Effective Space Organization Design for Large High-Resolution Environments

BY

HYEJUNG HUR
B.E., Duksung Women's University, 1999
M.S., Duksung Women's University, 2001

THESIS

Submitted as partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Computer Sciences
in the Graduate College of the
University of Illinois at Chicago, 2015

Chicago, Illinois

Defense Committee:

Andrew Johnson, Chair and Advisor
Jason Leigh
Tom Moher
Steve Jones, Department of Communication
Derrick Mancini, Argonne National Laboratory

ACKNOWLEDGEMENTS

First and foremost I would like to express gratitude to my advisor, Dr. Andrew Johnson, who gave me guidance and support in my PhD study. He was always available to provide feedback, offer advice. His feedback guided me to think about different perspectives and my lack points. This dissertation would not have been possible without his advice. I am deeply indebted to him. Many thanks go to Dr. Jason Leigh, who shared his remarkable experience. I also would like to thank the rest of my dissertation committee: Dr. Tom Moher, Dr. Steve Jones, and Dr. Derrick Mancini, for providing insightful comments.

I have to thank people at Argonne National Laboratory: Rodney East, Marcia Wood, Avarca Anthony, Dr. Katie Gregar, Dr. Daniel Lopez, Dr. Michael Papka, and Mirelez Rachel. They always supported my research and gave me feedback.

Sincerely, I would like to thank to every members at Electronic Visualization Laboratory. Special thanks go to Dr. Luc Renambot and Lance Long. They always helped, responded to my questions, and shared their experience. Many thank s to Maxine Brown and Dana Pleplys for their support.

Lastly, I would like to thank to my family.

HH

ii

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

xiii

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF ABBREVIATIONS

CAVE2   CAVE Automatic Virtual Environment 2

SAGE   Scalable Adaptive Graphics Environment

EVL   Electronic Visualization Laboratory

LCD   Liquid Crystal Display

UI   User Interface

DIM   Direct Interaction Manager

API   Application Programming Interface

LHD   Large High-resolution Display

SUMMARY

Theses days vast amounts of information are continuously being created. By analyzing these data, we could help solve current issues that we are faced with, and we might have a better ability to predict the future. Large high-resolution displays can support increasing the amount of data displayed. Therefore, large high-resolution environments have the potential to provide affordable infrastructure to maximize insight for exploration and analytic work on large and complex data. Unfortunately the current usage of large high-resolution environments has been limited to presentation, demonstration, or user studies due to usability issues on large high-resolution displays. User behavior analysis researchers have found that it became more difficult and time consuming to access and manipulate information as screen size increased, users were easily frustrated and confused when they changed environments, users wasted more space on large high-resolution displays, and users felt guilty about the wasted space. These usability issues can hinder the user from concentrating on their task and data. These are serious issues in moving beyond the current usage of large high-resolution display environments. As display size increases, the degree of these usability issues will also increase.

This dissertation focuses on space organization design to solve usability issues. Space organization design can impact how users can effectively make use of large high-resolution displays. First, we observed user behaviors in different use cases on large high-resolution displays. We introduced design principles driven from these observations.

SUMMARY (Continued)

We proposed space organization design. It consists of space organization policies, new enhanced techniques, and multi-touch interaction. To evaluate the proposed design we conducted a comparative user study in a data exploration and analytic workspace, and a case study in small group meeting space. The proposed design significantly impacts the user's analytic activity and usage of the space. Information manipulation time was significantly reduced, so participants could focus more on their task and data. Activity transitions were subtly changed to improve transition flow, which included less space layout activity. The used space ratio was significantly increased, the distribution used space was significantly fair, and the focal area of usage was slightly wider.

1   INTRODUCTION

These days vast amounts of information are continuously being created. All information is not always valuable, but much of this information could affect our lives in beneficial ways. Big data is a collection of data sets, typically large and complex data. By analyzing these data we could help solve current issues that we are faced with, and we might have a better ability to predict the future. To analyze these data we need applications to process and visualize the data. In addition, we also need large high-resolution displays (LHDs) to see the data in a more effective way. In this thesis, we focus on viewing data in large high-resolution display environments.

The Electronic Visualization Laboratory (EVL) has created a variety of large high-resolution displays for regular use in the lab. EVL began with 2x2 tiled-display with 20" LCDs in 2000. Five years later LambdaVision, an 11x5 –106 megapixel tiled display wall, was built. In 2009, EVL set up the Cyber-Commons, a 6x3 –18 megapixel near-seamless tiled display wall. The latest new large high-resolution display in EVL is CAVE2, which is 18x4 –74 megapixel near-seamless 320-degree panoramic tiled display wall. It was completed in 2012 (see figure 1). Large high-resolution tiled displays are commercial products, and the cost of 30"-80" 4K displays is dropping rapidly.

In the last decade, computer systems, networking, displays, and middleware have significantly evolved [Leigh13]. One PC can drive the Cyber-Commons. ESNet (Energy Science Network) provides 40Gbps to 100Gbps. Christle supplies 55-inch LCD panels with borders only 1.2 to 2.4 mm per side. Tiled display middleware provides easier management and use of these tiled displays as an interactive environment. Together this evolving hardware and middleware helps to build better and more usable large high-resolution display environments.

Figure 1. Large high-resolution displays at EVL in the last decade. (a-top left) is 2x2 tiled display built in 2000, (b-top right) is LambdaVision built in 2005, (c-bottom left) is Cyber-Commons built in 2009, (d-bottom right) is CAVE2 built in 2012.

This research started with simple questions: *Is the current hardware and middleware enough? Does it provide sufficient capabilities? Can we use it for browsing and exploring big data now?*

1.1   <u>Problem Statements</u>

EVL has a rich history of developing large high-resolution displays as feasible future display spaces. However, the current usage of large high-resolution displays is typically limited to presentation, demonstration, or user studies. Many researchers believe that large high-resolution displays have greater potential beyond this current usage. Previous research has pointed out that usability issues of large high-resolution display environments prevent users from concentrating on their task [Endert12]. Many researchers have worked to create improved interaction and workspace

designs to solve these usability issues in large high-resolution display environments [Andrews11, Ball05, Bi10, Czerwinski03, Jagodic11]. However, the current usage limitations indirectly show that we need to look for better solutions.

This thesis focuses on the following two primary problems for solving usability issues on large high-resolution displays.

- As screen size increases, it becomes more difficult and time consuming to access and manipulate information (window) [Robertson05].
- Users can be easily frustrated and confused when they change between a desktop environment and a large, high-resolution display environment [Ball05].
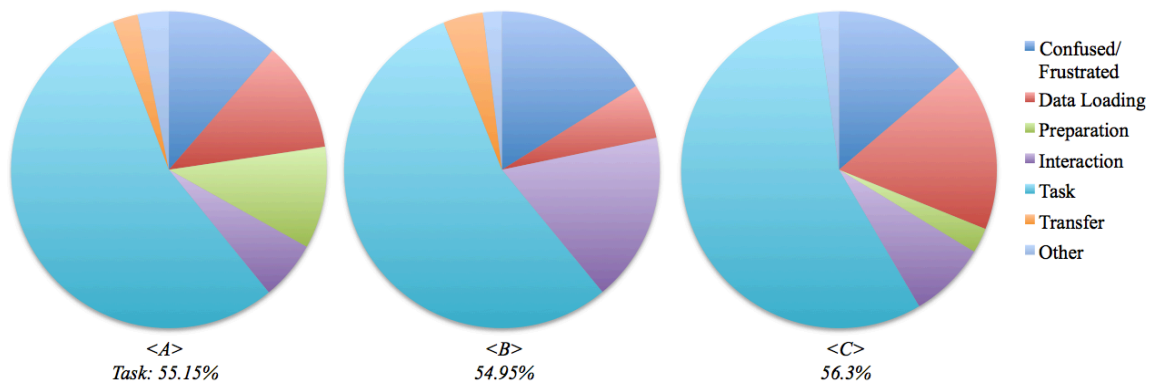
Figure 2. Activity pie charts showing data collected from our preliminary study. The display was 8.29 megapixels, 4x1 LCD displays. All three subjects could only spend approximately 55% of time on their work. The meaning of "Transfer" is activities to change a presenter.

Our preliminary study for this research shows similar points. Figure 2 shows one example of how long participants spent on specific activities during a meeting. Subjects spend a little bit more than half their time in the session on their actual task. During the rest of the time the subjects were

confused or frustrated, loading data, or interacting (window access, manipulation, and section changes), and so on. The detail of our preliminary study is presented in chapter 3.2.

This thesis will investigate space usage issue on large high-resolution displays.

- Users wasted more space on large high-resolution display [Ball05].
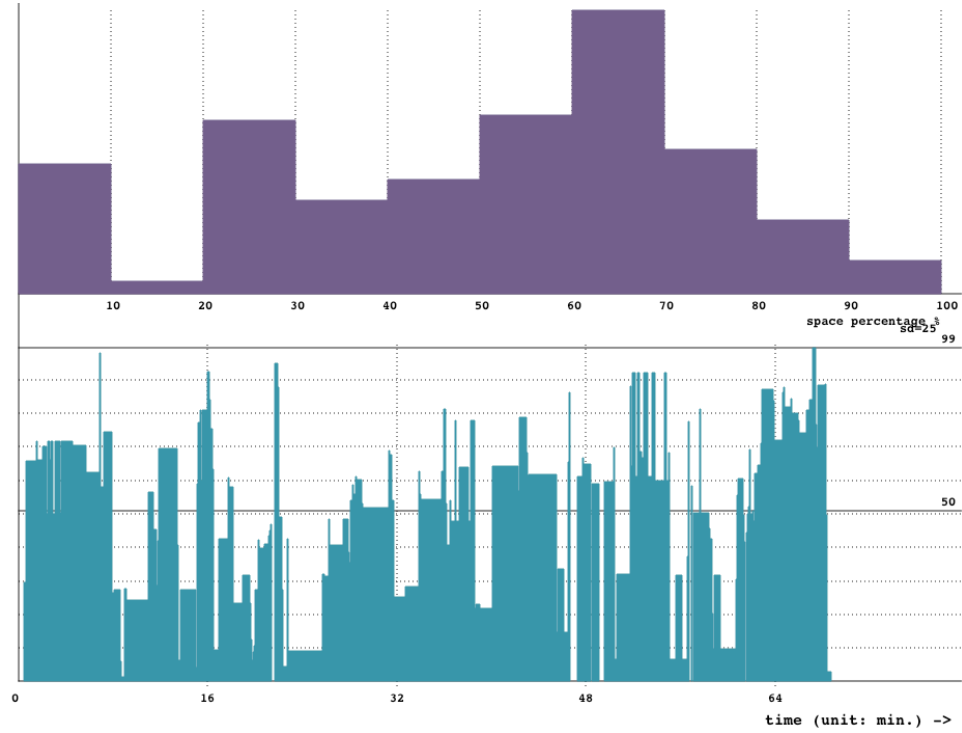
Figure 3. Space usability column chart showing data collected from our preliminary study. Average amount used space was 50% ($SD = 25\%$). (a-top) shows distribution of used space percentage. X-axis is the percentage of used space and basic unit is 10%. Y value is the accumulated time (second). (b-bottom) shows the percentage of used space at each time point (minute).

Figure 3 shows space usage from our preliminary study. While it is not good from a resource utilization point of view that there is wasted space on a large high-resolution display, this does not

mean that user did not use space effectively. Therefore, this creates another question: *What is effective use of space on large high-resolution display?*

Lastly, this thesis will look for the solution to the first issue which began this section.

- Large high-resolution displays are primarily limited to presentation. [Endert12].

1.2   **Proposed Solution**

Based on the problem statements, the core research questions in this thesis are the following:

- How can we provide improved window manipulation on large high-resolution displays?
- How can we guide the user to use space effectively on large high-resolution displays?
- How can we help the user avoid being frustrated and confused? Is there way to provide implicit guidelines to the user on making use of large high-resolution displays?
- How can we support creating a collaborative workspace on large high-resolution displays?

This research focuses on space organization design to answer these questions. This thesis outlines the design of space organization for large high-resolution display environments and evaluation of the design on large high-resolution display environments. First, we identify a set of display organization design principles based on the literature discoveries, observation from various use cases, and findings from our preliminary study. Next is designing enhanced space organization with automation based on the findings from the first phase. Finally a user study is conducted to evaluate the proposed design solution.

1.3   Document Structure

Chapter 2 covers background and related work including large high-resolution displays and associated middleware, user behavior analysis, interaction techniques and space organization techniques on large high-resolution displays. In Chapter 3, the analysis of use cases on large high-resolution display is discussed. Design for space organization with automation is described in Chapter 4. Chapter 5 covers the user study and evaluation of the proposed effective space organization design. In Chapter 6 another small group user study is presented. The final chapter summarizes the research results, and outlines potential future work.

2   FOUNDATION AND RELATED WORK

In this chapter we present the definition of large high-resolution displays including the associated hardware. We then describe middleware (software), which is needed for operating and interacting with large high-resolution displays. We turn our attention to user behavior analysis on large high-resolution displays to have idea of how users utilize the environment. Lastly, research on space organization techniques and user interaction techniques are introduced.

2.1   <u>Large High-resolution Displays</u>

First, let's look at the definition of large high-resolution displays. Large high-resolution displays can be defined as displays that are larger and contain more pixels than a traditional display. *Can we define a traditional display?* Technologies for traditional displays change over time, therefore, the definition for large high-resolution display needs to be more specific. Andrew defines "a large high-resolution display as a display are closely matched to the range of perception and influence of the human body" [Andrew11]. Jagodic's definition of a large high-resolution display is more specific. A large high-resolution display is a display that can comfortably accommodate multiple standing users and has significantly more resolution, typically over 10 megapixels [Jagodic11]. Figure 4 shows an example of a large high-resolution display. Many large high-resolution displays can be classified as wall-scale displays.

How can we make Large, High-resolution Displays? Large high-resolution displays can be constructed with multiple projectors or LCD panels. Today LCD-based large high-resolution displays are more common. Because the borders of LCD panels (the bezels) are getting smaller, we can put

LCD panels next to each other to create a nearly-seamless display surface. A cluster of computers typically drives a large high-resolution display, and middleware is needed for operating the cluster as one large high-resolution display system.

Figure 4. The Cyber-Commons at EVL is large high-resolution display wall with a 6x3 array of LCD panels, and a total resolution of 18 megapixels.

2.2   Middleware

A large high-resolution display is typically driven by a cluster of computers. The cluster configuration for large high-resolution display can vary, meaning that large high-resolution displays are scalable. Using a cluster of computers provides the ability to generate more pixels with reasonable performance, but it is often difficult to manage and make system appear as one seamless large display. In order to hide system complexity and drive large high-resolution displays, middleware interfaces between the application layer and the graphics hardware.

Large high-resolution display middleware consists of two types, distributed graphics rendering frameworks, and window managers. Both types of middleware support applications running on large high-resolution displays, but their goals are different. Distributed graphics rendering frameworks such as Chromium [Humphreys02], VRJuggler [Bierbaum01], CGLX [Doerr11], or Equalizer [Eilemann09], distribute low-level graphics commands. One application can run with full resolution at one time; they do not support running multiple applications simultaneously. Many scientific visualization applications often reply on this type of middleware. Large high-resolution display window managers emulate a multi-tasking operating system on a large high-resolution display, allowing users to run multiple applications, and interact with the applications (windows). DMX [DMX], SAGE [Defanti09, Jeong06, Leigh06, Leigh08, Leigh13] and DisplayCluster [Johnson12] are examples of this type of middleware. SAGE was developed at EVL. SAGE is large high-resolution display window manager type of middleware. As Figure 4 shown, multiple applications can run at same time, and users can interact with the windows as in a desktop environment. Each application can run on separate machines and stream the their visualization as pixels to a SAGE-driven large high-resolution display. SAGE provides mechanisms to capture, stream, and render at specific position and size for large high-resolution displays. SAGE supports multi-user and multi-modal interaction. DisplayCluster was developed at the Texas Advanced Computing Center. DisplayCluster is a window manager type of middleware. The functionality of DisplayCluster is similar to SAGE. DisplayCluster supports level of detail, so it can handle dynamic zooming within content.

Our target large high-resolution environments aim to manage large amounts of information effectively, so this thesis focuses on the window manager type of middleware.

2.3   **Behavioral Analysis and Space Design**

Many researchers have studied users' perceptions and behavior on large high-resolution displays to improve the design of these environments. Ball et al. performed a behavioral analysis learn "how large high-resolution displays help individuals or small groups of users with everyday tasks" [Ball05]. They found performance improvement on a large high-resolution display for the following.

- switching tasks (multi-tasking)
- looking large documents
- recall where the information is (cognitive memory)
- spatially position applications (spatial orientation)
- working collaboratively
- awareness for secondary tasks

They also presented negative aspects:

- needed adjustment periods
- wasted more screen space (did not use entire space effectively)
- unexpected behaviors (input focus, or losing the mouse cursor and so on)
- caused more physical strain

These results tell us that large high-resolution displays not only can display more information, but also actually can have an affect on user's perception, behavior, and performance. The next step for developing large high-resolution displays is to design the environment to take full advantage of the improvements while reducing the negative aspects discovered. The design of large high-resolution display can effect to how a user uses the display [Endert11]. Current large high-resolution display usage tends to focus more on presentation and demonstration, so many researchers focus on workspace design for large high-resolution displays [Andrew12, Andrew10, Bi09, Endert12, Haller10,

Khan09, Park05, Rogan12].

Endert et al. have classified large high-resolution display spaces into presentation spaces and workspaces based on user perception. They described a presentation space with the following characteristics.

- demonstrations and presentation scenario
- single presenter and large audiences. Or multiple presenters and small group audiences.
- theater seating or standing
- watching (not active interaction)

They described a workspace with the following characteristics.

- everyday work scenario
- individual or few collaborators
- office chairs or standing
- working on documents or analysis (not watching)

Ideally large high-resolution displays should support both presentation space and workspace usage with sufficient usability features. However, the current primary usage of large high-resolution displays is more as a presentation space. Therefore, they analyzed the characteristics for both spaces, and discussed several design factors to support better workspace usage with large high-resolution display [Endert12]. Endert pointed out that there could be two potential reasons that large high-resolution displays are not used as workspace environments. The first reason is usability issues-cumbersome clustering and un-uniformed interactive systems. The other reason is the "see it all" issue- users typically feel that they should stand or move back to a distance where they can see the entire display. Endert believes that "see it all" fits in presentation space in nature. Considering these

analyzed factors, they suggest physical configuration of the display to support workspace usage of the large high-resolution display. They found "small changes" in the design of a large high-resolution display could impact the task type. There is no task type limitation for large high-resolution display.

As the previous research shows that large high-resolution displays can support workspace usage, more analysis is needed to improve work performance with the space design. Andrew at el. Looked at designing a large high-resolution display environment for sense-making. They consider space and position as important data on large high-resolution displays, and they suggest utilizing sufficient representational affordances that can make meaningful space usage and help to create expressive environment [Andrew10]. They suggest that the space designer might consider more "intelligent" tools within the space, for example, automatic spatial tool reorganizes to manage temporal ordering.

Several researchers observed and analyzed users' behavior on large high-resolution displays and suggested better presentation space and workspace designs. Still many researchers are looking for ways to improve usability of large high-resolution displays, and support feasible workspace environments with LHD. This thesis focused on the words- "small changes", "more intelligent" and "spatial tool".

