risk for developing PD increases with age, and onset usually occurs at around 50 years of age or older (although the disease is not unknown in people in their 30s and 40s).

4. Prevention
    a. One can lower one's risk of developing PD by reducing one's intake of animal fats and sugar (eat a diet rich in fruits and vegetables), avoiding toxic metals (such as aluminum, manganese, mercury, cadmium and copper) and an excessive iron intake, and by ensuring an adequate intake of **antioxidants**.
    b. Antioxidants: Studies have shown that if healthy people take antioxidants throughout most of their lives, their risk of acquiring Parkinson's disease is reduced considerably.
    c. Antioxidants: That antioxidants also slow down the progression of existing Parkinson's disease was demonstrated in 1991 in a pilot study carried out by Dr. Stanley Fahn of Columbia University. Dr. Fahn found that Parkinson's disease patients given large doses of oral vitamin C and synthetic vitamin E supplements (3000 mg and 3200 IU daily respectively) delayed the progression of their disease to the point where they needed l-dopa 2.5 years later than a group of patients who were not taking supplements(39,40). Later research has shown that synthetic vitamin E in itself does not retard the progression of Parkinson's disease(2,41). Thus it is likely that it was vitamin C by itself or its combination with vitamin E that was the active component in Dr. Fahn's experiment. Clinical research suggests that PD patients may derive some benefit from antioxidants and amino acids such as tyrosine. Antioxidants that may have some value in the treatment of PD include alpha-tocopherol (vitamin E) and Coenzyme Q10 (CoQ10). The results of two studies suggest that alpha-tocopherol may have prophylactic value in the prevention of PD.

Appendix F (continued)

d. Antioxidants: Another promising candidate in PD prevention is coenzyme Q10 (ubiquinone) that also is absorbed in brain fluids and is a very powerful antioxidant. Recent research has shown that the coenzyme Q10 content of the mitochondria (energy-producing cell components) in the brain declines rapidly when Parkinson's disease is induced in monkeys; this reduction in coenzyme Q10 level leads to a detrimental increase in free radical destructive reactions.
e. Selegiline: Since the accidental discovery that MPTP causes parkinsonian symptoms in humans, scientists have found that by injecting MPTP into laboratory animals, they can reproduce the brain lesions that cause these symptoms. This allows them to study the mechanisms of the disease and helps in the development of new treatments. For instance, it was from animal studies that researchers discovered that the drug selegiline can prevent the toxic effects of MPTP. This discovery helped spark interest in studying selegiline as a preventive treatment in humans.

Sample Questions and Answers (Information Analysis and Pattern Detection Task):

4.5.1 Dataset:

The Cars dataset has 392 observations and 7 variables describing attributes of cars. The complete variables are:

1. **M**iles **P**er **G**allon
2. **Cylinders** (3, 4, 5, 6, and 8)
3. **Horsepower**
4. **Weight**
5. **Acceleration**
6. **Year** of manufacture (70-90)
7. Country of **Origin** (1=American, 2=European, 3=Japanese)

4.5.2 Hypotheses:

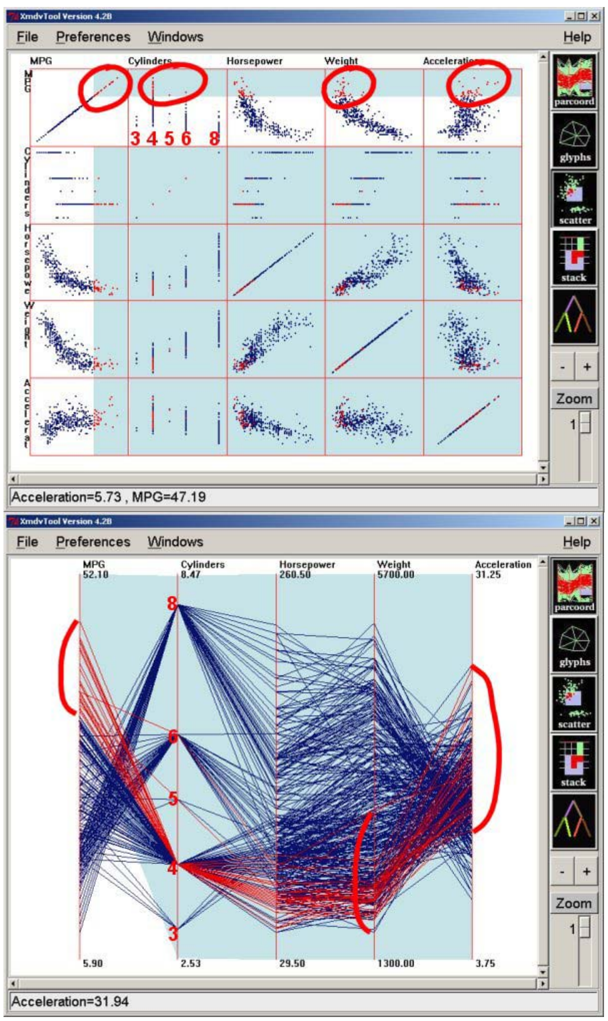
1. The cars with high MPG will be mostly 4 cylinder cars with low weight and acceleration.

Appendix F (continued)

2. Japanese make low weight cars.
3. Horsepower is highly correlated with weight overall.

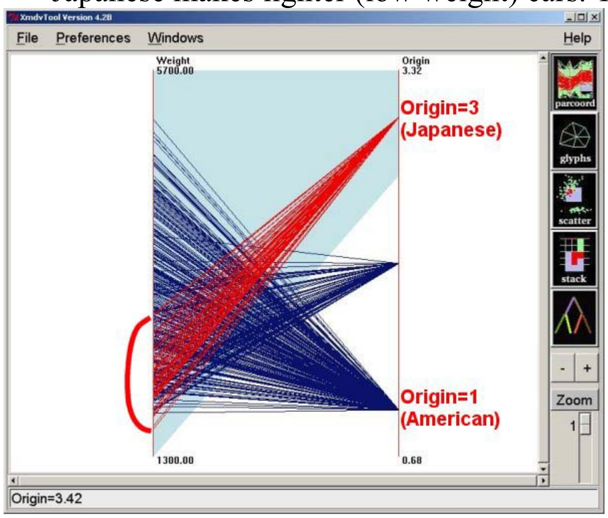
4.5.3 Analysis (to verify or refute any of these hypotheses):

1. Highlight cars with high MPG in order to verify that most of them are 4 cylinder cars with low weight, but not necessarily with low acceleration. Therefore, refute this hypothesis.

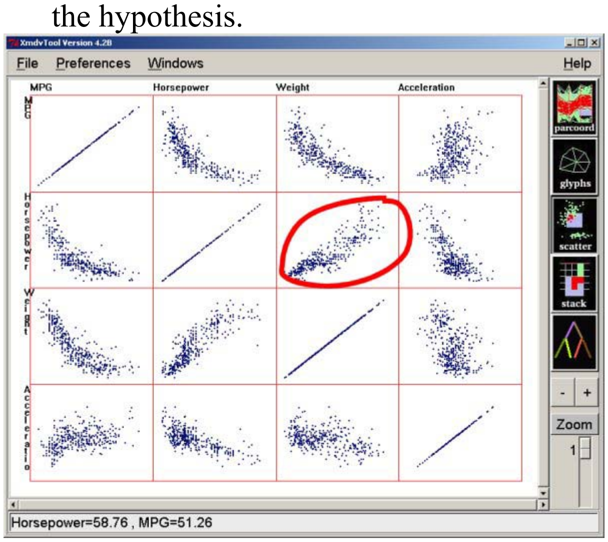


Appendix F (continued)

2. Highlight Japanese (Origin=3) on the parallel coordinates. The graphs show that Japanese makes lighter (low weight) cars. Therefore, verify this hypothesis.



3. The scatter plot shows high correlation between Horsepower and Weight. Verify the hypothesis.

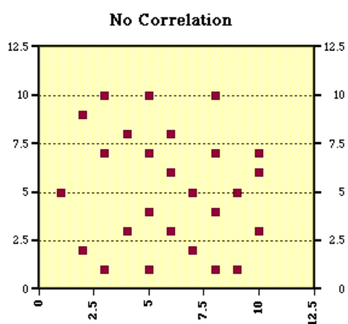


Appendix F (continued)

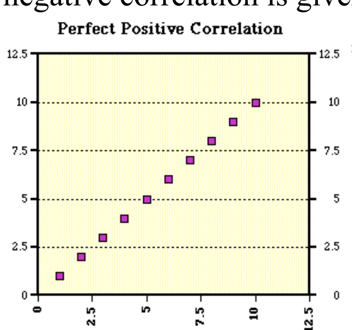
Scatter Plot:

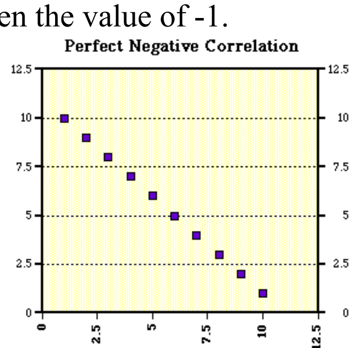
A scatter plot (Chambers 1983) reveals relationships or association between two variables. The relationship between two variables is called their **correlation**. A scatter plot usually consists of a large body of data. The closer the data points come when plotted to making a straight line, the higher the correlation between the two variables, or the stronger the relationship. If the data points make a straight line going from the origin out to high x- and y-values, then the variables are said to have a **positive correlation**. If the line goes from a high-value on the y-axis down to a high-value on the x-axis, the variables have a **negative correlation**.

No relationship: If there is absolutely no correlation present the value given is 0.



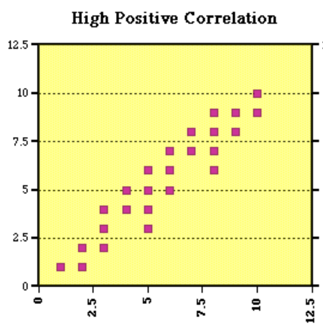
Perfect Correlation: A perfect positive correlation is given the value of 1. A perfect negative correlation is given the value of -1.

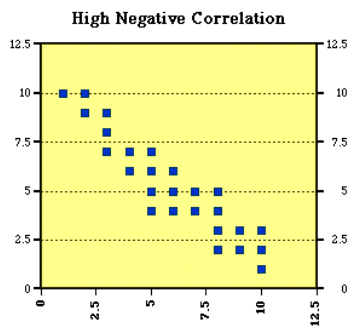




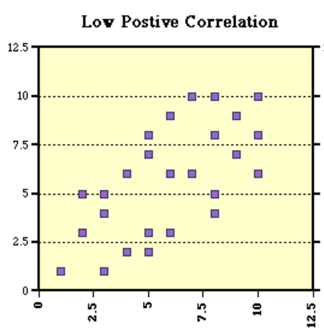
Strong linear correlation: The closer the number is to 1 or -1, the stronger the correlation, or the stronger the relationship between the variables.

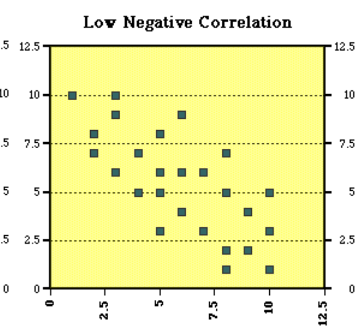
Appendix F (continued)



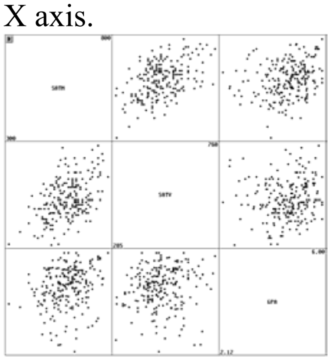


Weak linear correlation: The closer the number is to 0, the weaker the correlation.





Scatter plot matrix: Given a set of variables, the scatter plot matrix contains all the pair-wise scatter plots of the variables on a single page in a matrix format. The example generated by the SAS statistics tool shows a 3x3 scatter plot matrix of the variables SATM, SATV, and GPA. The plots are arranged so that adjacent plots share a common axis. All plots in a row share a common Y axis and all plots in a column share a common X axis.

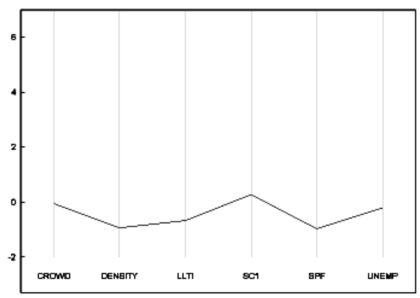


Appendix F (continued)

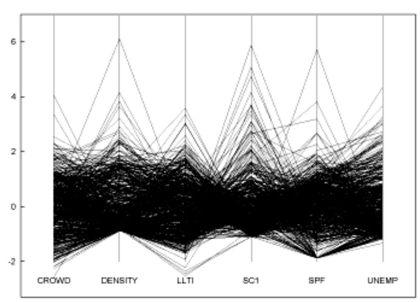
Parallel Coordinates:

The Parallel coordinates is a technique pioneered in the 1970's which has been applied to a diverse set of multidimensional problems (Inselberg et al. 1987). In this method, each dimension corresponds to an axis, and the N axes are organized as uniformly spaced vertical lines. A data element in N-dimensional space manifests itself as a connected set of points, one on each axis. Points lying on a common line or plane create readily perceived structures in the image.

A Parallel Coordinate Representation of One Case: CROWD=0, DENSITY=-0.9, LLTI=-0.6, SC1=0.2, SPF=-1, UNEMP=-0.2



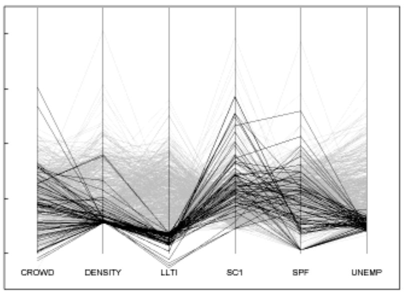
Parallel Coordinates Plot: To view an entire dimensional data set one simply plots all observations on the same graph. For large data sets, the appearance of such a plot appears confusing, but can be used to highlight outliers.