2.4   Space Organization Techniques

"We are constantly organizing and re-organizing our workspace to enhance performance. Space is a resource that must be managed, much like time, memory, and energy." -Kirsh 1993

Space is very important resource [Kirsh95]. Large high-resolution displays have large space, and designers and/or users are faced with space organization issues. Space organization means window management, or window layout, and how to layout windows effectively in a large space is the

problem [Bly86, Kandogan97, Mayers88]. Various space organization techniques have been proposed.

When users drag windows out from the center of the display, automatically the windows will shrink and move outside of the center area. This is *ScalableFabric* technique [Robertson04]. This technique is applied to a *focus plus context display*. The center focus area displays detailed information, and outer area shows coarser information [Baudisch02]. *QuickSpace* is new operation that automatically moves windows [Hutchings02]. *Expand* allows the selected window to take over its surrounding empty space if possible. *Shove* is a more aggressive technique. The user sets a window as a *shover*. The selected window will grow in each direction like *Expand*, and the other windows also move to the edges of the display making space for *shover*. *Task Gallery* has a 3D window manager [Roberson00]. Interactive 3D graphics are employed. *Task Gallery* was developed for task management. Beaudouin brought a physical paper organization concept onto a digital surface, so peeling, tapping, snapping, zipping and rotating windows are supported [Beaudouin01]. This allows for easy access to overlapped windows. There are more new space organization techniques [Andrew13, Beaudouin01, Bell00, Hutchings02, Hutchings04, Hutchings07, Ringel03, Roberts07]. These space organization techniques are not proposed for large high-resolution displays. However, that does not mean that these techniques will not work for large high-resolution displays. Some of these space organization techniques can be employed. For example, *ScalableFabric* and *QuickSpace* will scale to large high-resolution displays. Technique such as *Task Gallery* might need to be adapted for environments like CAVE2's -320-degree panoramic tiled display wall.

Large high-resolution display environments create additional space organization issues because of the large display size. As mentioned earlier, distal information access and manipulation are difficult and time-consuming tasks on large high-resolution displays. Space organization faces the same

problem. Manually moving and organizing windows on a large high-resolution display is time-consuming. Jagodic found that large screen real estate resulted in numerous window manipulations and frequent careful window alignments from his users. Therefore, he provided *automated tiling organization* to reduce the numerous window manipulations and manual window adjustments for careful window alignment, and a display space partition, *section,* to manage space more organized [Jagodic11]. Figure 5 is example of careful layout on large high-resolution display. Andrews et al. also provide alignment and distribution commands for spatial organization for the Analysts workspace [Andrews12]. Unlike desktop windowing environments, large high-resolution displays require automatic tiling technique as necessary function. Users do not like the idea of overlapped windows on large high-resolution display. They try to make all information fairly visible.
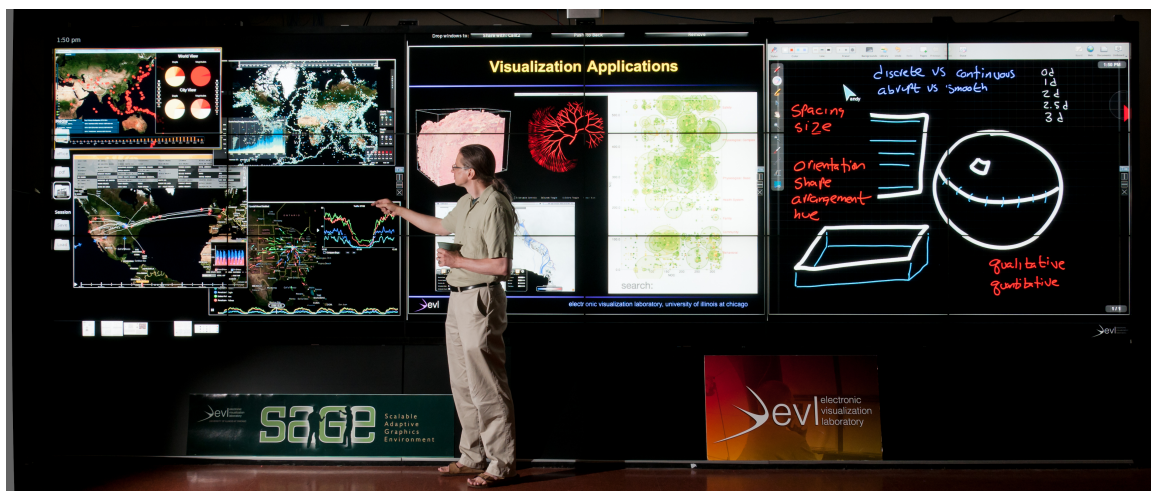
Figure 5. Class scenario in the Cyber-Commons where windows were carefully laid out.

Rogan compared slideshow presentation and distributed layout on a large high-resolution display [Rogan12]. Slideshow presentation resulted significantly better learning performance. Spatially distributed layout was better for recalling information location, but negatively affected learning

performance. Therefore, according to the usage scenario, the space of a large high-resolution display can be organized in different ways.

Comparing with interaction techniques, less research has been undertaken on space organization for large high-resolution displays. One of reasons could be that there was a great deal of research conducted on space organization mechanisms for desktop environments during the late 1990 and early 2000 and those techniques could be employed for large high-resolution displays. However, we should re-visit the space organization issue large high-resolution displays. This thesis revisits the space organization problem to look for better solutions on large high-resolution display environment.

2.5   <u>User Interface and Interaction Techniques</u>

"We think that when a display exceeds a certain size, it becomes qualitatively different: different design issues come into display and interaction design becomes full-brown environment design" – Kishore Swaminathan, 1997

This sentence is true. Even if desktop user interfaces and interaction have been developed for several decades, those designs are targeted for the standard desktop environment. User interface and interaction on the desktop generally does not work well on a large high-resolution display environment [Ball07, Ball05, Czerwinski06, Seifreid12]. Large high-resolution displays require new interfaces. Therefore, many researchers have proposed new interaction techniques and interfaces for large high-resolution displays.

Let's look at what were usability issues and proposed interaction techniques?

Large display size creates difficulty for information (icons, windows, start menu, etc) access and manipulation. It takes more time for a user to access or manipulate information. Many researchers proposed ways to access or manipulate information quickly. For example, *Drag-and-Pop* [Baudisch06], *TableCloth* [Baudisch06], *Distal Pointing* [Kopper11], *Mouse* [Robertson05], *Target Chooser* [Robertson05], and *SD (Distal Selection) of widgets* [Rashid11] etc are proposed. Researchers focused on how fast the actions could be completed. Therefore, accelerated mouse movement is often employed in LHDs to move a pointer efficiently across the large screen. This fast movement makes it harder to track the pointer and adds to target acquisition issues. To solve target acquisition issues, there are many interface and interaction techniques proposed -*Temporal Supersampling* [Baudisch06, Baudisch04], the *Vacuum* [Bezerianos05], *Semantic pointing* [Blanch04], *the Bubble cursor* [Grossman05], *Spotlight* [Khan05], *High-density cursor* [Robertson05], *Auto-locator cursor* [Robertson05], *DSS(Dynamic Size and Speed) cursor* [Szwedo06] and so on.

Various new interaction devices for LHD have been introduced -*VisionWand* [Cao03], *Direct Pointer* [Jiang06], and *ARC-Pad* [McCallum09] and so on. Large high-resolution displays do not need to use a mouse and keyboard as their only input devices. The display can have touch capacity, camera motion tracking, or voice commands. Different input devices may be better for different usage scenarios [Wallance09]. Based on the scenario, there can be presenters and audience members, and single or few collaborators. In addition, different setups can be applied. For example, a presenter stands in front of the display and the audiences sits, or several collaborators sit close to the display. According to their distance from the display, different interactions are possible. If a user is close to the display, direct touch, gesture, or voice commands could be a better choice. If the user is standing or sitting in the front row, direct gesture can be easier. If the user sits in the back of the room, indirect

pointing through a laptop wireless pointer can be possible solution to use [Rakto11]. Therefore, to support various usage scenarios on large high-resolution displays the environment needs to support multi-modal interaction allowing the users to interact through different input modalities.

There are multiple possible scenarios for using large high-resolution displays as mentioned before. One user can use a large high-resolution display, but multiple users can also use a large high-resolution display together. Large high-resolution displays promote collaboration because they provide a large display surface. Therefore, multi-user interaction is necessary. For multi-user support and interface control, cursor color or labels have been applied to differentiate who controls the cursor [Izadi03, Jagodic11]. Figure 6 shows the Dynamo interactive surface where each person has different cursor color.
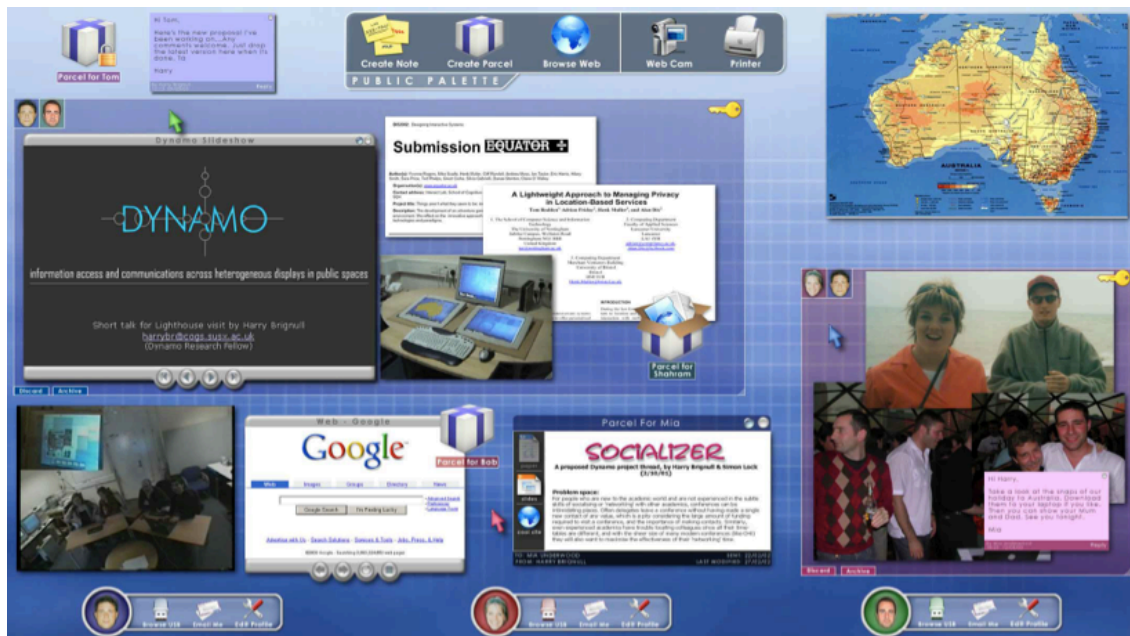
Figure 6. The Dynamo interaction surface [Izadi03]. Three people interact the surface. At the bottom of surface, *personal palette* has a small participant picture with a color. The cursor color is the same. Used with permission.

Window management on large high-resolution display also has usability issues. Users are exposed to a large space, and layout management is likely to be required. This problem was discussed in Chapter 2.4.

Effective interaction is still a major research challenge on large high-resolution displays and more research is required. Apple OS-X supports multiple gesture commands on the Apple Trackpad. While not exotic special purpose hardware such as motion-capture tracking via camera tracking system, it makes it easier for the user to scroll, zoom, rotate, and jump to the next screen and so on through simple gestures. This shows that small changes can make a relatively big difference. Microsoft Windows 7 added the Aero desktop experience which consisted of Aero *snap*, *shake*, and *peek* interaction techniques [Aero]. *Snap* and *Shake* was new way to resize windows. Dragging a window into edge of display means to maximize in different ways. Clicking the top of a pane and giving your mouse shake means to make every windows except the selected window disappear. Even if these techniques work on a standard desktop environment, this thesis assumes that these techniques could be scaled to a large high-resolution display environment. Therefore this thesis focuses on this kind of gesture-based approach to improve interaction on large high-resolution displays. This thesis focuses on users who are working at a distance from the display and are not close enough to the display to touch it. Therefore, we expect the users will use their laptops, tablets, etc to access the display from a distance.

2.6   Summary

In this chapter, we looked at the background of large high-resolution displays and reviewed some of the related work, which analyzed user behavior on large high-resolution displays, and previously proposed space organization and interaction techniques for large high-resolution displays.

Researchers analyzed user behavior on large high-resolution displays, reported what they found, and suggested some of factors that might be useful to design new techniques. We do not have evidence whether these new techniques helped users or changed their behavior. However, from their research, we found some key terms that we like to focus on: "small changes", "more intelligent", "gesture-based interaction approach", and "importance of space organization" on large high-resolution displays. With these key points, we did an analysis of current use cases on large high-resolution displays, and present those results in Chapter 3.

3   AN ANALYSIS OF USE CASES

We are regularly asked what is current problem with large high-resolution displays. The implied question is why large high-resolution displays are not common, even though the displays have continuously been improved for over two decades. We ask the same question to ourselves. The first thing to do is to look at actual use cases in large, high-resolution environments.

Our main question is whether this extra display space provides an effective environment or not, and can we find a set of design principles for effective spaces. This chapter presents observed user behaviors in several use cases on large high-resolution displays, lists questions, provides new design cases to answer those questions, and discusses what we found.

3.1   Scope

Large high-resolution environments can support work as meeting spaces, presentation spaces, and workspaces. Table I shows the detailed characteristics of each space. We analyzed user behaviors in meeting and presentation cases. Based on the resulting of analysis, we introduce design of space organization in Chapter 4. The evaluation of the design on data exploration and analytic workspace and small group meeting space are discussed in Chapters 5 and 6.

3.2   Environments

We analyzed user behaviors in meeting and presentation spaces. These use cases used the SAGE middleware to operate a large high-resolution display. Here we will talk about how the existing SAGE software works in regards to content and organization interaction.

Table I

Space Category and Characteristics

Category	Characteristics	Setup	
Meeting Space	Small Group (between 2~5)	- few collaborators - office chairs, or standing	✓
	Large Group (> 5)	- many collaborators - theater seating	✓
Presentation Space	General Presentation	- single presenter, large audience - theater seating, or standing	✓
	Simulation Result Demonstration	- single presenter, large audience - theater seating, or standing	✓
Workspace	Data Exploration and Analytic Work	- single worker, or few collaborators - office chairs, sometimes standing	✓
	Everyday Work	- single worker - office chairs	

SAGE supports a fixed position menu. The media browser is on left side of display. Sections are used for display space partition. The section menu is located on the right side of each section region. The trash-bin is on top middle of display.

There are many ways to add new content on a display running with SAGE, but we will talk about the generic way. Users use special software called the SAGE Pointer. Users can run the SAGE Pointer on their laptops, and drag new content from their desktop to the SAGE Pointer Window. Then the content will appear on the SAGE display, and it will be registered into media browser. If the content is already registered in the media browser, the user also can directly load it from the media browser, which is showing on left side of display.

Next, we will talk about where the new content will appear on the display. If content is loaded from the media browser, it will appear in the middle of the display. If content is loaded from the SAGE Pointer, the content will be shown on bottom left corner of the display. If users load multiple content, the position of the content will be same. Therefore this loaded content will be placed on top of each other, overlapped.

The content on the display is a window. If user wants to move a window on display, users move their pointers to the window, click their mouse button, and drag the window to the place that they want. If user wants to resize window, users move their pointers to the corner of window and the resize metaphor interface will be shown. Then users can drag the resize metaphor interface. It will make the window resize. If the user wants to resize a section, the users need to move their pointers to section boundary bar area. The section boundary bar will be activated, and visually change to look thicker. Then the user can drag the section boundary to change the size of the sections.

Lastly, SAGE adapts a trash-bin metaphor region. Users move their pointers to the window that you want to delete, drag the window into trash-bin metaphor region. The window will be removed on the display.

This is how the SAGE environment of use cases commonly works.

3.3   Small Group Meeting: Preliminary Study

We set up a small group meeting with a native LHD system for this preliminary study. The display was 8.29 megapixels, 4x1 LCD displays (see Figure 7). The purpose of the meeting was sharing information. The group members selected the topic of the meeting. The topics were top three best technologies, top three touristic places to recommend, scientific visualization examples and so on.

The group members selected three different items for the topic, and prepared meeting materials with at least five pieces of supporting data per item. Each person prepared at least 15 pieces of materials and 3-4 people participated. Meetings were held five times. At the end of the meeting, group members selected the top three items. Everyone was a presenter. The group members sat on office chairs and used remote pointers for interaction. The distance to the display was approximately 0.8 meters. The meeting materials were not high-resolution, but some user interaction was involved.

Figure 7. Small group meeting setup. 4 x1, 8.29 mega pixels LCD displays.

3.3.1 Observation

Step-1 (Preparation): The group member loaded multiple pieces of data – one per window. All of these new windows initially overlapped at the bottom-left corner of the display by the system. The user manually arranged the windows. Even though the users were familiar with section and tiling commands they seemed not to use the functionality.

Step-2 (talk preparation): The user normally maximized each window if the window size was not

large enough to see as a group. If the size was large enough, they didn't change it. The presenter started to talk about the materials.

Step-3 (after talk): The user closed all windows, and next presenter started at step-1 again. Figure 8 shows the activity transitions from step-1 to step-3.

Step-4 (select 3 tops): All group members loaded their data again on the display to pick the three best. They had hard time and did not initially have an idea how to handle this. At the beginning they tried to move windows, but later they just decided keep the windows and just talk to share their opinions.
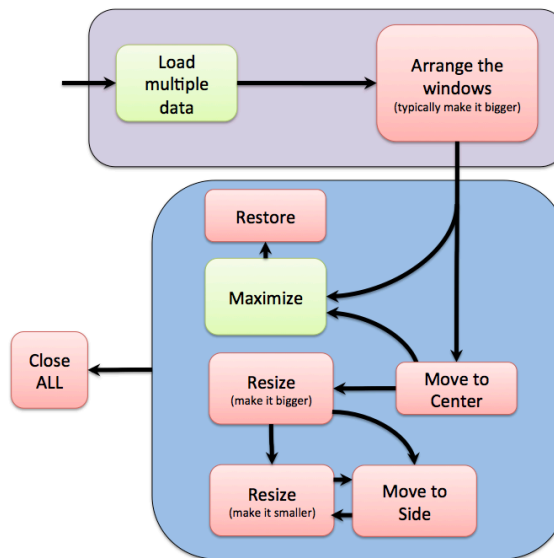
Figure 8. Activity Transition Diagram. It shows observed patterns at small group meeting.

Generally the users spent too much time interacting. Additionally, they also spent a relatively long time for data loading. The pie chart in Figure 9 shows how much time they spent for each task. These particular charts were from the fifth session. Even though they already prepared their materials, it

took time to load. Figure 10 shows the mouse interaction activity on the display. Users were confused by overlapping data and the situation when they lost track of the pointer cursor. Even if the users knew there was a section function to divide the display into sections, they did not use it. They also did not use the tile function which would tile all of the windows on the display into a grid so they do not overlap.
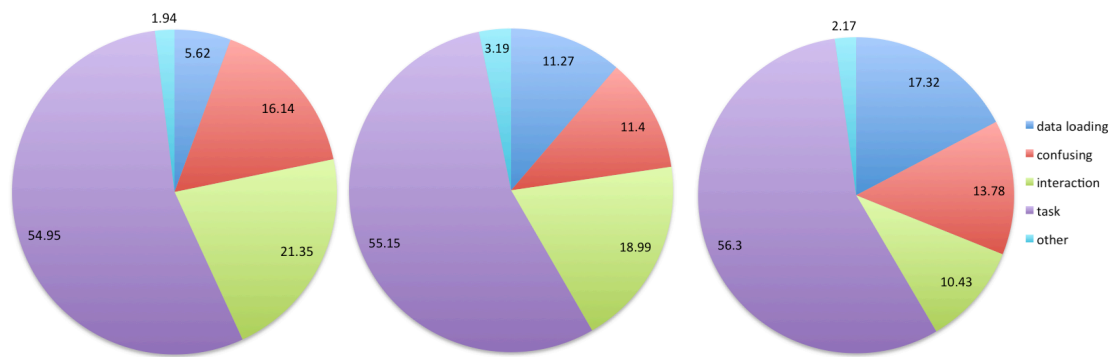
Figure 9. Activity pie chart. Small group members spent their time in data task, interaction, dealing with confusing situation, data load, etc.
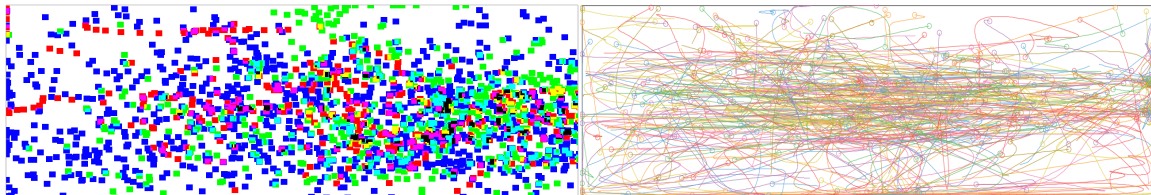
Figure 10. Pointer heatmap and movement graph. Each color represents a person. Data shown is from five iterations of the preliminary study. It shows intensive movement.

3.3.2   Questions

We have the following questions from these observations.

- Q1. How can we improve the amount of time spent on the task itself?

- Q2. How can we reduce arrangement time, Does it have unnecessary interaction repeated steps?
- Q3. How can we reduce data loading time, How can we reduce the time shifting from one person to the next?
- Q4. How can we encourage people to think about effective space and organization?
- Q5. Can we improve this use case better to make more effective use of the space?

3.3.3 <u>Space Design Scenario</u>

Data should not be shown overlapped at the same position. The overlapped initial position can cause people to be confused about whether the data is fully loaded. If new data is not loaded at a fixed initial position on the large high-resolution display then the system must decide where to put the new data. Users should be able to easily set an organization policy which is more proper to their situation (Q2, Q5). For example, if they have a very large amount of data, the user might think that it is more important to fill the space with lot of data, or if it is more important to organize the data in tiling manner, they can set it as policy.

If the users already have prepared data, they should be able to upload all their data including its structure. If one member has three different sub-topics to talk about and each subtopic has multiple materials, the member should be able to make a grouping and upload that grouping to the system. From the browser the hierarchy structure should be preserved. If the users can load all data in the group at once, it will reduce data loading preparation time (Q3).

Users might make an organization plan ahead of time if more organizational functions are supported. Maximization is good functionality, but it can hide other windows. Creating a section with more functions that they can easily control will promote people to think about space organization (Q4, Q5).

A function to close all of the windows is needed. It will reduce unnecessary window manipulation with button (Q2, Q5).

When users need to select some data from many data, or users need to rank the data together we can provide a vote operation to share their opinions in an easier way. Additionally we need to consider how to show the result of the voting,. For example, we can make the window size bigger if that window gets more points from user, and we can show the list of who voted on top of the window. This will help (Q5).

If Q2 and Q3 are resolved, users can have more time to focus on their task (Q1).

3.3.4   Suggested Improvements

- Space manager is needed. Space manager needs to manage the empty space so new material does not overlap when it appears.
- Space organization policy is needed, so user can have idea how to organize data.
- Brower needs to support hierarchy in easy way. People can make material grouping more easily. Grouped material needs to load with simple action like one button click.
- Additionally, voting can provide an easy way to share opinions.
- Close all windows will reduce repeated actions.
- No fixed position menu. Popup menu is required.

3.4   Large Group Meeting: EVL Weekly Meeting in Cyber-Commons

EVL has a weekly meeting in the Cyber-Commons room. Cyber-Commons is a 20-foot wide, 18 megapixel wall composed of 6x3 thin-bezel LCD displays (see figure11). The purpose of the meeting is for all of the students to give a progress report. We use the Cyber-Commons display to share

information with each other. There will be single presenter at any given time and an audience of 15-25 people. However everyone will be a presenter at some time during the meeting. People sit in theatre seating and each user uses a remote pointer for interaction. Normally a progress report does not have high-density pixels, and very little user interaction beyond positioning the window appropriately on the screen to it can be seen by everyone in the room.

Figure 11. EVL meeting in Cyber-Commons.

3.4.1   Observation

Step-1 (Preparation): First, people connect their laptop wirelessly to the Cyber-Commons display to share either their desktop or a slide in pdf or jpg format. The window will appear the top-left corner of the display. Typically people move their window to either left side or right side of the wall and make their window smaller so it is visible on the wall but out of the way of the person that is currently presenting. Sometimes, they make its size smaller and then move it to the side.

Step-2 (Talk-preparation): Before each person starts to talk, they bring their window to the center

of the display, and maximize or resize the window to make bigger. If they remember the maximize function (double-click) that will bring the window to center and maximize automatically.

Step-3 (After the talk): People close the window. Figure 12 shows the activity transitions from step-1 to step-3.
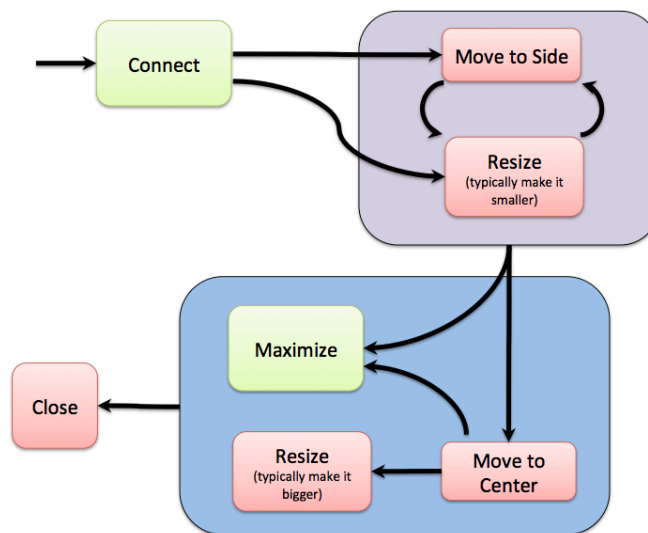
Figure 12. Activity Transition Diagram. This diagram shows observed patterns for large group meeting.

3.4.2   Questions

We have the following questions from observation.

- Q1. Does it have unnecessary repeated interaction steps? This usage case is simple. There are few interactions involved and they have a clear pattern. Unnecessary simple interaction steps are occurring. Can we improve this use case?
- Q2. Does the space provide an effective environment?

3.4.3   <u>Space Design Scenario</u>

The overlapped initial position issue occurs with this use case too. However, we already talked about the issue in Chapter 3.2.3. We will skip the issue here.

In this use case we could see repeated interaction steps and repeated flow from the observation. Therefore, we are going to talk about ways to improve this workflow through possible automation scenarios.

When a user needs to talk, the user connects to the display server to share their desktop view and the desktop view appears in the center with a large enough size to be seen by everyone. When another user connects a laptop to the display, the current desktop view is automatically disconnected, disappears from the display, and the wall shows the desktop view of the new user. Figure 13 (a) shows the space setup. It is the simplest space setup. However, it does not fully utilize the large high-resolution displays. This scenario acts like one projection based large display.

There can be different space layout setups. There are two scenarios we will look at here. We divide the space into two sections (see Figure 13 (b)). One is bottom and the other is top. The bottom section is the waiting space. New data appears in this section, aligned with the tile organization policy. The output link is to the focal space, which is the top section. The top section is focal space that is expected to get a focus. The focused window will be removed when new data needs to move from the bottom section to the focal space, which is the top section. The organization policy is tile. Here we present input and output of a section. Sections can have a flow, so input and output sections can be defined. Input can be new loaded data, or data from another section. Output can be a "closing" operation or sending data to another section.

Another scenario is to divide space to three sections (see Figure 13 (c)). The left section is defined as waiting space. Its organization policy set to tiling. This section has its input and output defined. Input is new data, so all new data is shown in this section. Output is to move to the focal space, which is the b section. The central section is the focal space. Its organization policy is tile. Input is from section a, and output is to section c. The right section is for the 'after talk' space. Its input is from focal space, and no output is defined. Policy is set to dynamic mode, which makes the size of a data item bigger if it was more recently presented. Scenarios include solution for Q1, Q2.
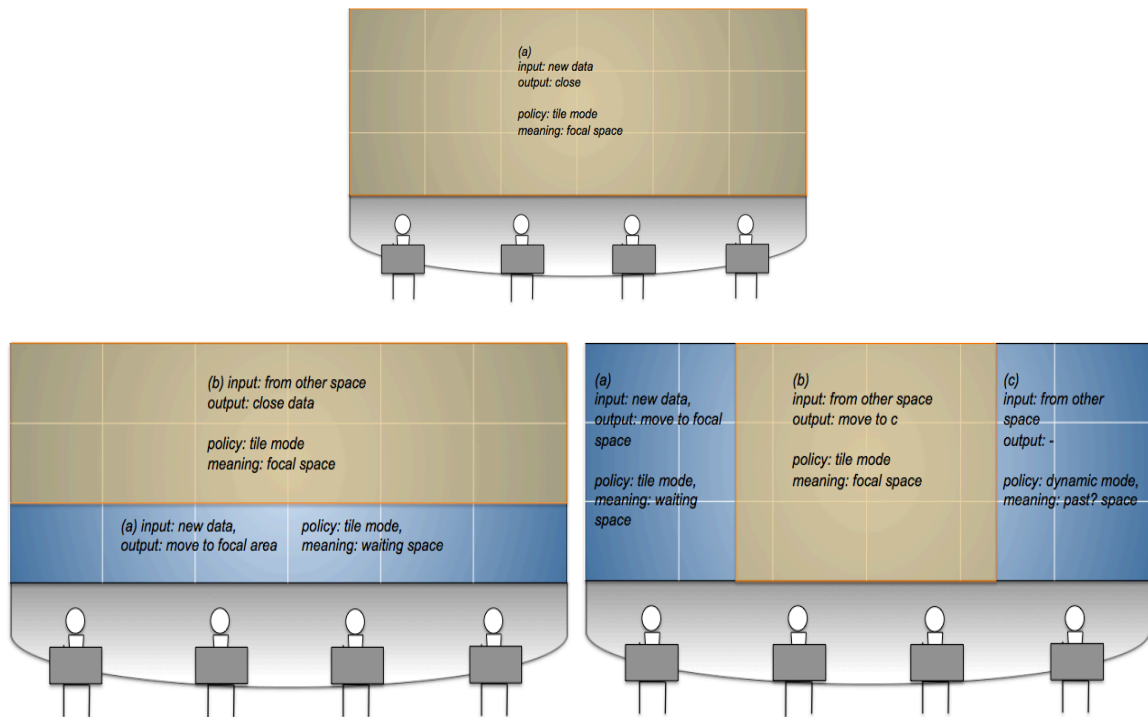
Figure 13. Space setup scenario. (a-top) one section scenario. (b-bottom left) two sections scenario. (c-bottom right) three section scenario. Each section has policy, meaning, input and output defined.

3.4.4 Suggested Improvements

- Sections are needed. Sections will improve organization.

- The meaning of sections should be under user control so sections can have meaning.
- Each section needs organization policy. Section and organization policy will help effectively use the space. For example: Recently added data to a section will have a larger size. Window size can have meaning as well.
- Input and output of section will reduce repeated interactions, and enhance a section's functionality. Window manipulation is improved with input, output, and organization policy automation.

3.5   General Presentation: Science Information Wall at Argonne National Laboratory

Figure 14. Science Information Wall at Argonne National Laboratory.

The Science Information Wall at Argonne National Laboratory was installed to enable the presentation of research findings, and the observation of clean room activities. The display was built from 18.6 megapixels, 3x3 seamless LCD displays (see figure 14). Typically there is a single presenter and large audiences. The audience members can sit or stand. The typical resolution of the contents on the display is not high-resolution in this use case. The presenter can change the set of data

displayed, and switch the focused material, or change the organization policy.

3.5.1 Observation

In this use case, we divided our observations into two phases. First, at the beginning this wall was not interactive. They made pre-set layouts with a typical l layout for their presentations as one content per monitor. They wanted to make the display interactive wall at this phase.

After upgrading their wall to an interactive wall, we held another observation phase. They had a list of sets of content. The typical starting layout was one content per monitor. During a presentation the presenter changed to full screen mode. At the end of the presentation the presenter changed back to tiling, the starting layout, and showed all of the content to audience. The presenter believed that this layout encouraged the audiences to remember what they talked about and ask more questions.

If the audience members were standing during the presentation, full screen mode made the audiences move to back. Audiences seemed like they wanted to see the entire screen. The presenter did not like this effect. The presenter wanted to make audiences close to display when they were standing.

If the video had an audio track, they made a set with the video only. However, if the video did not have audio, they made a group the video with additional information.

3.5.2 Questions

Because they did not really have a proper interactive large high-resolution display environment setup at the beginning, we started from scratch. The following questions came from the people who wanted to use this display.

- Q1. Can the interaction be easy enough for everyone to use?
- Q2. Can we make a list of materials to present and store it? Can we add an approval process to make the material? Can we set and keep the order of material?
- Q3. Can we create groupings with multiple materials?

After upgrading the wall, we had the following additional question.

- Q4. Can we have several different organization policies? We like full screen mode, but we prefer to see the other data as well because seeing related materials at the same time can help the audience.

3.5.3   Space Design Scenario

Based on the questions, we designed the display interaction scenario. The interaction device can be a menu on touch screen, controlled from an Apple Magic Trackpad, or the menu on iPad (Q1). From the simple menu presenters can browse through available sets of materials and load a specific set. They can change the organization policy. They can make a specific window full screen or tile the windows, etc.

We can provide a website that the users can use to create sets of data and request approval of the set (Q2). Users can load data, find data, and arrange the data however they want. Each set can include multiple types of media. Users can make a group. Grouped media acts like a single asset, but they can also maximize individual assets (Q3). Once the data is approved the data, the new set is shown on the menu of the display.

We can provide three different defined organization policies (Q4). The first one is focus mode. This divides the space to threes sections. One asset window covers 4/9 of the screen, located in the top-left area. The top-left area is a focus area that makes people to focus on the specific asset. The

right remaining space shows previous assets, so people can look at what they missed. On the bottom-left area, the display shows incoming assets that will go to the focus area soon.

The second policy is tiling mode. Assets are shown on an evenly divided space. People can see all the assets in set. User can look at what they are interested in. Presenters said that people asked more question with tiled mode. Therefore at the end of a presentation the presenters make all of the assets visible in tiling so the audience can remember what they wanted to ask. However, the presenters prefer one tile per display mode. Therefore, they requested that we create a set with 9 assets (one per LCD tile).

The final policy is full screen mode. One asset window covers whole screen, so people really focus on the one asset. Presenters rarely use this mode. If they have high-resolution image that is worthy to show on the whole screen, they use this mode.

3.5.4 Suggested Improvements

- Easy interaction is needed.
- Sections are needed. A section has meaning. Flow between sections is needed.
- Multiple organization policies are required. One tile per display is preferred over a tiling pattern that does not take the physical tile borders into account
- Tool for creating pre-defined set is needed.
- Grouping assets is required.

3.6 Simulation Result Demonstration: Science Information Wall at Argonne National Laboratory

The science Information Wall at Argonne National Laboratory was installed to enable the examination of experimental as well as simulation data from research experiments. The display was

18.6 megapixels, built from 3x3 seamless LCD displays (see figure 15). Typically, there is a single presenter and a large audiences. Audience members can sit or stand. It has high-resolution pixels, and does not involve much interaction.
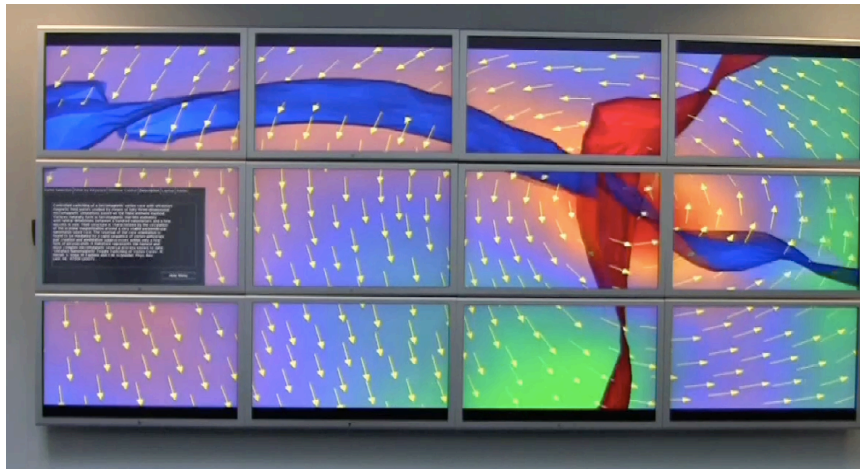
Figure 15. Science Information Wall at Argonne National Laboratory.

3.6.1   Observation

Presenters use full screen mode. They create videos based on their simulation result. They also show real-time application usage with their data sets. However, even with a real-time application, they prefer to set viewpoints, and follow paths through their visualizations automatically, so it is similar to playing a video. They sometimes pause the animation or simulation. There is very little interaction involved. Some of the scientists do not want to put their data on the wall persistently.

3.6.2   Questions

This is typical use case for presentation space in large high-resolution display.

- Q1. Is there more effective way to present simulation result?

3.6.3   Space Design Scenario

If the resolution of the simulation result is smaller than the whole display, we can divide the display space. We can make a large enough area as focus area, and we can put supplementary information that the user wants to talk more about in the other area. If the presenter wants the audience to keep focus on the main asset, the simulation tool or video can be shown in full screen mode. After the talk about the main simulation results, then the presenter can come back to the original divided mode so the audience can see all the other related materials. The audience can still see the animated simulation result, but also they can talk about other material as well (Q1).

3.6.4   Suggested Improvements

- User can hide other materials, and show one asset in full screen mode.
- When loading data, an option for persistent or not persistent storage is needed.

3.7   Summary

This chapter presents user behaviors in several scenarios involving LHDs, and discuss the findings from those scenarios. The following are what we found as design considerations.

Space Organization:

- Space manager is needed. Space manager need to manage empty space. So new data needs not to be overlapped.
- Section is needed. Section will help to organize better.
- Each section needs an organization policy. Section and organization policies will help effectively use the space. Section and organization policies will help to reduce repeated actions and will help that user have idea how to organize data. Multiple organization policies are required. For example: Recently added data to a section has larger size. Window size can have meaning as well. Tile per display is needed for some cases.