Blushing of Parallel Coordinates Plot (Lowest Decile of LLTI Highlighted): However, the real strength of the technique can be seen when subsets of the data are selected,

Appendix F (continued)

usually on the basis of one particular variable. In this example, the subset of the data in the lowest decile of the variable LLTI is shown in black, and the remainder of the dataset in gray. However, looking at the locations of the black lines on the other axes shows whether the low values of this variable tend to be accompanied by any notable distributional patterns in the other variables. From the plot, it may be seen that often there are also low values of DENSITY and UNEMP.

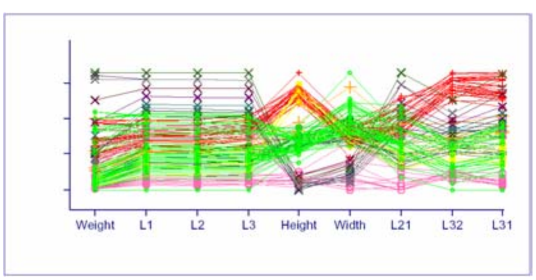


High Linear Correlation in Parallel Coordinates – Example 1 (a line in 3D):

The line segments x1 = t; x2 = 1 – 0.5*t; x3 = 0.5 – 0.1*t; with 0 < t < 1 is drawn in normal 3D coordinates and in the parallel coordinates plot. The color is relative t value. Note that each point on the line becomes two line segments in the parallel coordinates plot (x1-to-x2 and x2-to-x3).

This parallel coordinates plot shows high inverse linear correlation between x1 and x2 and high linear correlation between x2 and x3.The 3D scatter plot depicts the data represents a line in 3D.

High Linear Correlation in Parallel Coordinates – Example 2 (the fish data with 9 variables): The parallel coordinates plot shows that the three length variables (L1, L2, L3) are very highly correlated. This finding implies that the variables L2 and L3 contribute very little additional information.



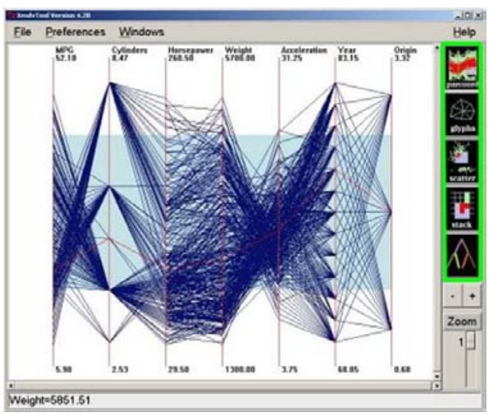
Appendix F (continued)

<u>XmdvTool Overview:</u>

XmdvTool is a public-domain software package for the interactive visual exploration of multivariate data sets. Xmdvtool supports brush-and-linkable scatter plot matrices, parallel coordinates, star glyphs, dimensional stacking, and hierarchical parallel coordinates.

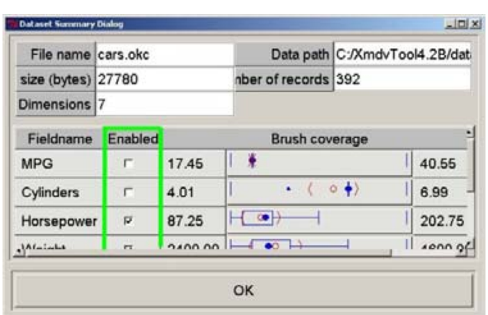
Selecting a graph tool:

1. Click the tool icon button on the right to select the different graph tool.



Selecting dimensions (variables):

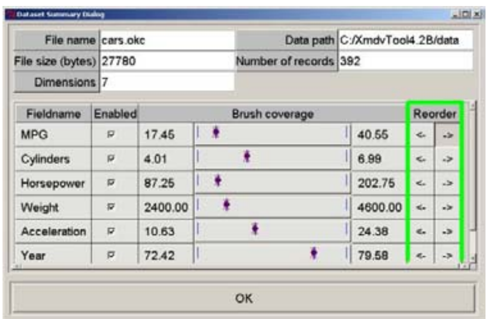
1. On the **Windows** menu, click **Dataset Summary Dialog**.
2. Click the toggle button **Enabled** to enable or disable the dimension.
3. Click **OK**.



Appendix F (continued)

Reordering dimensions (variables):

1. On the **Windows** menu, click **Dataset Summary Dialog**.
2. Click the button **Reorder** left or right right arrow to move the dimension.
3. Click **OK**.



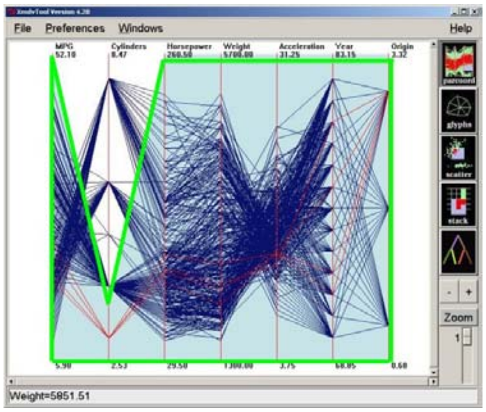
Brush Toolbox:

1. On the **Windows** menu, click **Brush Toolbox**.
2. On the **Brush Selection** on Brush Toolbox, click button to enable and display different brushing tool.
3. On the **Global Brush Resize** on Brush Toolbox, click button to resize brushing tool.
4. Click **OK**.

Brushing data on the graph:

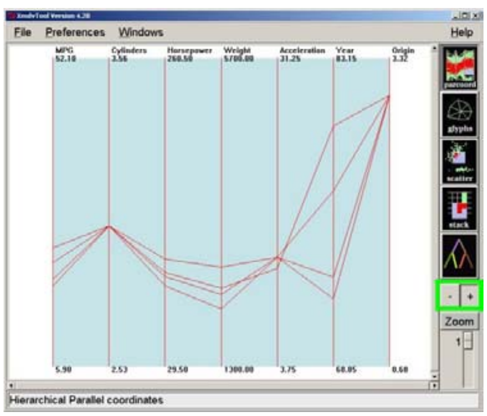
1. On scatter plot or parallel coordinates, move a mouse pointer to brush data.

Appendix F (continued)



Magnifying brushed data (region zoom):

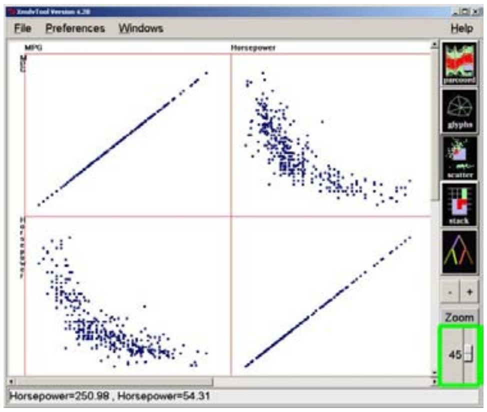
1. Click the '+' icon button on the right to magnifying brushed data.
2. To bring back to normal, click the '-' icon button.



Zoom main canvas:

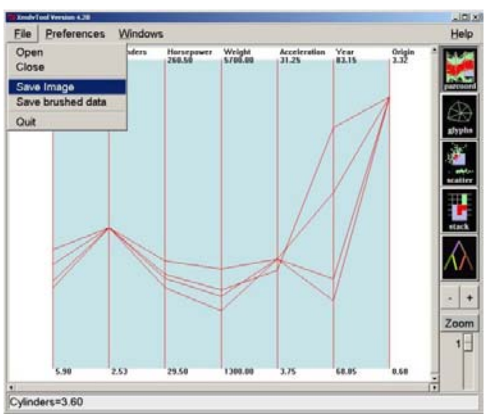
1. Move the zoom scroll bar for zooming the main canvas.

Appendix F (continued)



Save image:

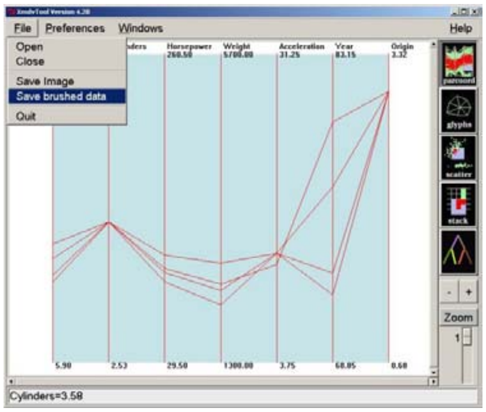
1. On the **File** menu, click **Save Image**.
2. Type the name for an image file.
3. Click **OK**.



Save brushed data:

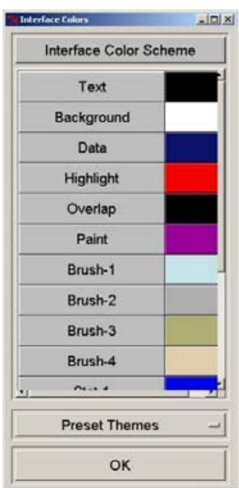
1. On the **File** menu, click **Save brushed data**.
2. Type the name for a data file.
3. Click **OK**.

Appendix F (continued)



Changing color scheme:

1. On the **Preferences** menu, click **Color Requestor**.
2. Click the color button to change different color.
3. Click **OK**.



Reference:

XmdvTool, http://davis.wpi.edu/~xmdv/

Appendix G

Information Query and Gathering

Instruction:

In the information query and gathering task (30 minutes), you and your group members will work cooperatively to query and gather information on the web to answer the questions.

1) **Understand the questions.**
2) **Search the web for relevant information on a particular topic.**
   You can use automated search engines during this process. Since search engines have different criteria in creating the indexes, it is useful to use more than one engine in searching the web to gain relevant information. Example search engines are below:
   - Altavista - http://www.altavista.com
   - Excite - http://www.excite.com
   - Google - http://www.google.com
   - Hotbot - http://hotbot.lycos.com
   - Infoseek - http://infoseek.go.com
   - MSN Search - http://search.msn.com
   - Teoma - http://www.teoma.com
3) **Write up a report on your group findings on Smartboard electronic whiteboard.**
   Write up a summary of your answers and the relevant web links **as many as you can** to prove your findings. Note that different web sites with almost identical information are considered one finding.

Cuba Questions:

1) How much sugar does Cuba export and which countries import it (in 1990~2001)? List the quantity of sugar export in 1990~2001.
2) Who are the two top most buyers in 1990~2001?
3) Find the trend of Cuban sugar production and export in 1990~2001.

Appendix G (continued)

University Questions:

You are guidance counselors helping a student, Joe, to find the college that is right for him.

1. What are the admission requirements (e.g. minimal GPA, SAT I & II) for each university?
2. What are 2002-2003 expenses (e.g. in-state, out-of-state tuition and fees, and room and board) for each university?
3. Decide which department and university is the best for Joe. Explain your decision criteria in depth.

Joe is interested in following schools:

- California Institute of Technology
- University of California at Berkeley
- University of Michigan at Ann Arbor
- University of Washington at Seattle
- Washington University in St. Louis

Joe's stats are:

- SAT I verbal: 670
- SAT I math: 690
- relevant GPA: 3.53/4.0
- Annual tuition & fee level: Up to $20,000
- Annual living cost level: Up to $15,000
- Career interest: Discover new drugs in Brazilian rain forest
- Glendale High School, California

Appendix H

Information Analysis and Pattern Detection

Instruction:

In the information analysis and pattern detection task (45 minutes), you and your group members will work cooperatively to perform exploratory data analysis on a dataset: exploration (searching a dataset for interesting phenomena), confirmation (validating or refuting a hypothesis about phenomena in the data), and presentation (conveying information to others).

1) **Scan the raw data and hypotheses/questions.**
   Briefly scan the text of raw data and familiarize yourself with the variables (dimensions). Also, briefly scan the hypotheses that are given.
2) **Use XmdvTool to explore around the dataset.**
   Load the data into XmdvTool, and test hypotheses. See if you can find evidence to verify or refute any of these hypotheses. Also, look for other unexpected kinds of relations.
3) **Write up a report of your group findings on Smartboard.**
   Write up a summary of these results of what your group found. You should include **some snapshots** (i.e. the name of ppm image file) to help convey your discoveries in the summary.

Data2.okc:

Data2.okc has 77 observations and 15 variables (Obs.No., A, B, C, D, E, F, G, H, I, J, K, L, M, N, and O).

Hypotheses and questions:

1. Verify or refute the following statement: When A's values are 0 (A=0), H's values are also ranked high (high H).
2. Verify or refute the following statement: When G, J, and F's values are low (low G, low J, low F), M also has high values (high M).
3. Verify or refute the following statement: When D's values are high (high D), F and J also have high values (high F, high J). Find the other variable(s) that relate to high values in D (D>130).
4. Verify or refute the following two statements: N has no correlation to any other variables. O has no correlation to any other variables.

Appendix H (continued)

5. Find B's values when M has the highest value (M=100). Find B's values when M has the lowest value (M=0). Find the other variable(s) that are also related to the highest and the lowest M.
6. Find Obs.No.'s value(s) when B's values are 2, E and H's values are high, but J and F's values are low (B=2, high E, high H, low J, low F).
7. Find the highly correlated variables (strong correlation between two variables).

Data1-1.okc & Data1-2.okc:

Data1-1.okc has 506 observations and 10 variables (Obs.No., A, B, C, D, E, F, G, H, I, and J).
Data1-2.okc has 506 observations and 13 variables (Obs.No., A, B, C, D, K, L, M, N, O, P, Q, R, and S).