- Multiple organization policies are required. One tile per display is preferred over a tiling pattern that does not take the physical tile borders into account

- Meaning of section can be set. A section has meaning.

- Flow between sections is needed. Input and output of a section will reduce repeated interactions, and enhance a section's functionality. Window manipulation is improved with input, output, and organization policy automation.

- Additionally, voting can provide easy way to share opinion.

- Close all windows will reduce repeated actions.

- User can hide other materials, and show one asset in full screen mode.

Data Handling:

- Tool for creating pre-defined set is needed.

- Brower needs to support hierarchy in an easy way. People can make material grouping more easily. Grouped material needs to load with simple action like a one button click.

- When loading data, an option for persistent or not persistent storage is needed.

Interaction:

- Easy interaction is needed.

- It is better to have not fixed position menu. Popup menu is required.

In the following chapter, we present the design of space organization based on these findings.

4   SPACE ORGANIZATION DESIGN

Researchers have introduced many different designs for large high-resolution display environments. Some have investigated how the physical display configuration can make an impact meaningfully on user's perceptions. Some have presented new user interaction devices for these environments. Some have talked about new tools that can be useful for analytic work. All of these proposed design changes are to improve user performance in these spaces.

This dissertation focuses on space organization design. Space organization design can impact how users can effectively make use of large high-resolution display. Space is an important resource that users need to use meaningfully. Well-organized space can enhance work performance. However, interaction design affects space organization design, so we will also investigate interaction design.

Primary considerations for our space organization design are that space can provide "intelligent", "effective", and "improved interaction".

Our design goal is to create an effective space organization interaction solution. In other words, our goal is to create an environment where users can focus more on the task and data through automation and the reduction of extraneous interaction. Therefore, the design will help users to create organized and meaningful spaces, and reduce unnecessary interactions to reduce interruptions in their actual task.

In this chapter, we present design principles driven from our observation. We discuss whether legacy desktop operations can expand to large, high-resolution displays, and how often these existing operations were used on large, high-resolution displays. We introduce new operations designed based on what we found from our observations, and discus the possibility of using multi-touch interaction for users that are sitting or standing some distance away from the display

4.1   Design Principles

We define our space organization design principles based on our observations.

- Reduce repeated operation steps
- Spend less effort to organize space and more time on task
- Provide methods for effective use of space
- Support effective workflow
- Provide easy, fast, and correct interaction

Based on our proposed design principles, we design interaction, space organization policy, and enhanced operation for space organization in large high-resolution environments.

4.2   Considerations for Legacy Desktop Operations

Looking at legacy window operations on desktop environment, *can the operations expand to large, high-resolution displays?* This thesis starts from basic window operations. On large high-resolution displays, window create, destroy, move, resize, maximize, minimize, restore, and push back functionality needs to be supported. However, because of their use on large high-resolution displays, each operation needs to be revisited and redesigned. In this section, we present considerations that need to be taken into account when we take desktop operations to large high-resolution displays. We will also present how SAGE supports those legacy desktop operations. This is

also described in chapter 3.2. There is no standard window manager user interface for large high-resolution display. However, SAGE can represent current window manager design status on large high-resolution displays since many international collaborators are using the SAGE environment. DisplayCluster also provides operations in a similar way as SAGE.

Create Window

Windows can be loaded from the media browser on the large high-resolution display itself. A window can also be loaded from remote applications like file transfer applications, or media websites etc. In either case the system must decide where to place the new window initially and what size it should be.

SAGE supports media browser and remote loading, and the window's initial position is fixed to the bottom left corner. The initial size is set according to the raw resolution of the content. However, desktop sharing uses raw resolution, videos are shown at two times raw resolution size.

Destroy window

Of course, closing a window is also a necessary operation on large high-resolution displays. Should the window be closed through a typical iconic button in the window's menu bar or should other actions be considered?

SAGE has close metaphor area. In the SAGE environment a window does not have title bar with a close iconic button on title bar. To destroy a window users need to drag the window to the close metaphor area. As a way of indirect interaction, there is additionally a graphical user interface where users can change the window layout. From that application the user can close the window by clicking

a close iconic button.

Move and resize window

Some users can have difficulty dragging a window on large high-resolution display either through touch or through a mouse / trackpad. On a large display space is big, making dragging more difficult than in a desktop environment.

In the SAGE environment users need to drag a window to move it. When users move their pointer cursor to the corners of a window the resize metaphor will appear. The user can drag there to resize the window. As we mentioned before, there is an additional application to change the sage window layout but it does not use direct interaction on display.

Maximize window

Maximize operation will not work the same as on a desktop. On large display users typically prefer to keep a window's aspect ratio constant. If the window is maximized on the entire display it might not cover the entire screen because they have different aspect ratios. In addition, some of other windows might still shown in other areas.

With a double-click on a window SAGE maximizes the window. The Window is moved to the center of section and resized based on size of section and window's aspect ratio. A section is a partition of display which is described in chapter 4.3.

Minimize window

Is the minimize operation needed on large high-resolution display? Is the operation necessary? Where should the window go when it is minimized?

SAGE supports minimization. On bottom of the display there is area for holding minimized windows.

Restore window

If maximize or minimize window operations are supported, then the restore window operation should be supported as well to bring the window back to its previous location and size.

In the SAGE environment by double-clicking a maximized window the window restores back. By selecting a minimized window, the window moves back to previous location and resizes.

Push back

Push back changes the depth of window on the display. This function is still needed, but it will not be commonly used because there is a higher chance that windows will not need to be overlapped on large high-resolution display.

SAGE supports push back as in a desktop environment.

4.3   Considerations for Existing Operations

Many researchers have suggested new techniques for solving different interaction problems on large high-resolution display. In this section, we present considerations of existing space organization operation and interaction operation on large high-resolution display.

Section

Section creation and destruction is very helpful when the user wants to divide the display into multiple spaces to organize content, however in our observations users did not use the capability very

much. We want to encourage the use of this feature so we should investigate how sections are currently created. SAGE provides a section creation button on the right side of each section boundary. Users move their hand or their mouse pointer to the position of the button, and touch or click the button to divide the section in half, horizontally or vertically Users then need to adjust size of these new sections. This includes unnecessary actions and can be improved.

Piling

The piling function was not used very much in our observations.

Tiling

Tiling is a very helpful operation. Tiling is applied to all windows in a given section. Windows will not be overlapped, and are resized within a fairly divided space. Users could then manually move windows around that section overriding the tiling. Therefore users needed to click tiling button again if they wanted to re-tile that section. The order of tiled windows was fixed and could not be changed by the user. If users want to change the tiling order, they had to change the layout manually by moving individual windows. Once a section is tiled should the section remained tiled even windows within that section are moved?

Alignment

Window alignment is a useful operation to have but in our observations users on large high-resolution display were showing less precise alignment behaviors. Therefore, we are not sure whether this is a necessary operation. It might be useful until a certain size of wall.

Table clothing

If the entire display space is divided into several sections then a tablecloth operation shifts and shrinks the sections area. As in the real world when people pull a tablecloth in a certain direction the tablecloth is moved in the forced direction. The position of sections is changed by tablecloth operation. It might be useful for certain situations.

In addition, we took into consideration other existing interaction techniques.

Missile Mouse

Since the space is large, moving a mouse pointer from the left side to the right side can take longer time. Missile mouse can accelerate movement speed for navigation. However, it might cause confusing situation like users lose where the pointer is.

Target Chooser

Since the space is large, more windows could be opened on the display and more windows could be un-minimized. Therefore the desired window might be hidden by other windows. Target chooser shows ray cast, and highlights the window closest to the ray. Target chooser is like a selection operation in 3D environment. Jagodic tried to adapt this operation into SAGE with a gyro mouse. It showed issue of target acquisition difficulty.

4.4   Effective Space Organization Design

With the findings from the use cases and considerations of desktop operations and existing operations, we designed a set of Effective Space Organization Operations. First, we introduce space

organization design for media browser, section space organization policies, enhanced section operations, and other necessary operations. We present multi-touch interaction design.

4.4.1   Media Browser

The media browser on the display shows previously loaded media. Users can select and load data. SAGE provides a fixed position media browser on the left side of the display. The media browser position should not be fixed. Launching the browser from a popup menu allows it to be accessed from anywhere on the wall. Each section can have one media browser. Individual data can be selected. Grouping is supported, and the user can load all of the data in that group. Users can close the browser with two fingers pinching motion. Users can put their pointer cursor at any place in section, and using a pinching in motion with two fingers will close the browser in the section.

4.4.2   Section

Each section has space manager that will manage the empty space. The space manager helps each section layout windows according to that section's organization policy.

4.4.2.1   Space Organization Policy

Each section has four possible space organization policies.

Free

The user can change the layout manually as in a desktop environment. In this mode the space manager is still operational. If a new window is loaded or moved into this section, the space manager checks the empty space in the section and places the window in the empty area. If there is enough empty space to accommodate the native size of the window then the window will appear at its native size. However, if there isn't enough empty space the, size of the window will be changed to be

smaller to fit.

Dynamic

Dynamic policy tries to fill the space as best it can, with priority considerations. If the priority of a window is high then the window will be larger than the other windows. If the priorities of all windows in the section are the same then all of the windows will cover a fairly similar area with consideration of each window's aspect ratio. In that case dynamic policy acts like tiling policy. The difference with tile policy is that the default order of windows is different. In dynamic policy the order of windows is according to the reverse order of each window being moved in the section, so newer windows moved into the section will be placed at the left or bottom left. After filling the space of a section, dynamic policy applied final alignment to the center of display. Space is filled with windows from the left and bottom of a section, so there could be an empty area on right or top area. The boundary of filled space in a section is shifted to the direction of the display center, but the shift is limited to the boundary of the section. In addition, dynamic policy supports manual layout, but tile policy does not support manual layout by the user. Voting operation can change the window priority. According to the priority assignment policy we can create multiple dynamic policies. However we limited the function with voting operation here. Automatic layout does not support overlapped, but manual movement is allowed to user. Overlapped by manual movement is allowed.

Tile

Tile policy puts the windows into a grid. The cell size of the grid is calculated from the number of windows, the aspect ratio of the windows, and the aspect ratio of the section boundary. The size of each window is fairly similar. The order of windows is according to the order in which each window

was loaded. Manual movement is not allowed. The default order of tiling is by load time.

Tile per Display

This policy places each window into one physical monitor. It is a special case of the tile policy. Manual movement is not allowed.

4.4.2.2   <u>Enhanced Operations</u>

All operations were designed based on our design principles. Specially, we focused on reducing unnecessary repeated actions and reducing the effort to organize the layout.

Create Section

There are two ways to create a section- dragging and button from popup menu. The new divided section will be created based on the current mouse position. All settings for the new divided section such as its organization policy will be preserved. If there are windows in the section, the windows will be moved to the smaller side of the divided section as smaller sections tend to be used as window storage in preparation for viewing in the larger section. If not, there area other operations like "Move to other Section" and "Apply" that will help move all existing windows to the other side of a new divided section.

Destroy Section

We provide a close-button from popup menu to destroy a section. We expect this will reduce mouse pointer movement. We considered about other ways to close a section. Motion tracking was considered, but we decided to limit motion tracking only to optional interaction. If one motion has multiple meanings, it might cause confusion to the users. It could be helpful if we have an interaction

device like a multi-touch mouse with special button.

Resize Section

Users expect to drag section resize bar to resize a section. The section resize bar should be large enough for a user to grab it via touch or mouse / trackpad easily.

Apply

With Apply the system remembers a user's previous action and applies the same action to all windows in the section. Size change, position change, size and position change, and moving the window to other section are possible apply-actions. This is good when the user wants to clean up the focus area and move the windows into a peripheral area. It can reduce multiple repeated actions, so we expect the user will save time and get back to wotking on their task more quickly.

Data-In Section

Large high-resolution displays have large space so users frequently divide that space into sections. The Data-In section defines the section where new windows will appear. Set up from a popup menu, this function defines the focal area, which is working area. This operation can be used to support assigning meaning to a section.

Flow Section

The user can set a flow between sections. The user sets the flow by clicking on an area of the incoming section, dragging to the area of outgoing section, and releasing the button. Repeating this action, user can create continuous flows between multiple sections. By double-clicking, the flow will

be started. This operation can be used to support assigning meaning to a section.

Swap the Position in Section

User can swap the position of two windows in same section. The user can drag a window into the area of the window that you want to swap in tile mode or tile per display mode. In dynamic mode and free mode dragging is user's intention to move the window freely. Two fingers swipe motion means swap the position in the section in any mode. Users can place their mouse cursor over the window, and swipe with two fingers. According to the swipe direction, the system will find the corresponding window. The order of two windows will be changed. Further motions will be continuously applied to the first activated window.

Move to Other Section

The user can move a window to another section. The user can do this manually by dragging the window into the other section. A three fingers swipe motion will mean move the window to the other section. The user can place the mouse cursor on the window, and swipe with three fingers. According to the swipe direction, window will move to the other section that is in the same direction as the swipe. Further motions will be continuously applied to the first activated window.

Flock

In tile mode the user can place windows close together. Windows sometimes are located farther apart than user expects, making it difficult to compare data. Some users may try to resize the section to place the windows closer together, or manually move or resize the window by themselves.. The flock operation replaces these efforts. Users can put the mouse pointer onto the section that they want

to apply the flock operation to, and pinching with two fingers will trigger the flocking operation. Flock is applied to all windows in section.

Expand

Expand is similar to maximize. It works only in free mode. The system checks for empty area near the window. If there is empty area around the window the window will be resized to try and fill the empty area. The user can move the mouse pointer onto the window, and a pinch out motion with two fingers will trigger the expand operation.

Push-Expand

Push-Expand is a forced version of expand. Instead of checking for empty area around the window, push-expand checks the entire section for empty area and pushes other windows to the edge of the section boundary to make empty area and then resizes the window to fill it. This operation also works in free mode only. This operation will apply after the Expand operation. User can move the mouse pointer onto the window, and pinch out motion with two fingers will trigger the push-expand operation.

Section Maximize

By double clicking a window in a section the window will be positioned in center of the section and maximized in the section. The window aspect ratio will be kept.

Change Space Organization Policy

The user can change the organization policy of a section. Free, dynamic, tile, and tile per display policy are possible policies to select.

Vote /Un-vote

The user can change the priority of window. This will affect window size or position accordingly if the organization policy is dynamic policy. The user can click the button to vote from the popup menu.

Clear All Windows in Section

The user can close all windows in a section by clicking button from popup menu.

4.4.3   Other Operations

Set Center

The user can change the center of the display. The center of display affects the global maximize operation, and position adjustment in dynamic policy. User can set the position from the popup menu, The center will be set using the position of the mouse pointer.

Global maximize

The global maximize operation will hide all the other windows, make the screen black, maximize the selected window, and put that window into the center of display. This is good for users that need to concentrate on one window.

New

Clear all section layouts and all windows. The user can select this from the popup menu.

4.4.4 **User Interface: Multi-touch Interaction**

Figure 16. Multi-touch capable devices. From left to right, Apple Magic Mouse, Wacom Intuos Tablet, Apple Magic Trackpad.

Here we consider distance interaction, which is interaction for people at some distance from the display. Generally we observed our users using a mouse as their interaction device for distance interaction on large, high-resolution displays. However, with a mouse dragging is difficult for some users on large, high-resolution displays due to the distance that a window must be dragged across the display.

Multi-touch interaction as distance interaction can assist dragging with automated operations. Directional motion also can include additionally the user's intention, where to move or what to do. Another merit of multi-touch interaction at distance is that the user applies the same motion for the same operation on an up-close interaction display like a touch screen.

First, what kind of operations can be assigned with motions. Some of dragging interaction can be replaced with automatic operations like swap and move to other section operation with directed swipe motion, since the directional motion can include the user's intention. We presented these operations in chapter 4.4.2.2. We also assigned an operation to close the media browser with a 'pinch in' action instead of clicking the close button (in chapter 4.4.1). Table II shows multi-touch motion and

corresponding operations.

We checked Apple Magic Trackpad, Wacom Intuos Tablet, and Apple Magic Mouse (see figure 16). Apple Magic Mouse and Microsoft Touch Mouse have a good shape for user to use, but they do not support three fingers left, right swipe, pinch in/out motion. Wacom Intuos Table is not sensitive enough with touch and sometimes the user can feel latency. The flat angle of its shape might give tension to the user's fingers. However it has additional buttons that can be assigned. We can assign a button for a specific operation such as close window. It also supports pen interaction, which could support an annotation tool on large high-resolution displays. The Apple Magic Trackpad was sensitive enough for motion and its angled surface was better than flat shape of the Wacom. However it still has issue with three fingers swipe. It can easily lose one finger from a three fingers swipe. Even though there are some issues with multi-touch devices, they are still good potential distance interaction devices for specific operations on large high-resolution displays. New devices which merge the functionality of the Apple Magic Trackpad and Wacom Intuos Tablet could be better solution for our space organization design. However, we used the Apple Magic Trackpad for our user study.

Table II

Multi-Touch Interaction and Corresponding Operations

Multi-Touch Interaction	Operations
Two Finger Swipe	- Change window position within section
Three Fingers Swipe	- Move window to other section
Pinch in/out with Two fingers (Magnify +/-)	- Close media browser - Flock/unFlock - Expand/Push-Expand

4.5   <u>**Summary**</u>

In this chapter, we reviewed legacy WIMP desktop operations and looked at what we need to consider if we port these operation to large high-resolution display environments. Then we looked at multi-touch interaction, and suggested Effective Space Organization Design. Data handling and Enhanced sections are the primary contributions. The key point here is to reduce unnecessary repeated operations through automated operation.

In the following chapter, we present an evaluation of the Effective Space Organization Design.

5   EVALUATION- WORKSPACE

How does our design affect the user's behavior? How does the user use space? Does this design solution provide an environment where users can focus more on their work and data on large high-resolution displays? We have many questions for the design solution described in chapter 4.

This chapter provides an evaluation of our designed environment so we can answer those questions. In this chapter, we describe our user study scenario, dataset, and experimental environment. Then we present the results of our user study.

5.1   Scenario

The City of Chicago wants to implement a smart data platform. In other words the city would like to forecast the future from the present data. This campaign is called as "Chicago: City of Big Data". Therefore the City of Chicago shares some of its big data with the public. By sharing this big data, the City of Chicago expects that programmers, designers, and citizens to work together to find solutions for some of Chicago's most pressing urban issues. Big data Analysis can be a very good activity example on large high-resolution display. To analyze big complex data large high-resolution displays can provide a better environment than a desktop environment since it has more space and more pixels to view more data.

We took crime data shared by the City of Chicago for our user study. Crime data is

complex data. The scenario of our study is to analysis crime patterns with a native window organization system and our designed solution in large high-resolution display environment. We provided graphs based on crime data of selected districts. The City of Chicago is divided into 25 districts, and a district consists of multiple police beat regions. The data includes information on crimes that took place from 2009 to 2013.

We asked each participant to explore the graphs, analyze the data, and suggest strategies to reduce crime rate. Specifically, we asked the participant the following questions.

- What kind of crime types do the Chicago Police need to focus on?

- Which location must Chicago Police concentrate on?

- Which beat area should Chicago Police officer focus more on? The Chicago region is divided into districts, and each district consists of typically 12 beats.

With these findings, participants also were asked to find answer of the following questions.

For the crime type or location that was found,

- Which month of the year do the Chicago Police need to focus on?

- Which day of week do more Chicago Police officers need to be on duty?

- Which time of day do the Chicago Police need to concentrate on?

Each participant was expected to explore and analyze the crime data and present what they wanted to suggest for the Chicago Police of that district based on the questions that we provided. Our official user study scenario is in Appendix A.

5.2   Experimental Methodology

Here, we describe visualization of crime data, apparatus, participants, procedures, and data gathering for the study. The hypotheses are also presented.

5.2.1   Data Preparation: Visualization of Crime Data

We provided various graphs for the participants to explore various kinds of data. Two ways were supported for the participant to access the graphs. First, participants could access graphs from the media browser. Alternatively we provided a tool to the participants. Participants could choose graph type with options like time of year, beat number, crime types, or locations (see figure 17).
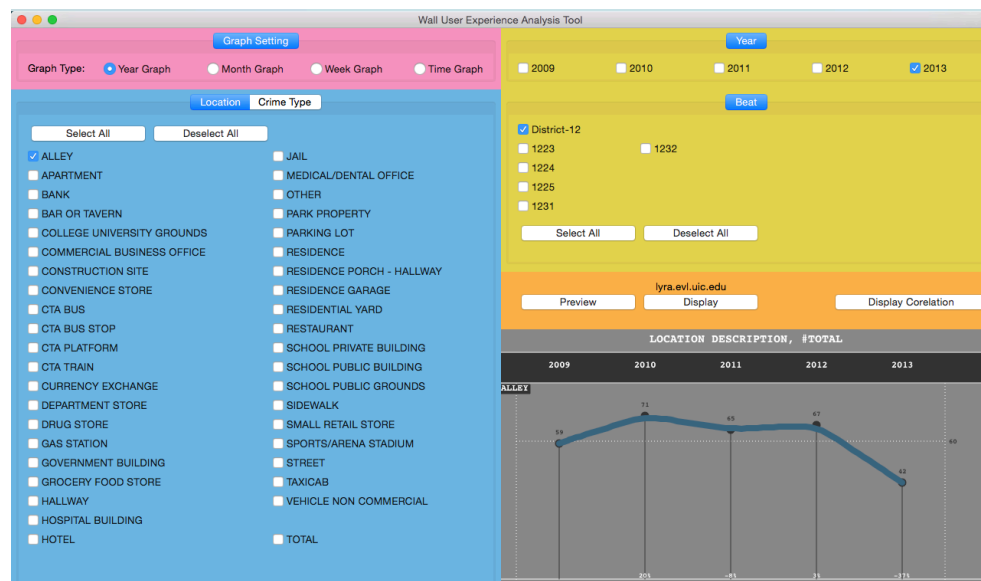
Figure 17. Graph-Generation Tool: Because there is a large amount of data for a district, we provided tool that can create graphs. Participants can choose graph type, year, location, crime type, and beat number.

Heatmap graphs were provided for seeing an overview. A location-based heatmap graph shows the top 20 locations in the columns and all the beats in the district in row (see figure 18). On Left side

the yellow color bars show population of each beat area, and the pink color bars on right side present the median income of each beat area. Dark yellow and dark pink colors mean that its value is above average. In middle area, color indicates the crime rate for the location and the beat area. For example, in Figure 18, the highest crime rate area (the black cell) is in department store column and 122 beat area row. The participant also could find which location or which beat area has more crimes. For example, in figure 18, street location has more darker cells in the street column, and the 131 and 132 beats show more darker cells in the corresponding row. In same way, a crime type-based heatmap was provided to the participants. For a district a total 20 of heatmaps for location and crime type were provided from 2009 to 2013.
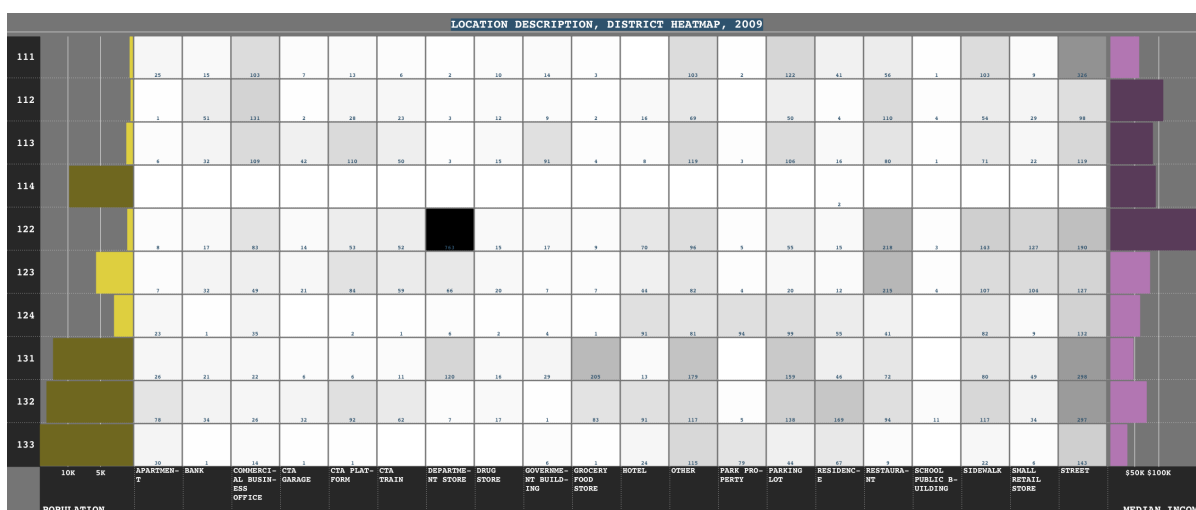
Figure 18. Location-based Heatmap. The heatmap shows top 20 locations in rows and all beats in the district in the columns. Left yellow bars show population of the beat, and right pink bars present median income for the beat. Cells in middle area indicates crime rate with gray-scaled color on the location and the beat area.

In addition, correlation heatmaps between location and crime type were provided. Figure 19 shows a sample graph. The heatmap has top 20 locations in column and top 10 crime types in rows. In

the middle area it shows the crime rate of that crime type at that location, so the participant could find where the crimes were happening. For example, in Figure X, motor vehicle theft crime type happened in parking lots and on the street. We provided 5 correlation heatmaps, and each participant can create additional co-relation heatmaps for specific beat areas with the graph-generation tool.
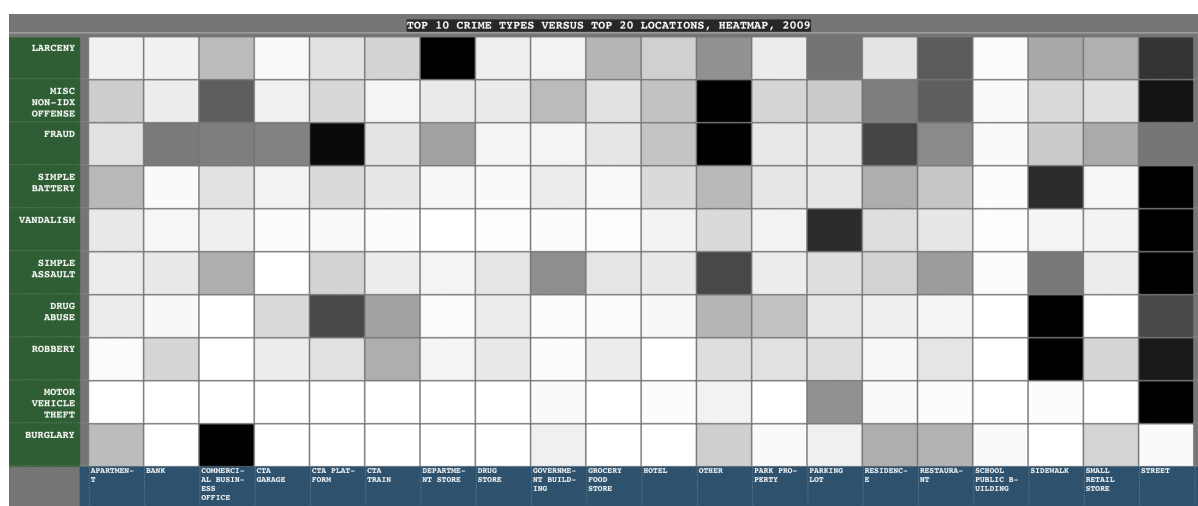
Figure 19. Co-Relation Heatmaps. The heatmap shows top 20 location in columns and top 10 crime types in rows. Gray-scaled color of cells in middle area indicates crime rate of crime types happened on the location.

There is another way to see an overview. It is bar chart. Figure 20 (a) is location-based bar chart. This bar chart shows all locations and frequency at the location. Figure 20 (b) is crime type-based bar chart provided. The participant can find graphs from 2009 to 2013.

We provided trend graphs from 2009 to 2013 (see figure 21). Location-based and crime type-based trend graphs are supported. Some of trend graphs were already created and available in the media browser. The participant could create a trend graph with selected locations or crime types for a selected beat area with the graph-generation tool.

Figure 20. Frequency Graphs. (a-left) is location-based bar chart, and (b-right) is crime type-based bar chart. The graphs show all locations or all crime types. The graphs show frequencies.

Figure 21. Trend Graphs. Trend graphs shows the trend of crime rates from 2009 to 2013. (a-left) is a location-based trend graph, and (b-right) is a crime type-based trend graph.

Month graphs and week graphs use bar charts with smoothed trend lines (see figure 22). The month graph can be used to see whether there is pattern or not with the month of year. The X-axis is month, and y value is the number of crimes on the selected location or crime type in the month.

Participants also could select a beat area. The week graph is a bar chart like the month graph. The X-axis is the day of week, and the y value is frequency on the selected location or crime type in the day of week. A particular beat area can be selected as well. For example, Figure 22 (b) shows the week graph for CTA Platform and Parking Lot. Darker blue means the frequency is above average frequency. Crimes happened more on weekdays at a CTA Platform, and the highest crime rate occurred on Thursday.
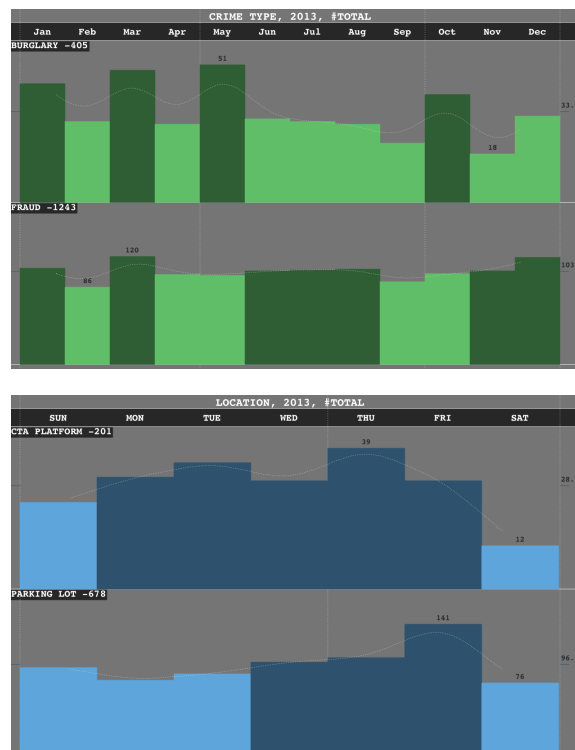
Figure 22. (a-top) Month Graphs, (b-bottom) Week Graphs. The month graph shows the number of the selected crime type that occurred each month. The week graph presents the number of crimes that occurred at the selected location on that day of week.

Figure 23 is location based time graph. The graph shows what time the selected crime type happened, or when any crime happened at the selected location. For example, in Figure 23 we see bar

or tavern locations. Crimes in bars or taverns happened more often between 1 am and 2 am. Participants could select crime type or location to see the time graph. For all the graphs participants could select a specific beat area or year.
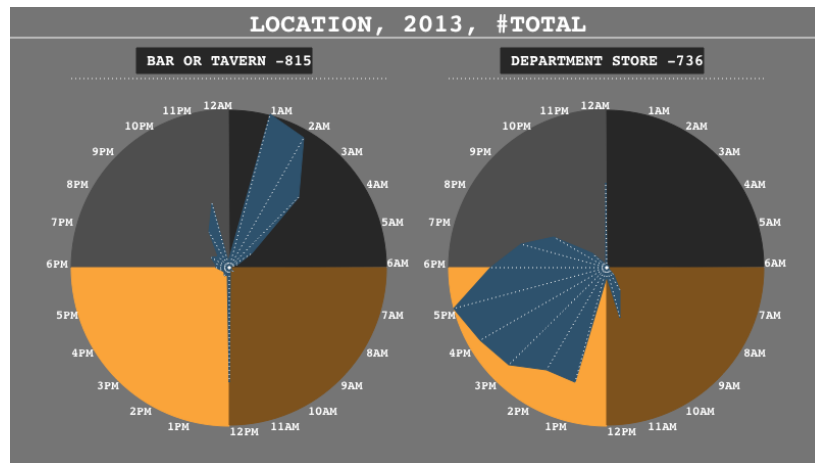
Figure 23. Time Graphs. The graph shows when crimes happened at the selected location.

With these various graphs we described here, participants were asked to analyze crime pattern in a given district. By intension we created various aspect ratio graphs.

5.2.2 **Apparatus**

Our study was held in the CAVE2. CAVE2 is 320-degree panoramic 18x4 tiled-display environment. The size is 7.3 meters in diameter and 2.4 meters in height (see figure 24). The participant sat at distance of 6.3 meters far from the front center display. The experimenter sat next to participant. Participants were also allowed to walk close to screen.

Participants worked in the native system environment and our designed environment. The native system environment provided similar operations as a desktop environment. Additionally the native system has section and tile function.
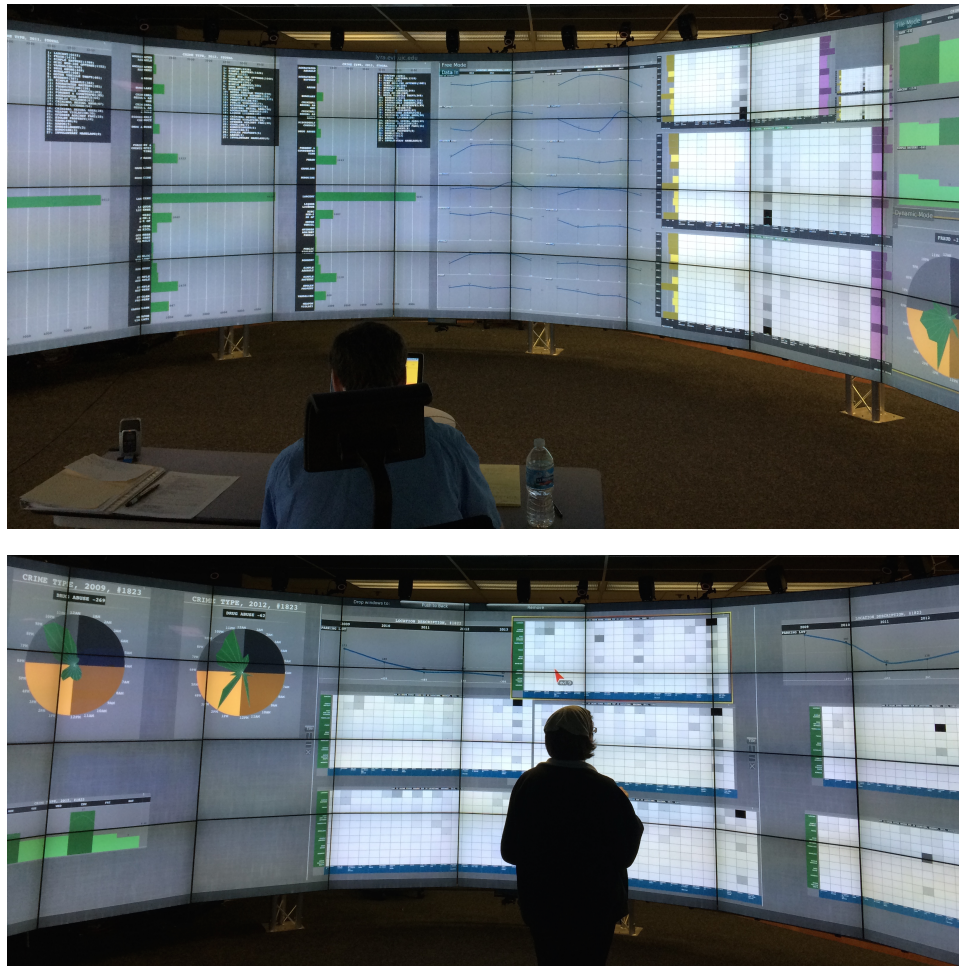
Figure 24. CAVE2. (a-top) Participants sat at distance of 6.3 meters far from the front center display. In picture (a), P4 was using upgraded version. (b-bottom) Participants were also allowed to walk close to screen for observation. In picture (b), P9 worked in native system environment.

We compared two systems - the native system and our solution. We used SAGE as the native system. SAGE is described in chapter 3.2, 4.2, and 4.3.

5.2.3   Participants

Fifteen volunteer participants were recruited. Ten participants were male and five were female. The majority were computer science graduate students. The average age range was 30-35 ($SD = 9.8$).

Participants reported their familiarity with large high-resolution display. We grouped them according to that reported familiarity. Four participants were naïve users, four participants were medium-level users, and seven participants were high-level users. Participants also self-reported how fast they could generally learn new functions in new environment with 1 being "slow" and 10 being "fast" ($mean = 8, SD = 1.3$). We asked each participant about their working style. When they work, do they organize their work better, or not? They reported with 1 being "not organize at all" and 10 being "organize very well" ($mean = 8.2, SD = 0.75$). All participants lived in the Chicago area. They were familiar with the region. We also choose a popular central district that people might have more knowledge of than other areas of the city.

5.2.4   Procedure

Participants sat at a distance of approximately 6.3 meters from the display (see figure 25). They sat in a swivel, height-adjustable chair. Pen and paper notepad were provided to participants. Detailed descriptions about the crime types was also provided in binder. Participants used Apple Magic Trackpad to interact with display, and laptop to use the graph generation tool.

Each participant had 50 minutes training. During training we explained the scenario and the meaning of the graphs. We also showed them where to find graphs, how to create graphs, what kind of function they could use on display and multi-touch interaction. It took approximately 15 minutes to explain all this. For 35 minutes the participant had pre-session with sample data for a sample district near the university area-district 12.
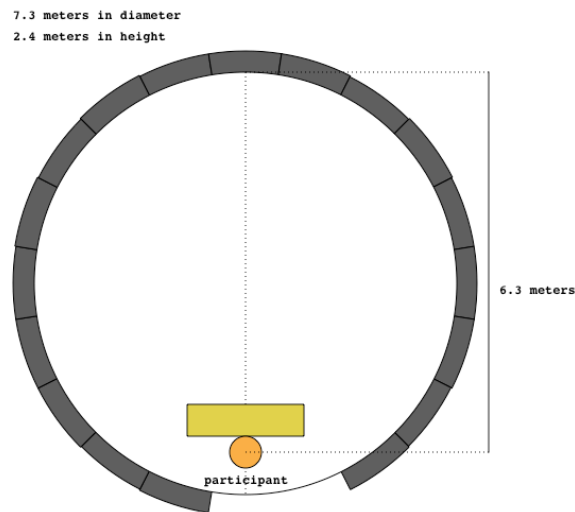
Figure 25. Experimental Setup in CAVE2.