Hypotheses and Questions:

1. Verify or refute the following statement: When O's values are low (O<25) and N's values are high (N>7), C's values are also ranked high (high C). What is the general trend in other variables when O<25 and N>7?
2. Verify or refute the following statement: When K's values are high (K>30), C's values are also ranked low (low C). What is the general trend in other variables when K>30?
3. Verify or refute the following statement: When L's values are 0 and M's values are 18 (L=0, M=18), I and J also have high values (high I, high J).
4. Verify or refute the following statement: When H's values are the highest (H=0.871), K and L also have low values (low K, low L).
5. Verify or refute the following statement: When C's values are low (C<=10), G and I also have low values, but K and P have high values (low G, low I, high K, high P).
6. Find the highly correlated variables (strong correlation between two variables) overall.
7. Find the variable(s) that are highly correlated with C (overall).

Appendix I

Collaborative Brainstorming and Design

Instruction (Design ideas for improvements):

In the collaborative brainstorming task (30 minutes), **you and your group members will work cooperatively to come up with a better version of the Continuum**. Ideally we want the Continuum to be a room that will help people work together even though they are 1000s of miles apart.

1) **Brainstorm for ideas.**
   Given your experience with the current version of the Continuum, how might you improve the design of Continuum to better support collaborative work? Think of ideas for better hardware; better layout of the hardware in the room; and better software capabilities, etc.
2) **Prioritize your ideas.**
   Group together any ideas that are similar or related. In each group, sort the ideas in terms of "most important" first.
3) **Summarize and explain your ideas.**
   Using the Smartboard, summarize your entire group's ideas to your evaluator. You should include **the prioritized list and any drawings (sketches)** in your summary, as well as explain why you think they are important.

Instruction (Suggestions for future users):

This is a collaborative brainstorming task (30 minutes). Last time you have worked on brainstorming design ideas to improve Continuum technologies to better support collaborative work. **This time, you and your group members will work cooperatively to come up with advice for future users to make the best use of current Continuum technologies.**

1) **Brainstorm for ideas.**
   Given the technological constraints in the current version of the Continuum, how would you suggest which way to use the Continuum to share information (such as documents, data and/or visualizations) with remote collaborators?
2) **Prioritize your suggestions.**
   Group together any ideas that are similar or related. In each group, sort the ideas in terms of "most important" first.
3) **Summarize and explain your suggestions.**

Appendix I (continued)

Using the Smartboard, summarize your entire group's ideas to your evaluator. You should include **the prioritized list and any drawings (sketches)** in your summary, as well as explain why you think they are important.

Appendix J

Informed Consent Form

University of Illinois at Chicago
Consent for Participation in Research
The Continuum: Advanced Collaborative Work Environment

<u>Why am I being asked?</u>

You are being asked to be a subject in a research study about the design of technologies and user interfaces for the Continuum advanced collaborative work environment. Continuum is designed to help distributed teams to work in intensive collaboration sessions. The goal of this research is to identify the appropriate technologies that encourage increased collaboration and performance. Your feedback is an important part in determining the effectiveness of this proposal. This research is being conducted under the direction of Kyoung S. Park, Jason Leigh and Andrew Johnson, Electronic Visualization Laboratory, Computer Science Department of the College of Engineering at the University of Illinois at Chicago. Kyoung S. Park is a graduate student, who is doing this research as part of her dissertation, and is the primary researcher of this investigation. Jason Leigh and Andrew Johnson are acting as the faculty sponsors for this dissertation. You have been asked to participate in the research because you have interests of using our advanced collaborative work environment. You are a graduate (or undergraduate) student at UIC and/or are a UIC employee. You may be eligible to participate. We ask that you read this form and ask any questions you may have before agreeing to be in the research.

Your participation in this research is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University. If you decide to participate, you are free to withdraw at any time without affecting that relationship.

Appendix J (continued)

4.2 Why is this research being done?

Most of the work in the field of computer supported cooperative work and its related fields have focused on technologies for electronic workspaces for sharing and disseminating information and for creating communication technologies for remote collaboration. While these technologies are valuable, there has recently been a reassessment of the basic value of team members working in dedicated project rooms, often called “war-rooms”. The results of fieldwork and interviews conducted at several corporate sites suggested that war-rooms lead to increased learning, coordination, and productivity. The Continuum Project is an effort to explore new technologies and tools to extend these same benefits for remote teamwork.

What is the purpose of this research?

This is survey research designed to obtain user evaluations during the use of Continuum and after using Continuum – opinions and recommendations for consideration and potential implementation. The Continuum is an augmented work environment where distributed knowledge workers (such as, scientists and engineers) solve complex problems using advanced collaboration, computational and visualization technologies. The collaboration and visualization technologies include a multi-party video conferencing system called Access Grid, an interactive stereoscopic display called AGAVE (Access Grid Augmented Virtual Environments), high-resolution tiled displays, and shared plasma touch screens. One of the goals of this study is to investigate how behavior in Continuum differed from regular meetings. User interaction and group behavior with Continuum presents design challenges for not only effective interaction with the work-related data but also for communication and interaction with distantly located collaborators. A better understanding of what can be achieved in Continuum and what aspects of distance will remain, will help us to better choose the appropriate technologies and to craft an organizational design that creates effective remote work.

What procedures are involved?

If you agree to be in this research, we would ask you to do the following things:

- Discuss this consent form and your choice of whether or not to participate in this research and take a brief motor and visual skills test to indicate your physical ability to participate in the research (10 minutes).

Appendix J (continued)

- Receive a brief presentation about the Continuum technologies and how to use the software user interfaces (10 minutes).
- Receive the task instructions and basic concepts of correlation statistics and multivariate dataset analysis; such as scatter plot matrix and parallel coordinates (20 minutes).
- Perform a collaborative group work
    - Play a concentration game twice (15 minutes).
    - Short break (5 minutes)
    - Search web sites to find answers for two or three questions (30 minutes).
    - Short break (5 minutes)
    - Analysis a dataset to answer five or seven questions using an information visualization tool (45 minutes).
    - Short break (5 minutes)
- Evaluate the Continuum (10 minutes).
    - Answer several questions to rate the usability, readability and general effectiveness of the tools provided verbally and in written paper forms.

You will not be penalized if you are unable to complete the task.

During your experience with Continuum you will be photographed or videotaped for document purposes. By signing this consent document, you are agreeing to photographed or videotaped during each interview. If you choose not to be photographed or videotaped, you will not be eligible to participate in this research project.

You may choose not to answer any of questions during the evaluation of the Continuum. The time involving the evaluation of the Continuum will involve you verbally answering questions that will allow you to give feedback about different aspects of the Continuum.

At any time, you may choose to take a break. During the break, recording will be stopped. You will determine the length of the break. After you decide to end the break, you may continue participation or end participation. There will be no penalty for choosing to end participation at any point during the research session.

Approximately 60 people may be involved in this research at the University of Illinois at Chicago.

Appendix J (continued)

What are the potential risks and discomforts?
The risks associated with this research are minimal:

In most cases, the experience will cause a level of discomfort comparable with standard computer usage. The computer usage you will be performing is not extraordinary and can be compared to typical computer usage with using the operating system and applications.

You may experience physical or mental fatigue, frustration, or negative feelings toward yourself if you have a difficult time completing the task or using the various collaboration technologies that we offered. These same feelings may also apply while answering the written survey or verbal interview questions. It is very unlikely that any of these discomforts will be long lasting or permanent.

At any time, you may choose to take a break. During the break, recording will be stopped. You will determine the length of the break. After you decide to end the break, you may continue participation or end participation. There will be no penalty for choosing to end participation at any point during the research session.

Are there benefits to taking part in the research?
There are no direct benefits to the subject to taking part in this research.

What about privacy and confidentiality?
The only people who will know that you are a research subject are members of this research team. No information about you, or provided by you during the research, will be disclosed to others without your written permission, except:

- if necessary to protect your rights or welfare (for example, if you are injured and need emergency care or when the UIC Institutional Review Board monitors the research or consent process); or
- if required by law.

When the results of the research are published or discussed in conferences, no information will be included that would reveal your identity.

Appendix J (continued)

All materials that include records, raw data, questionnaires, audio, or video related to this study will be stored under lock and key within the Electronic Visualization Laboratory facilities. Only researchers assigned to the study will have access to these materials. These materials will be kept until the primary investigator completes her doctoral degree or for the duration of 2 (two) years, whichever occurs sooner. Once the materials no longer are kept, videotapes will be erased, written notes will be shredded and thrown into the garbage, and computer files will be erased.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

What if I am injured as a result of my participation?

In the event of injury related to this research study, treatment will be made available through the University of Illinois at Chicago Hospital. However, you or your third party payer, if any, will be responsible for payment of this treatment. There is no compensation and/or payment for such medical treatment from the University of Illinois at Chicago for such injury, except as may be required of the University by law. If you feel you have been injured, you may contact the faculty advisors, Jason Leigh and Andrew Johnson at 312-996-3002.

What are the costs for participating in this research?

There are no costs associated with participation in this research.

Will I be reimbursed for any of my expenses or paid for my participation in this research?

You will not receive any payment or reimbursement for participation in this research.

Can I withdraw or be removed from the study?

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don’t want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

Appendix J (continued)

Why should I contact if I have questions?
The primary researcher conducting this study is Kyoung S. Park. The faculty advisors are Jason Leigh and Andrew Johnson. You may ask any questions you have now. If you have questions later, you may contact the researchers at: Phone: 312-996-3002.

What are my rights as a research subject?
If you have any questions about your rights as a research subject, you may call the primary investigator or faculty sponsors at 312-996-3002. You may also call the Office for Protection of Research Subjects at 312-996-1711.

What if I am a UIC student?
You may choose not to participate or to stop your participation in this research at any time. This will not affect your class standing or grades at UIC. The investigator may also end your participation in the research. If this happens, you class standing or grades will not be affected. You will not be offered or receive any special consideration if you participate in this research.

What if I am a UIC employee?
Your participation in this research is in no way a part of your university duties, and your refusal to participate will not in any way affects your employment with the university, or the benefits, privileges, or opportunities associated with your employment at UIC. You will not be offered or receive any special consideration if you participate in this research.

Remember:
Your participation in this research is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University. If you decide to participate, you are free to withdraw at any time without affecting that relationship. You will be given a copy of this form for your information and to keep for your records.

Signature of Subject or Legally Authorized Representative:
I have read the above information. I have been given an opportunity to ask questions and my questions have been answered to my satisfaction. I agree to participate in this research. I have been given a copy of this form.

Appendix J (continued)

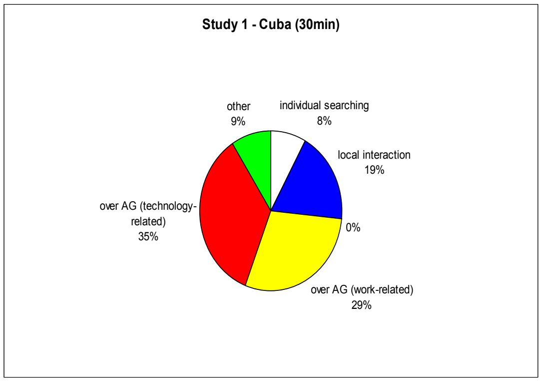
____________________________ ___________
Signature Date

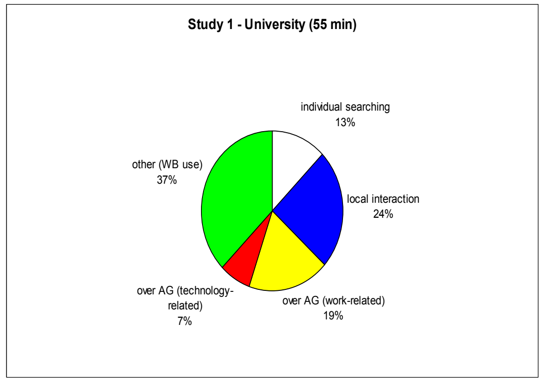
____
Printed Name

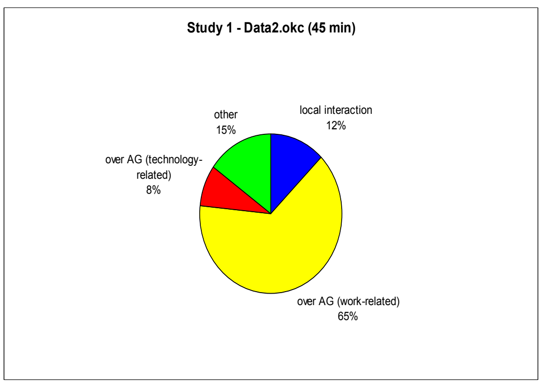
____________________________ ___________
Signature of Researcher Date (must be same as subject's)