After the training, participants had two sessions. Each session took a maximum of 50 minutes. A session consists of three phases. The first phase is analysis phase. Participants could use a maximum 30 minutes for the analysis phase. Participants could explore graph data and analyze the data to answer questions which were asked (see section 5.1, Scenario). The second phase is a 15-minute preparation phase. Participants were expected to prepare a presentation during this time. If participants felt they did not need more time, they could finish the analysis or preparation phase earlier. The last phase is a 5-minute presentation. The presentation should answer the questions with showing supporting graphs. Participants were allowed to take breaks if they needed.

Session 1 was south loop area of Chicago-district 1, and session 2 was north loop area of Chicago-district 18 (add web link). All participants used the native system and the upgraded version. Half of the participants used the native system in session 1, and then they used our solution in session 2. The other half started with our solution and then used the native system.

At the end of study the participants filled out questionnaires to give feedback.

5.2.5 Data Gathering

We recorded audio and three videos. Two video cameras faced the display, and one camera on the laptop recorded participants when they sat. All activity on display except pointer movement was recorded in a display log file. Pointer movement was recorded on the laptop. The pointer movement log was merged with the display log later.

5.2.6 Hypotheses

Our hypotheses for this study were:

- H_1: We hypothesize that upgraded version would improve window manipulation comparing with native system. Therefore, participants could have more time to explore data. We expect that performance would be affected.

- H_2: We expect participants to use space more effectively with the upgraded version. Participants would use more space on the display. Additionally we expect participants to use space with meaning.

- H_3: We hypothesize that the participant would learn how to use space on large high-resolution display with the upgraded version. The upgrade version provides guideline to participants.

5.3 Quantitative results

5.3.1 Activity Analysis

When the system is changed, we expected user behavior to change. Here, we investigate the participant' activity to find the evidence of improvement on our design solution.

5.3.1.1   Behavior Transition Diagram

Figure 26. Activity Graphs. The graphs show pattern of thinking and manipulation activity (green rectangles and red lines on green rectangle area). In addition, the graphs show when operation of window and session was run. Blue color bars show the analysis phase, brown color bars show the preparation phase, and yellow bars show duration for presentation phase.

Figure 26 shows how participants used their time. The first top graph show mouse activity and analysis activity. Red lines indicate mouse-activity. The green areas show that participants were in analytic activities like observing the data, formulating hypothesis, or forming a goal. The graph also shows specific activities like loading new window, resizing the window, closing window, changing status, creating new session and so on. The area of the blue bar indicates the analysis phase, the brown bar area is for the preparation phase, and the yellow bar is for the presentation phase. Window-change on the upgraded version would occur from other activities like apply, or move to other section.
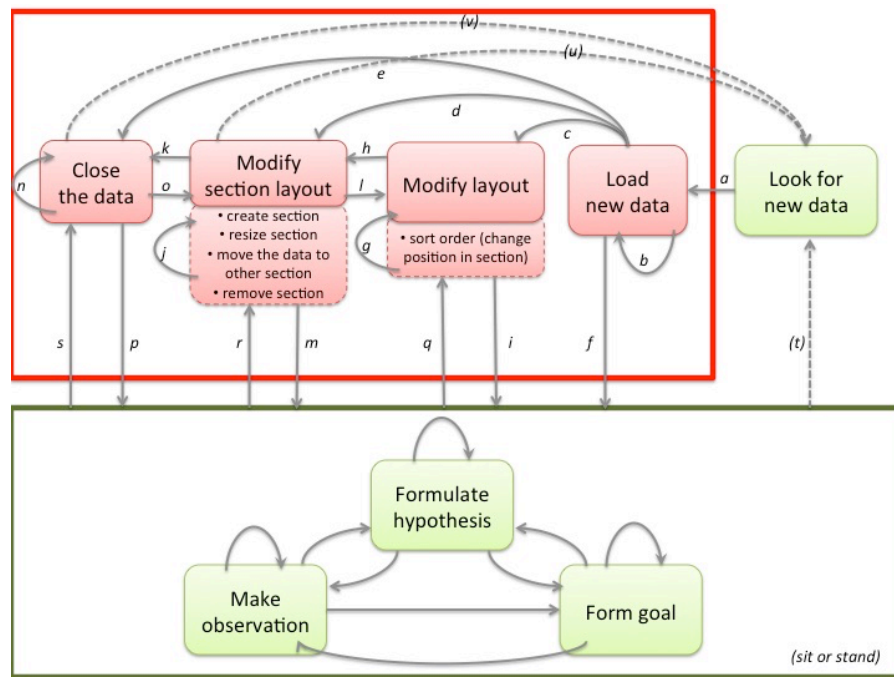
Figure 27. Behavior Transition Diagram. The diagram shows all activities and transitions observed in our user study. States in the green box is show analytic activities. States in the red box show organization activities. We assigned labels to each transition.
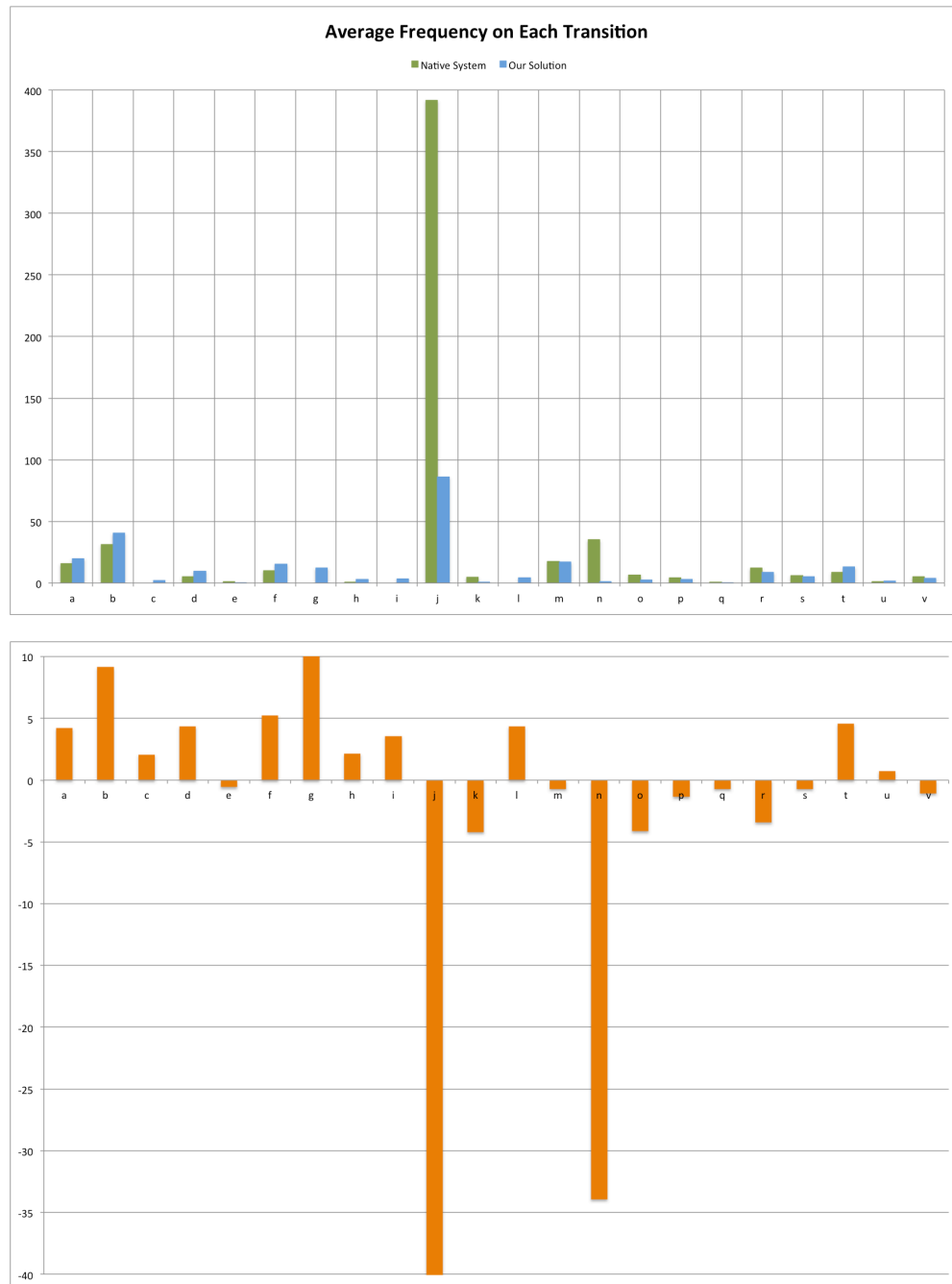
Figure 28. (a-top) The graph shows the average frequency on each transition. (b-bottom) difference of frequency from upgraded version to native system is shown.

We draw transition diagrams with the observed behavior (Figure 27). The transition links between the states are labeled with the number of transitions that were observed during a session. Figure 28 shows the number of transitions on the native system and the upgraded version. Average difference on *transition-10* is 305 $(mean = 305.57, SD = 285.17)$. Average difference on *transition-14* is 35 $(mean = 35, SD = 18.37)$. We can re-draw the transition diagram. The graph does not show how much time is taken for an action in a state, however we can see how often that state occurred in a session.

Overall, Figure 29 (a) and (b) show a similar flow. Participants looked for new data, and moved to the "Load new data" state. Participants might repeat the "Load new data" activity if they desired. The main flow of transition was to the "Analytic activity" (green box) or "Modify section layout" state. The order of states we mentioned here is based on the frequency number on the transition edge. If participants moved to "Modify section layout" the participants might repeat the "Modify section layout" state.

On the native system (see figure 29 (a)), from this point the transition mainly flew to "Analytic activity" or "Close the data". At "Close the data" state the participants might repeat "Close the data" state. Also the flow moved to "Look for new data", "Modify section layout" back or "Analytic activity" state. From "Analytic activity" (green box), the participants might move to "Modify section layout", "Look for new data", or "Close the data" state.

Now we look at upgraded version from "Modify section layout" state (see figure 29 (b)). It shows a subtlely different flow compared with the transitions on native system. Transition mainly flew to "Analytic activity" or "Modify layout" state. From "Analytic activity" (green box),

Figure 29. (a-top) Behavior transition diagram with native system. (b-bottom) behavior transition diagram with upgraded version. The number on each transition is the average frequency. The color and width scale on each transition edge indicates the degree of frequency. Darker and thicker edges mean that the transition has higher frequency.

participants might move to "Modify section layout", "Look for new data", or "Close the data" state. From the "Close the data" state, the flow moved to "Look for new data", or "Analytic activity" state back. Participants might repeat the "Modify layout" state, or might move to "Analytic activity" state.

We specifically checked *transition-6*, which moves from "Load new data" to "Analysis activity" (green box). It is good case that participants could load data and start analysis directly. It is also possible to move from "Analysis activity" to other organization activity through transition flow. However, it has more chance to work on data. In Figure 30, native system shows average 10.14 times on *transition-6* ($mean = 10.14, SD = 4.64$), and upgraded version shows average 15.36 times on *transition-6* ($mean = 15.36, SD = 4.11$). This difference is significant ($t(14) = 3.49, \rho < 0.004$) on two systems.

If we looked at the link starts from "Look for new data" and take the highest transition,

On the native system, from Figure 30 (a), the flow is

"Look for new data" ➔*"Load new data"* ✚ ➔ *"Analytic Activity"* ➔ *"Modify section layout"* ✚ ➔ *"Analytic Activity"* ➔ *"Look for new data"*.

On upgraded version, from Figure 29 (b), the flow is

"Look for new data" ➔ *"Load new data"* ✚ ➔ *"Analytic Activity"* ➔ *"Look for new data"*.

✚ means repeat transition on the same state.

Additionally the upgraded version promoted flow with "Modify layout" states. It can imply that participants started to look at organization strategy.

Next we looked at the total frequency number on all transitions. We did not count the transactions that moved to "Analysis activity" state. Figure 30 shows average number of transaction on both systems. The native system had an average of 525.57 ($SD = 338.20$), and the upgraded version had 214.64 ($SD = 80.40$). The differences between the two systems are significant ($t(14) = 3.78, p < 0.003$). On the native system, participants had 2.45 times more state transitions than upgraded version.
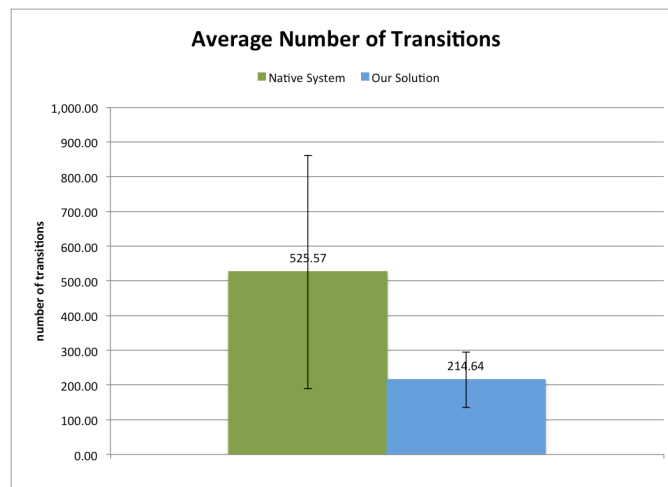
Figure 30. Average total frequency number happened on transitions.

Figure 31 shows total frequency number of transitions by each participant. We found P2 was the only participant with a higher frequency on our solution. P2 was only participant who reported a preference for the native system. Here we could assume that the total frequency of transitions might affect a positive or negative impression of the environment. P5, P6, P8, P9 and P10 have relatively larger difference numbers between the two systems. They are high-level users. P12, P14 and P15 also show larger difference numbers between the two systems. They are in the naïve user group. It means that the difference does not seem to be related to familiarity with the environment.
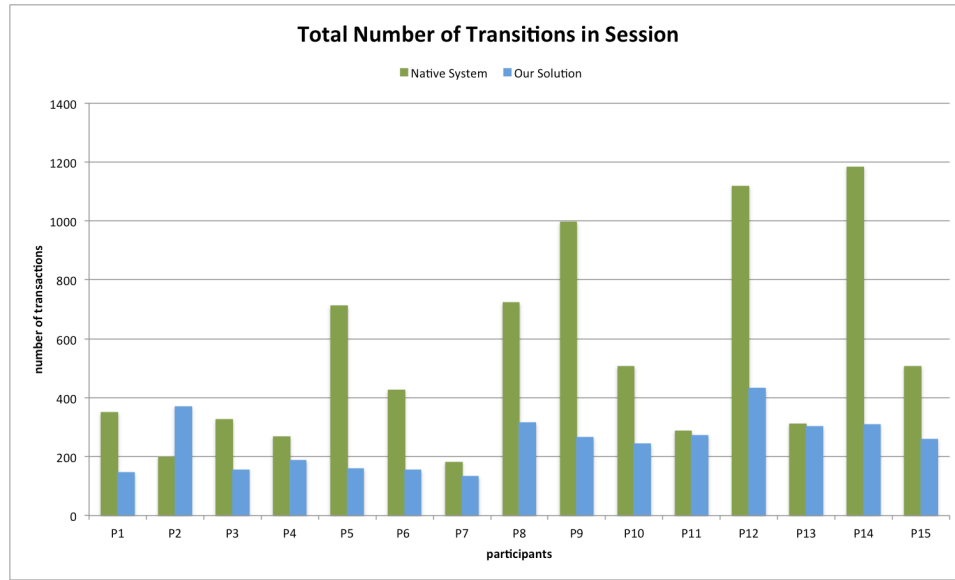
Figure 31. Total number of transitions for each participant. P2 was the only participant who had more transitions with our solution.

5.3.1.2 Average Length of Analysis Activity

We investigated the length of the analysis activity in analysis phase. Figure 32 (a) shows the average length of the analysis activity. Participants spent an average of 72 percent of the analysis phase for analysis activity on the native system ($mean = 72.0, SD = 6.43$), and they spent 84.36% on the upgraded version ($mean = 84.36, SD = 6.96$). The two systems show significant difference ($t(14) = 8.58341, \rho = 0.0$). We also checked each session. For session 1, the native system users spent 75.57% of the analysis phase in analysis ($SD = 4.47$), and the upgraded system users spent 83.14% of the analysis phase in analysis ($SD = 4.27$). The difference between two systems in session 1 is significant too ($t(14) = 2.69067, \rho < 0.02$). In session 2, users of the native system spent 68.43% ($SD = 3.76$), and users of the upgraded version spent 85.57% ($SD = 4.6$). T-test proves difference ($t(13) = 4.40732, \rho < 0.001$). Clearly, this result shows that participants had

more analysis time on the upgraded version than on the native system.
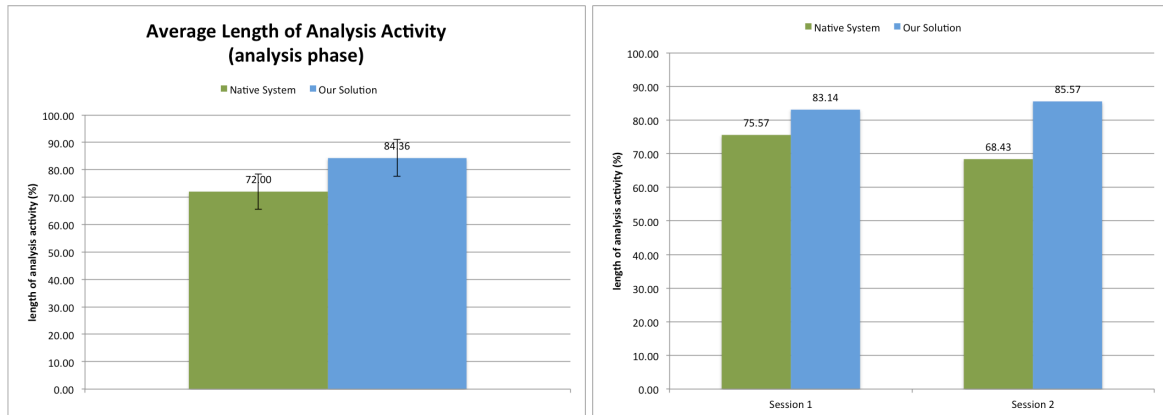
Figure 32. (a-left) Average length of the analysis activity during the analysis phase. (b-right) The graph shows the result of each session.