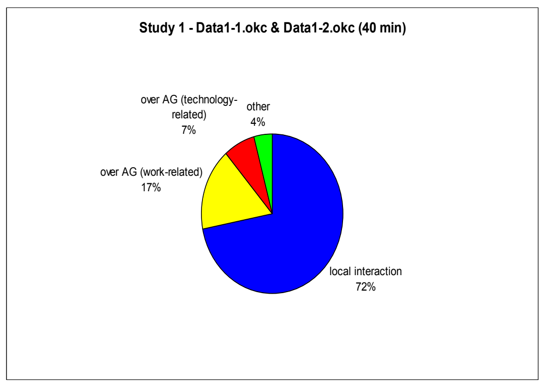
Appendix K

Group Work Pattern

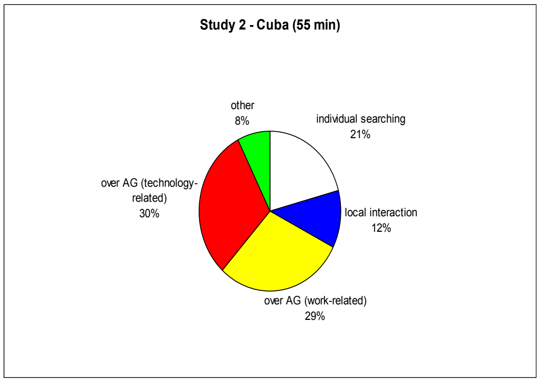


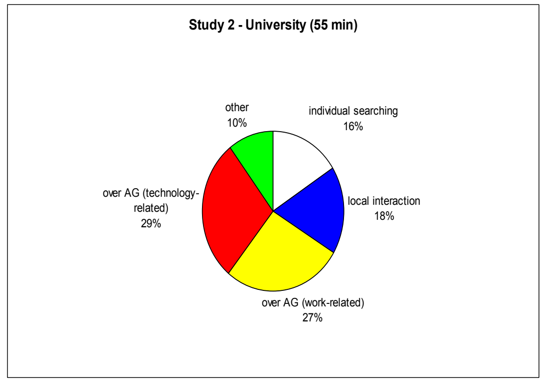


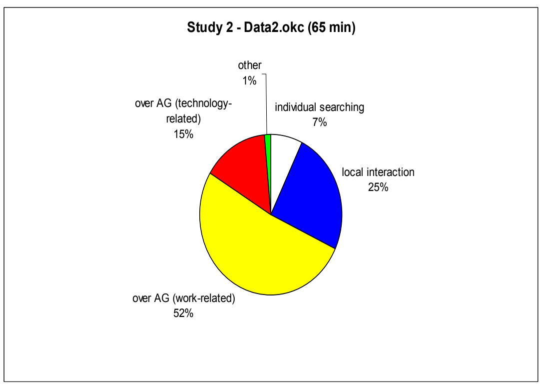


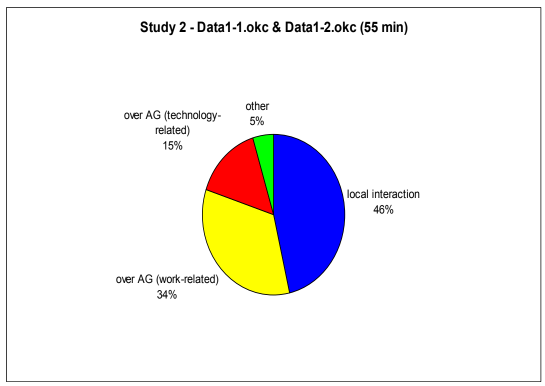


Appendix K (continued)

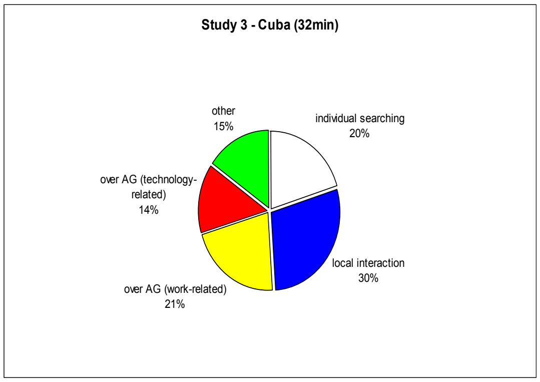


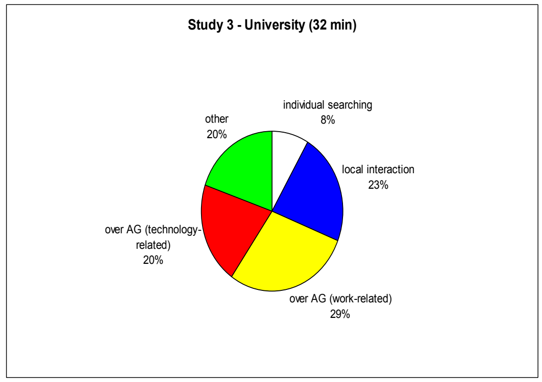


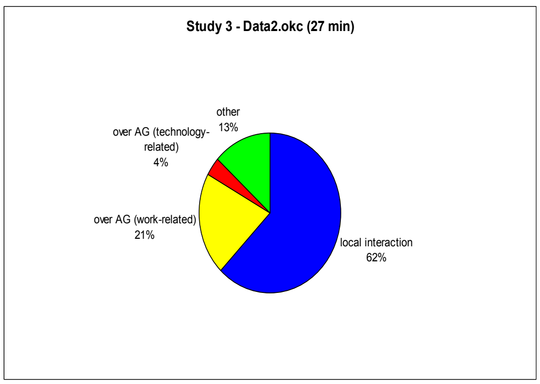


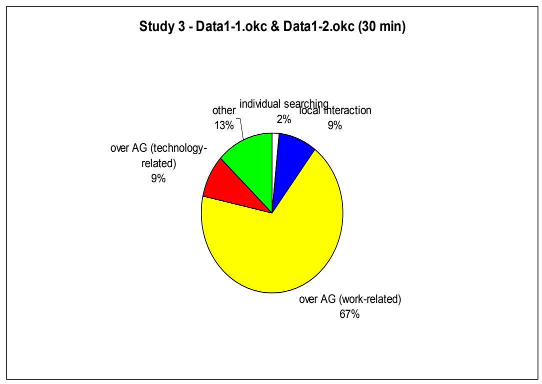


Appendix K (continued)

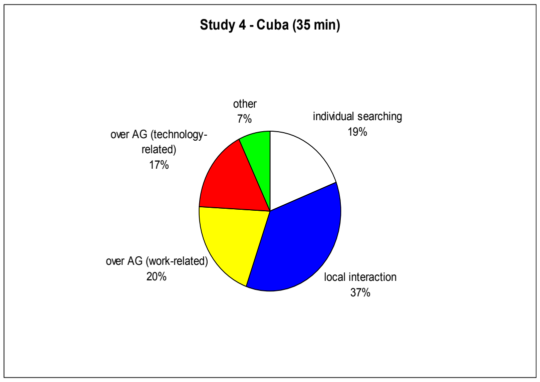


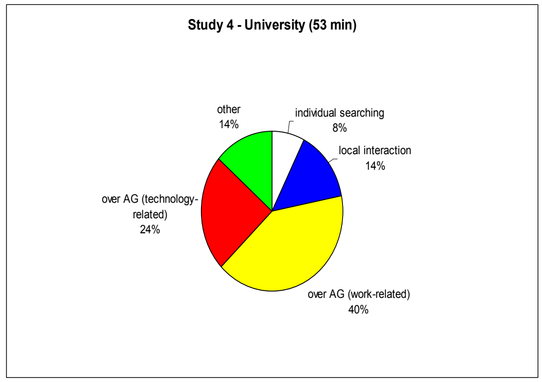


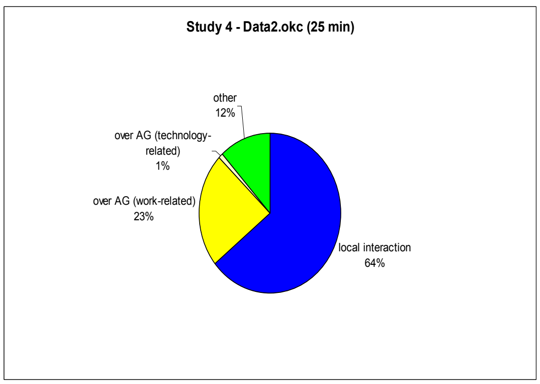


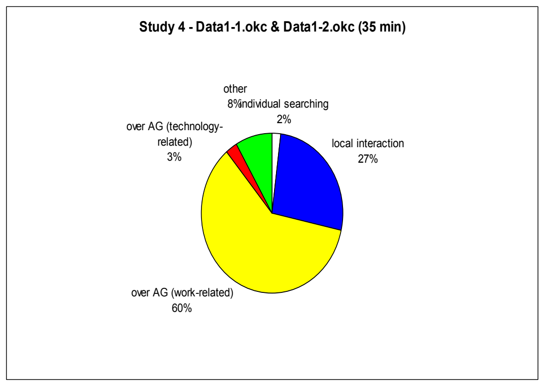


Appendix K (continued)









VITA

NAME: Kyoung Shin Park

EDUCATION: Ph.D., Computer Science, University of Illinois at Chicago, 2003

M.S., Electrical Engineering and Computer Science, University of Illinois at Chicago, 1997

B.S., Mathematics, Duksung Women's University, Seoul, Korea, 1991

TEACHING EXPERIENCE: Department of Electrical Engineering and Computer Science, University of Illinois at Chicago, Chicago, Illinois: Computer Graphics, August 1995 ~ December 1995.

EMPLOYMENT: Electronic Visualization Laboratory, University of Illinois at Chicago, Chicago Illinois: Research Assistantship, January 1996 – December 2003.

Argonne National Laboratory, Argonne, Illinois: Summer Intern, June – September 1995.

Department of Electrical Engineering and Computer Science, University of Illinois at Chicago, Chicago Illinois: Tuition Scholarship, August 1994 – July 1995.

PROFESSIONAL ACTIVITIES:
Member, Association for Computing Machinery
Member, IEEE Computer Society
Demo Support Team, IGRID 2002
Demo Support Team, IGRID 2000
Demo Support Team, Supercomputing '99: ASCI
Demo Support Team, Supercomputing '98: IGRID
Treasurer, Korean Graduate Student Association '96 - '98
Student Volunteer, Computer Supported Collaborative Works '96
Student Volunteer, Supercomputing '95: GII Testbed
Member, Honor College at the University of Illinois at Chicago '93 - '94
Student Volunteer, Seoul Olympic Game '88

HONORS:
International Student Service Award at UIC '98
Scholarship in Korean American Scholarship Foundation '96
Dean's List in the College of Engineering at the University of Illinois at Chicago '93

PUBLICATIONS
Park, K., Renambot, L., Leigh, J., Johnson, A., The Impact of Display-rich Environments for Enhancing Task Parallelism and Group Awareness in Advanced Collaborative Environments, In Workshop on Advanced Collaboration Environments, Seattle, WA, June 22-24, 2003.

Leigh, J., Renambot, L., DeFanti, T., Brown, M., He, E., Krishnaprasad, N., Meerasa, J., Nayak, A., Park, K., Singh, R., Venkataraman, S., Zhang, C., Livingston, D. and McLaughlin, M., An Experimental OptiPuter Architecture for Data-Intensive Collaborative Visualization , In Workshop on Advanced Collaboration Environments, June 22-24, 2003, Seattle, WA.

Leigh, J., Johnson, A., Park, K., Nayak, A., Singh, R., Chowdry, V., Amplified Collaboration Environments, In the proceedings of VR Grid Workshop, November 26, 2002, Daejun, Korea, pp. 77-85.

Thorson, M., Leigh, J., Maajid,G., Park, K., Nayak, A., Salva, P., Berry, S., AccessGrid-to-Go : Providing AccessGrid access on Personal Digital Assistants, In proceedings of Access Grid Retreat, La Jolla CA, March 4-5, 2002.

Leigh, J., Girado, J., Singh, R., Johnson, A., Park, K., DeFanti, T., "TeraVision: a Platform and Software Independent Solution for Real Time Display Distribution in Advanced Collaborative Environments." In proceedings of Access Grid Retreat, La Jolla CA, March 4-5, 2002.

Park, K., Leigh, J., Johnson, A., How Humanities Students Cope with the Technologies of Virtual Harlem, In Virtual Experiences of Harlem Renaissance: The Virtual Harlem Project - Works and Days 37/38, Spring/Fall 2001, Vol 19. 1 & 2, pp. 67-76.

Park, K., Leigh, J., Johnson, A., Carter, B., Brody, J., Sosnoski, J., Distance Learning Classroom Using Virtual Harlem, In the proceedings of the Seventh International Conference on Virtual Systems and Multimedia (VSMM 2001), Berkeley CA, Oct 25-27, 2001, pp. 489-498.

Leigh, J., Yu, O., Schonfeld, D., Ansari, R., He, E., Nayak, A., Ge, J., Krishnaprasad, N., Park, K., Cho, Y., Fang, R., Verlo, A., Winkler, L., DeFanti, T., Adaptive Networking for Tele-Immersion, Proceedings of the Immersive Projection Technology/Eurographics Virtual Environments Workshop (IPT/EGVE), May 16-18, Stuttgart, Germany, 2001.

Park, K., Cho, Y., Krishnaprasad, N., Scharver, C., Lewis, M., Leigh, J., Johnson, A., CAVERNsoft G2: A Toolkit for High Performance Tele-Immersive Collaboration, Proceedings of the ACM Symposium on Virtual Reality Software and Technology 2000, Oct 22-25, 2000, Seoul, Korea, pp. 8-15.

Park, K., Kapoor, A., Leigh, J., Lessons Learned from Employing Multiple Perspectives In a Collaborative Virtual Environment for Visualizing Scientific Data, Proceedings of ACM CVE 2000, San Francisco, CA, 09/10/00-09/12/00, pp. 73-82.

Park, K., Kapoor A., Scharver, C., Leigh, J., Exploiting Multiple Perspectives in Tele-Immersion, Proceedings of IPT 2000: Immersive Projection Technology Workshop, Ames, IA, 06/19/00-06/20/00.

Leigh, J., Johnson, A., DeFanti, T., et al., A Review of Tele-Immersive

Applications in the CAVE Research Network, Proceedings of IEEE VR99, Houston TX, March 13-17, 1999.

Park, K., Kenyon, R., Effects of Network Characteristics on Human Performance in a Collaborative Virtual Environment, Proceedings of IEEE VR `99, Houston, TX, 03/13/99-03/17/99.

Leigh, J., Park, K., Kenyon, R., Johnson, A., DeFanti T., Wong, H., Preliminary STAR TAP Tele-Immersion Experiments between Chicago and Singapore, Proceedings of HPCAsia '98, Singapore, 09/22/98-09/22/98, pp. 687-693.