We counted activity cycles in the analysis phase. If participants started to look at another piece of data (*transition-1*, in Figure 33), it was counted as 1 cycle. With the native system the average number of cycles in the analysis phase was 12.24 $(SD = 2.5)$, the upgraded version shows 14.70 as average cycles $(SD = 3.07)$. A t-test shows that the two systems are significantly different $(t(14 = 3.89, \rho < 0.003)$. We also checked the average number of cycles for each session in Figure 33 (b). The upgraded version has a larger average number of cycles during the analysis phase. The number of cycles is not only one state but also might create multiple transactions. The number of cycles might affect task performance since participants could observe more data. This could be evidence for improvement based on window manipulation.
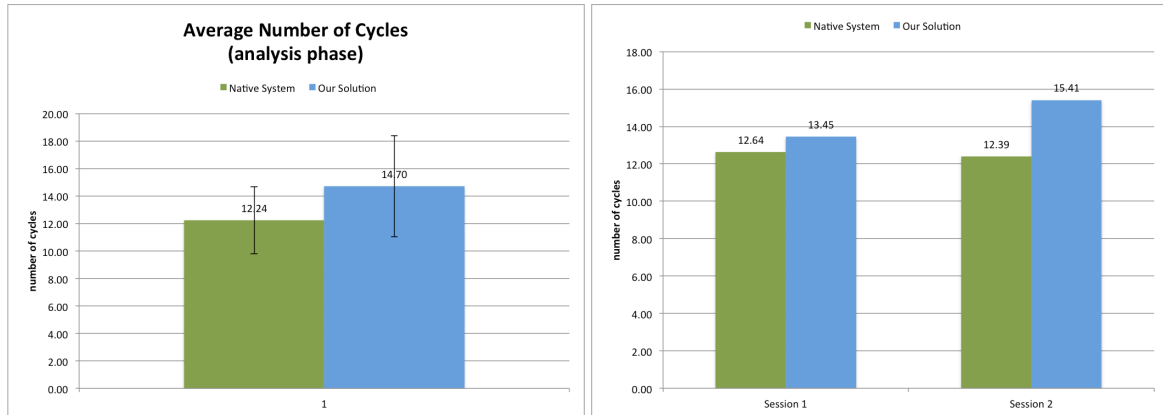
Figure 33. (a-left) Average number of cycle in analysis phase is counted. (b-right) The graph shows the result of each session.

5.3.2   Window Manipulation

People feel it is more difficult to manipulate windows on a large high-resolution display than on a desktop environment. Here we will show that our design solution improves window manipulation. In this experiment a graph is a window so in this section we will use the term window instead of graph.

5.3.2.1   Average Window Manipulation Time

First we looked at how much time a participant spent manipulating a window. Figure 34 shows average manipulation time for a window during the analysis phase. Users of the native system ($mean = 14.59, SD = 5.95$) took longer average time in managing a window than users of the upgraded version did ($mean = 7.69, SD = 3.89$). The difference between native system and upgraded version environment is significant ($t(14) = 4.05, \rho < 0.002$).
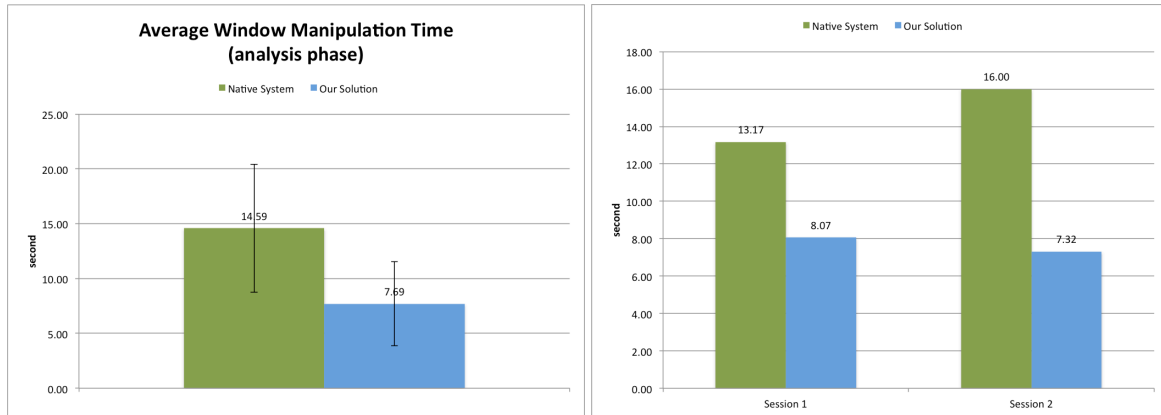
Figure 34. During analysis phase, (a-left) Average window manipulation time for a window between native system and upgraded version environment is significant difference ($t(14) = 4.05, \rho < 0.002$). (b-right) average window manipulation time for a window for each session.

Figure 34 (a) did not take into account the session order. Now Figure 34 (b) shows the time difference between the systems, and between the sessions. In session 1 participants who used the native system took 13.17 seconds for manipulation windows ($mean = 13.17, SD = 4.89$). With the upgraded version, in session 1 the average window management time for a window was 8.07 seconds ($mean = 8.07, SD = 3.06$). For session 1, with t-test, we could find a difference ($t(13) = 2.17, \rho = 0.051$) between the two systems. Now we look at session 2. A person who worked with the native system in session 1 worked on the upgraded version in session 2. Participants spent 13.17 seconds in session 1, but they spent 7.32 seconds in session 2 ($mean = 7.32, SD = 4.29$). However participants who worked on the upgraded version in session 1 took more time for managing a window in session 2. Participants spent 8.07 seconds at session 1, but they spent 16.0 seconds in session 2 ($mean = 16.0, SD = 6.16$). In session 2 the native system and upgraded versions are significantly different. ($t(13) = 2.83, \rho < 0.02$). Native system users spent more time for window manipulation than upgraded version users.

We looked at the average number of windows opened during the analysis phase (see figure 35). In Session 1 with the native system participants explored 34.64 windows on average ($mean = 34.64, SD = 6.21$). With the upgraded version participants explored 41.96 windows ($mean = 41.96, SD = 15.26$). In session 2 with the native system participants explored 41.47 windows ($mean = 41.47, SD = 17.09$). With the upgraded version participants explored 45.57 windows ($mean = 45.47, SD = 20.50$). For the average number of windows, we could not find difference with t-test.
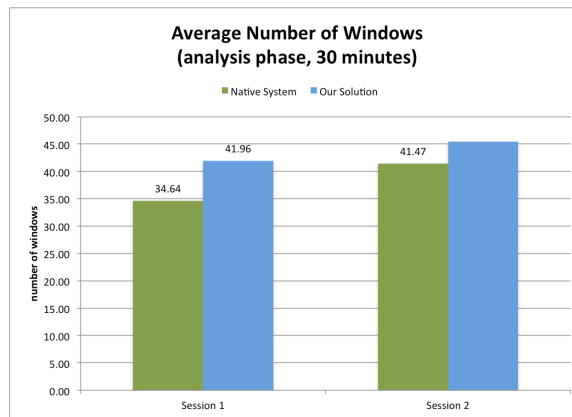
Figure 35. Average number of windows during analysis phase.

We investigated the preparation phases. Some of the participants did not run preparation phases at session 2. Therefore for the preparation phase we only had logs for 10 people who ran preparation phase in session 1 and session 2. As with the analysis phase, during the preparation phases participants spent less time managing on our solution. In Figure 36, the upgraded version shows 5.53 seconds ($mean = 5.53, SD = 3.8$). The native system took 6.92 seconds (mean=6.92, SD=4.08). We could not find a difference from t-test.
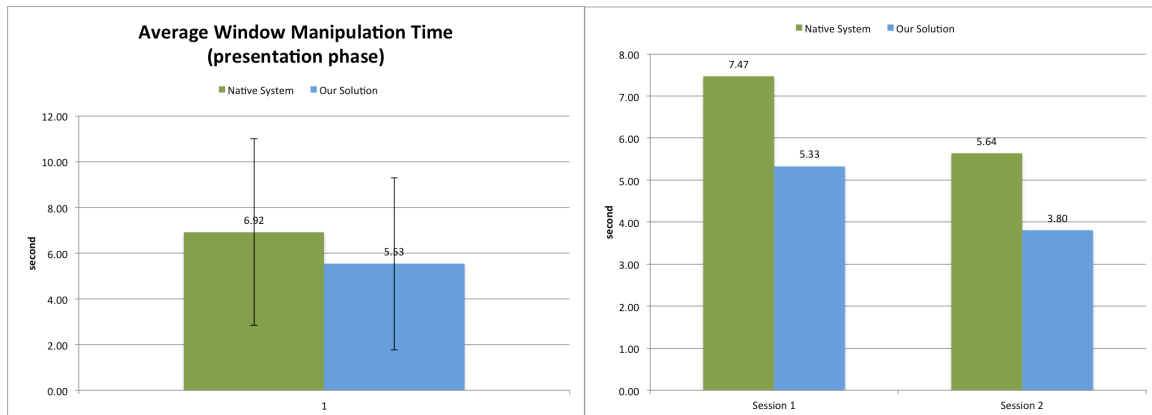
Figure 36. (a-left) Average window manipulation time for a window during presentation phase. (b-right) The graph shows the result of each session.

Let's compare window manipulation time in the analysis phase and the preparation phase. During the analysis time the native system users took an average of 14.59 seconds for window manipulation. During preparation time, native system users took 6.92 seconds. Average window manipulation time was reduced after working for approximately 30 minutes of analysis time. Upgraded version spent 7.69 seconds during the analysis phase, and 5.53 seconds in the preparation phase. Like native system users, upgraded version users also decreased their window manipulation time for a window. This could be evidence of learning activity.

We compared session 1 and session 2 with the native system and the upgraded version. In session 1, native system users took 7.47 seconds ($mean = 7.47, SD = 4.59$). Upgraded version users spent 5.32 seconds ($mean = 5.32, SD = 2.98$). In session 2, native system users took 5.64 seconds ($mean = 5.64, SD = 3.12$, and upgraded version users spent 3.8 seconds ($mean = 3.8, SD = 1.42$). We noticed that participants who worked with the upgraded version at session 1 still spent similar time with the native system in session 2. We assume that they might learn how to organize with the

upgraded version and mimic similar organization on the native system. P8 mentioned "I have learned how to organize the space efficiently with previous session 1".

Generally during the analysis phase and preparation phase participants spent more time managing a window on the native system. This means that the upgraded version improves window manipulation, so participants did not spend more time on managing windows. Additionally the analysis phase shows a significant difference between the native system and the upgraded version. This suggests that the upgraded version could help more for exploration and analysis behavior.

5.3.2.2   Changes of interaction activity

We found that average window manipulation time was decreased with our design solution (upgraded version). Now, we will look at what specifically causes these differences. We investigate differences with mouse interaction activity. In the upgraded version dragging activity was reduced and replaced with multi-fingers motions. The average number of dragging during analysis phase was 76.95 times on the native system ($mean = 76.95, SD = 22.59$), and 13.53 times on the upgraded version ($mean = 13.54, SD = 15.09$). Participants still needed to use the dragging activity for some of their actions. For example, they needed to resize a section and they sometimes moved windows by dragging. Clearly Figure 37 shows the average number of drag interaction is reduced on the upgraded version. The native system and the upgraded version show significant difference for the average number of drag activity ($t(14) = 12.38, \rho = 0.0$). We also compared sessions. In session 1, the native system and the upgraded version show similar significant differences ($t(7) = 6.26, \rho < 0.0001$. The native system shows an average of 71.46 ($SD = 25.44$), and the upgraded version has 9.5 ($SD = 6.22$). In session 2 the average number of drags is significantly different ($t(7) = 6.05, \rho < 0.0001$). The native system shows an average of 82.45 ($SD = 19.69$), and the upgraded

version has 17.57 ($SD = 20.41$).
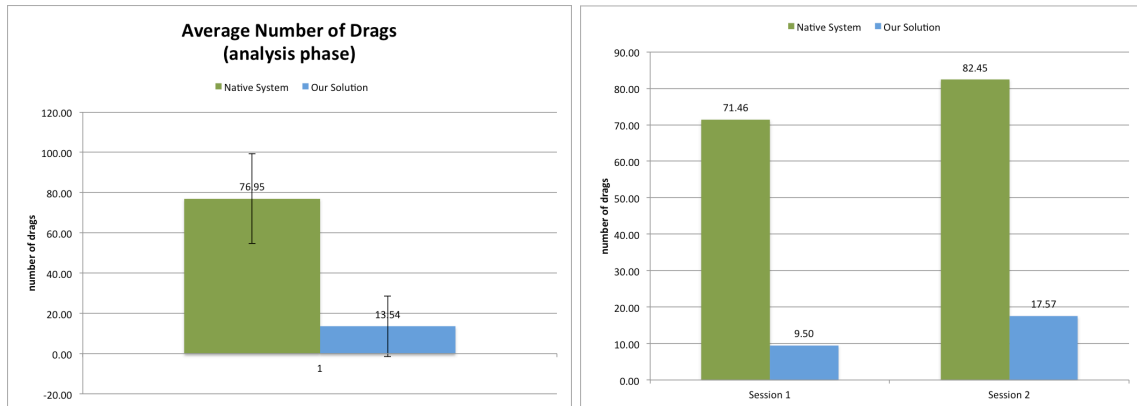
Figure 37. (a-left) Average number of drags in analysis phase. (b-right) The graph shows the result of each session.

Instead of dragging activity, participants used multi-touch motions as Figure 38 shows. We will not talk about the t-test result. The native system does not support multi-touch motion, so it is just different without t-test. Some participant still tried to do multi-touch motions on the native system. Almost all of the participants asked us whether multi-motion did not work on native system. This might imply that participants have a positive response with multi-motion interaction.
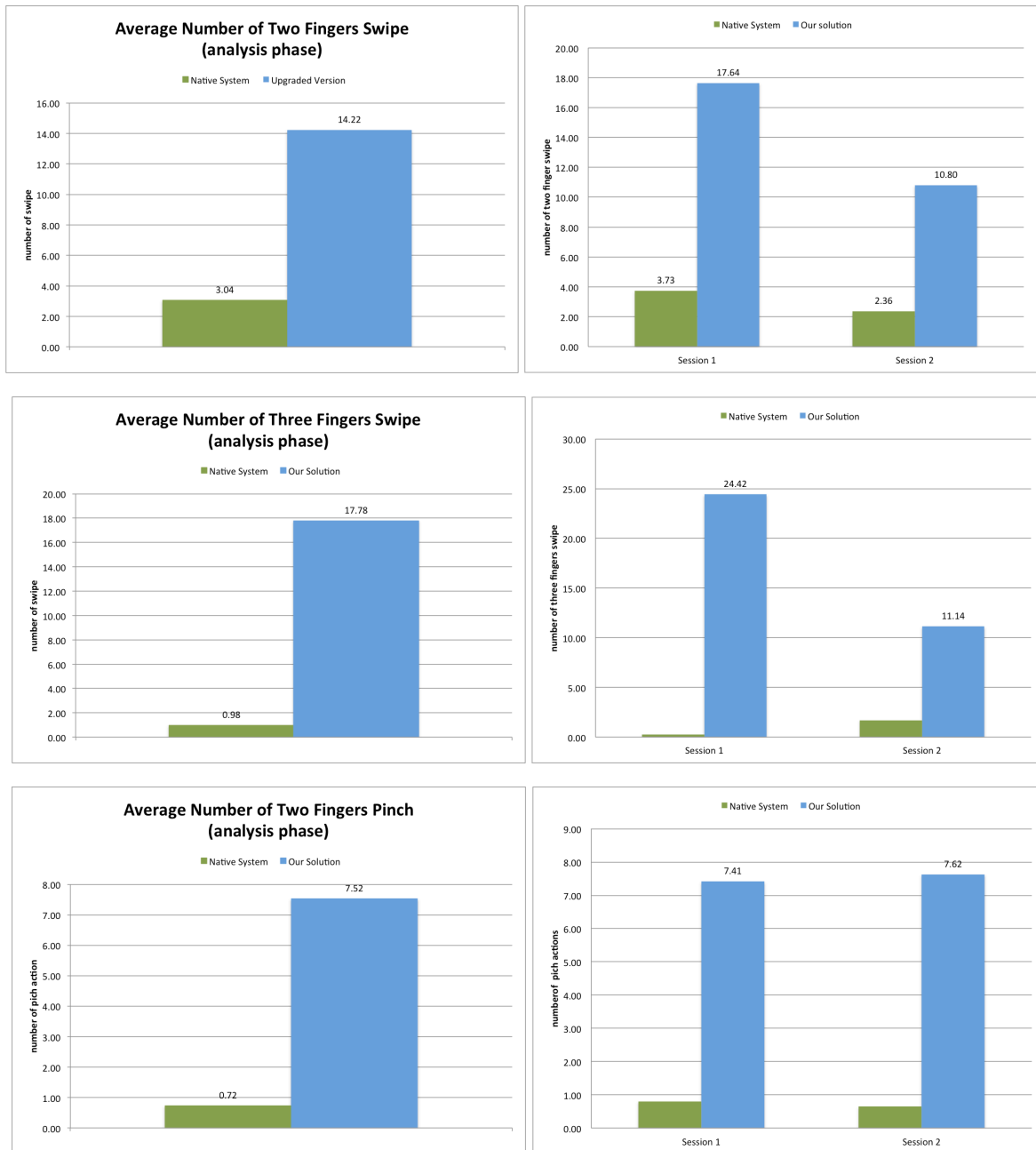
Figure 38. Graphs showing the frequency of multi-touch interactions in the analysis phase.
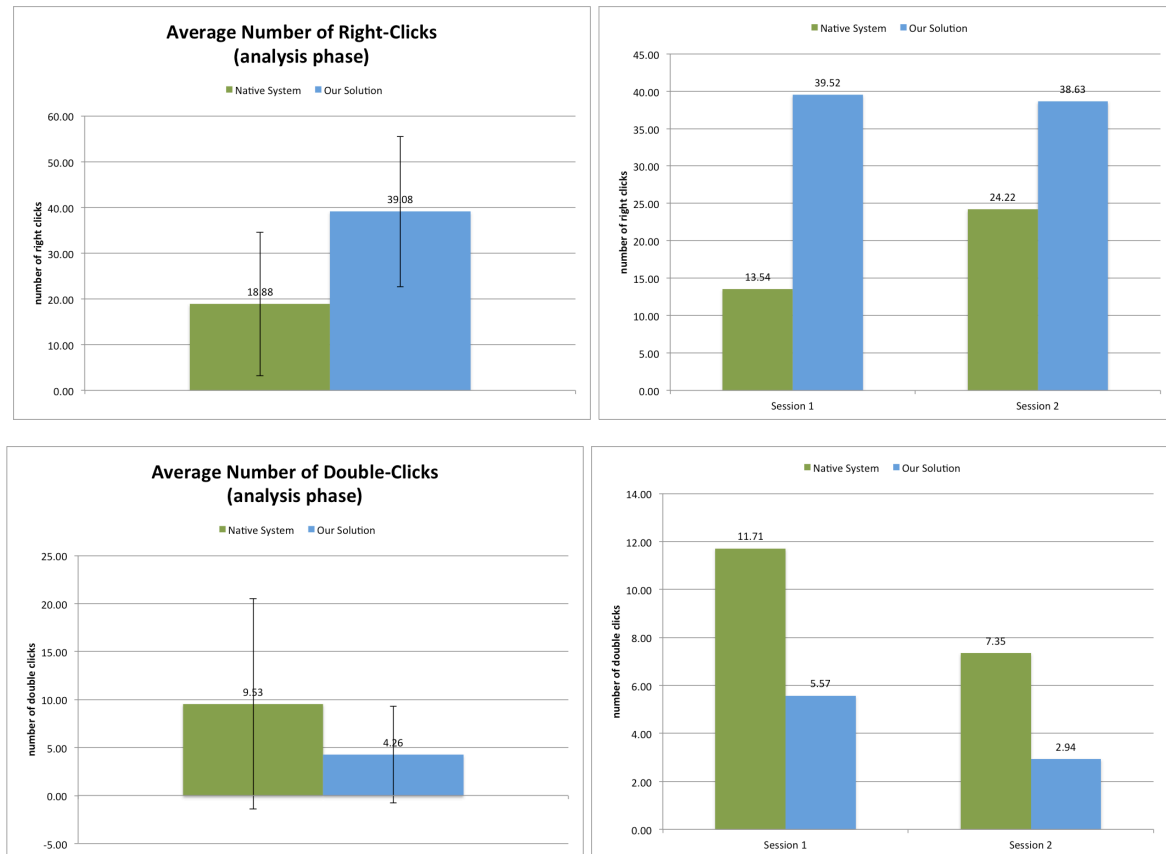
Figure 39. Graphs showing the frequency of right click(a-top) and double click(b-bottom) in the analysis phase.

There is another difference in mouse-related interaction behavior between the native system and the upgraded version. The upgraded version supports a localized popup menu. Therefore participants used more right clicking as Figure X shows. For the average number of right clicks the native system has 18.88 times ($mean = 18.88, SD = 2.77$), and the upgraded version has 39.08 ($mean = 39.08, SD = 16.40$). The native system and the upgraded version are significantly different on the number of right clicks ($t(14) = 2.52, \rho < 0.03$).

The log also shows different mouse-related interaction activities with double-click. Figure 39

shows that native version participants used double-clicks more than in the upgraded version. With the native system participants used double-click 9.53 times $(mean = 9.53, SD = 10.93)$, and the average number of double-clicks is 4.26 $(mean = 4.26, SD = 5.02)$ on the upgraded version. However the native system and the upgraded version do not show a significant difference $(t(14) = 1.72, \rho = 0.108)$. We observed that people used maximize to see their data more on the native system. That might be reason that participants used more double click interaction on the native system. Maximization in the native system could provide easy manipulation.

Average Window manipulation time for a window on the upgraded version is shorter than on the native system. Participants explored more windows on the upgraded version as well. Clearly mouse activity changed between the native system and the upgraded version. We consider this as evidence that our designed solution improved window manipulation and changed how participants interacted with system.

5.3.3 Use of Space

We looked at how participants used space. Here we show that our design solution guided participants to use space more effectively compared with the native system.

Figure 40 shows a window heatmap graph with horizontal distribution graph. The window heatmap presents the distribution of used pixels on the display. Used time is also reflected in the graph. The horizontal distribution graph shows the data in a different way than the heatmap graph. Given the used time of each pixel, we divided display area with 100 x 1 grid, and accumulated the used time of the pixel according to the cell. The X-axis is column of the grid, which is the display x-axis. The Y-axis shows accumulated used time ratio for the cell. The ratio is calculated using the maximum used time for the cell. For comparing between the native system and the upgraded version,

we set same maximum number for both results. Figure 40 is created with the accumulated data- log of 15 participants. Also we ignored the first 5% of display because the initial window position of the native system is the bottom left corner of display. Even though we did not include initial position in the window heatmap and horizontal distribution graph some of the participants moved newly opened windows around this initial position. The numbers within 5% of the left side display might cause bias. In the horizontal distribution graph values within 5% of the left side of display grayed out. The display x-position with the highest value is colored with red. The graph also shows a smoothed trend line. In addition, the natural center from where participants sat and center of the CAVE2 display are different. Therefore we adjusted the x-axis coordinates with natural coordinates based on the participant's initial setup position. We did not look at the vertical distribution here.
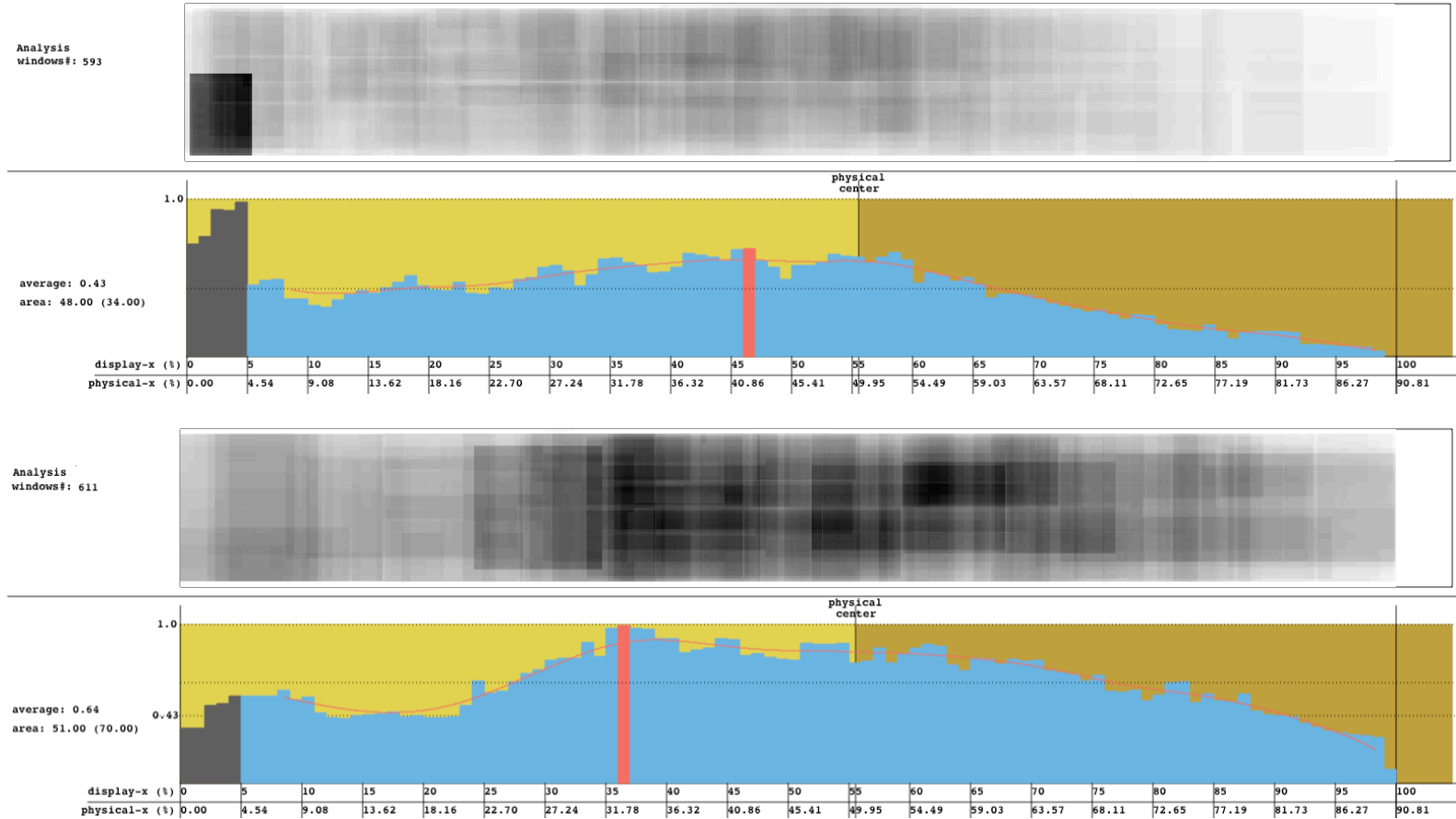
Figure 40. (a-top) Window heatmap and horizontal distribution graph of analysis phase on the native system, (b-bottom) Window heatmap and horizontal distribution graph of analysis phase on the upgraded system. The graphs show how 15 participants used the space. The results are accumulated. 5 % of left side could be ignored (gray-out area). Natural-x is standard X-axis coordination. The red bar is showing the x position with highest used pixel ratio value. (a) and (b) can be compared. The total duration and total number of windows are similar.
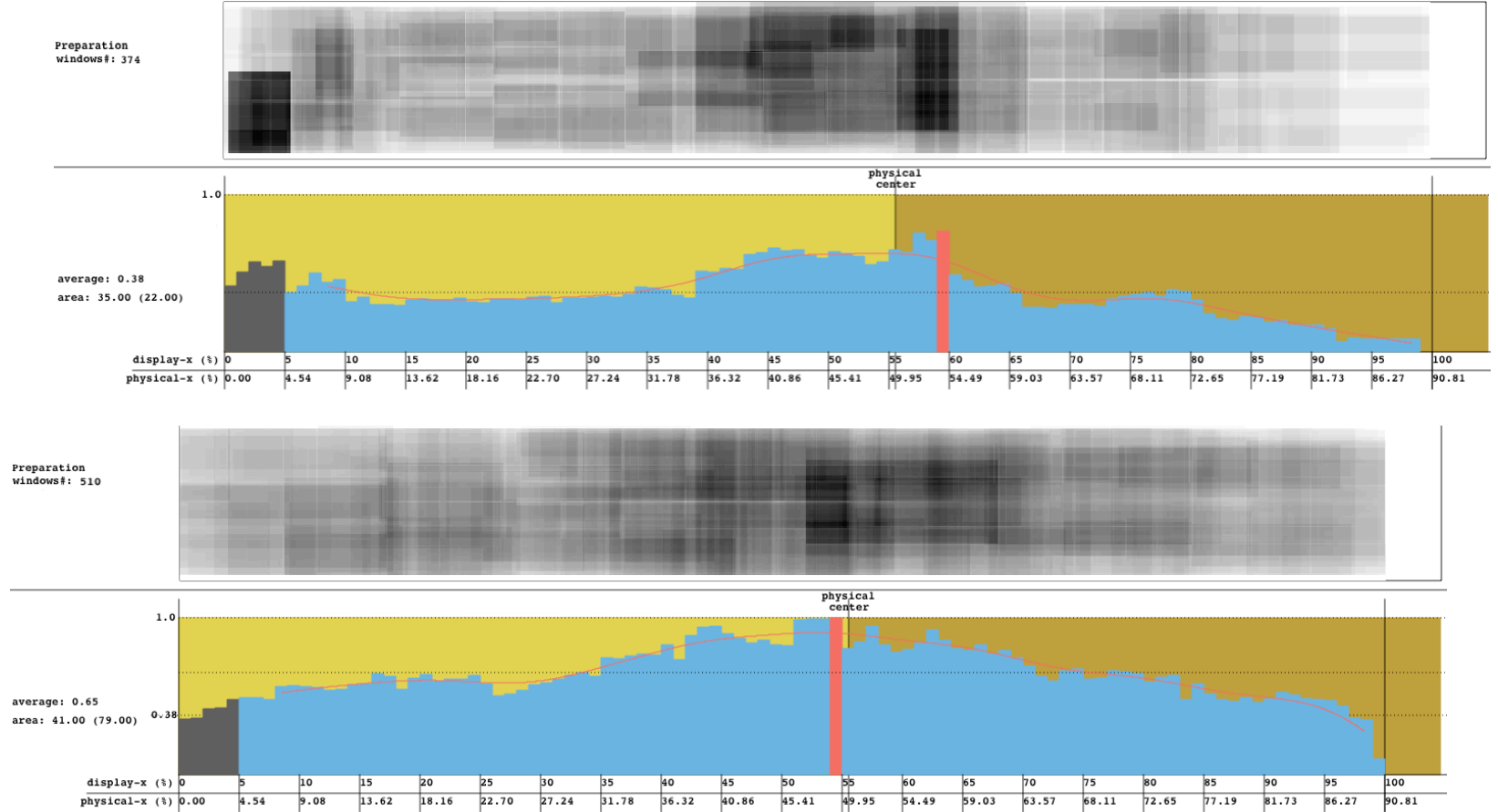
Figure 41. (a-top) Window heatmap and horizontal distribution graph of the preparation phase on the native system, (b-bottom) Window heatmap and horizontal distribution graph of the preparation phase on the upgraded system. The results are accumulated. 5 % of left side could be ignored (gray-out area). Natural-x is standard X-axis coordination. The red bar is showing the x position with highest used pixel ratio value. (a) and (b) can not be directly compared. Total duration and total number of windows are not similar.

5.3.3.1   <u>Use of Space during Analysis Phase</u>

The total duration of the analysis phase for the native system and the upgraded system are similar. With the native system the accumulated time is 7 hours and 23 minutes, and the upgraded version has 7 hours and 26 minutes for the analysis phase. The accumulated number of windows for both is similar as well. The native system has 593 windows explored, and the upgraded version has 611 explored. The native system and the upgraded version have similar conditions to compare.
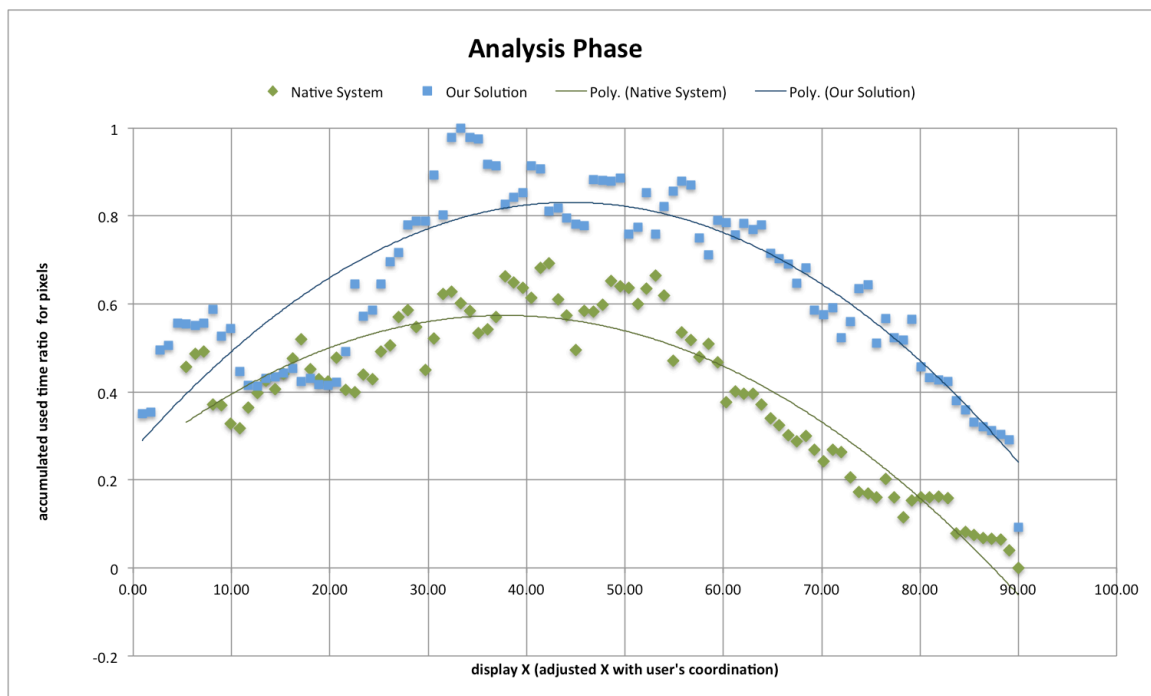
Figure 42. Used pixel distribution graph for analysis phase.

Shape of distribution

The used pixel distribution graph is shown in Figure 39 and Figure 42. Participants used the central area the most. Participants used the left side more than the right side. X-axis coordination was adjusted with natural center position. The center of display is 45.41% in adjusted X- axis coordination.

The shape of distribution trend for the native system and the upgraded version are different. The native system shows more of a decrease on the right side of the display. The upgraded version shows a more symmetric curve from approximately the 45% point.

Average

The average used pixel ratio on the native system is 0.43, and the average used pixel ratio on the upgraded system is 0.64. The upgraded version shows 1.49 times higher average used pixel ratio then native system.

Focal Area

We defined the focal area as the continuous area above average from the center. With a 0.43 ratio value the focal area of the native system is from 22.50 – 59.4% (from display range, 25 – 66%). With the same ratio value, which is 0.43, the focal area of the upgraded version is from 12.6 -82.79% (from display range, 14 – 92%). The size of the focal area on the native system is 36.9%, and on the upgraded version it is 70.19%. The upgraded version area is 1.92 times wider. We also calculated the angle and distance for the focal area from the participants' initial setup position. With the native system, the angle is 75 degrees, and the distance is 2.01 meters. The focal angle of the upgraded version is 151 degrees, and the distance is 1.92 meters (see figure 43). The total number of pixels on the native system is 31 megapixels, and the total number of pixels on the upgraded version is 59 megapixels. With a 0.64 ratio value, which is the average of the upgraded version, the focal area of the upgraded version is from 24.3- 68.40% (from display range, 27 -76,%). The size of the focal area on the upgraded version is 44.1%. The calculated angle is 89 degree, and the distance is 2.34 meters (see figure 43). The total number of pixels on the upgraded version is 37 megapixels. The native

system has 36.9% focal area and a 75 degree focal angle. The upgraded version has 44.1%, and a 89

degree focal angle. The upgraded version has wider range and a wider focal angle.

Figure 43. (a-top left) Focal area graph on the native system with 0.43 ratio. (b-top right) Focal area graph on upgraded version with 0.43 ratio. (c-bottom) Focal area graph on the upgraded version with 0.64 ratio. The orange area on the display circumference indicates the focal area. The orange line from the circumference is the center of the focal area, and the black line is the highest ratio point.

Center

We checked two different centers, which are the point with the highest used pixel ratio, and the center of the focal area. With the highest point the center on the native system was 41.40% (46%), and the center point on the upgraded version was 32.40% (36%). The center of the focal area on the native system was 40.95% (45.50%), and the center of the focal area on the upgraded version was 46.35% (51.50%). The highest used pixel ratio point for the native system and the upgraded version are located on the left side of the natural center position. On the native system the highest used pixel ratio point and the center of the focal area are at a similar position. On the upgraded version the highest points are more shifted to the left side. However the center of the focal area is nearly in natural the center position (see figure 43).

Area

We counted area use that was greater than average. On the native system, 48% of the display area is above the average of 0.43. On the upgraded version, 51% of the display area is above the average of 0.64. If we check the area over a 0.5 ratio, native system has 34% over and the upgraded version has 70% area over. Users of the upgraded version used space more fairly than users of the native system.

5.3.3.2   Use of Space during Presentation Phase

The total duration of the preparation phase for the native system and the upgraded system are different. Accumulated preparation time for the native system is 1 hour and 27 minutes, while the accumulated preparation period on the upgraded version is 2 hours and 16 minutes. The number of managed windows during the preparation phase was 374 on the native system, and 510 on the upgraded version.

Shape of distribution

As in the analysis phase, the distribution shape of used pixels is a curved shape. From the left to around center of display the used pixel ratio increases and then decreases from around the center to the right side. From the natural central point the distribution graph shows that the left side was used more than the right size. Figure 44 (b) shows that users of the native system did not use right side of the space as much as users of the upgraded version did. The upgraded version shows a more symmetric curve from approximately the 45% point.

Average

The average used pixel ratio on the native system is 0.38, and the average used pixel ratio on the upgraded version is 0.65.

Focal Area

We defined the focal area as the continuous area above average from center. With 0.38, the focal area of the native system is from 35.10 – 59.4% (display range, 39 – 66%). The focus area of the upgraded version is from 31.50- 63.89% (display range, 35 -71%) with an average of 0.65. The native system range is 24.30%, and the upgraded version range is 32.40%. The angle of the focal area on the native system is 48 degrees, and the angle is 65 degrees with the upgraded version. Additionally the distance on the native system is 1.65 meters, and the distance on upgraded version is 2.03 meters (see figure 45). The total number of pixels in the focal area on the native system is 20 megapixels, and the total number of pixels in the focal area on the upgraded version is 27 megapixels.
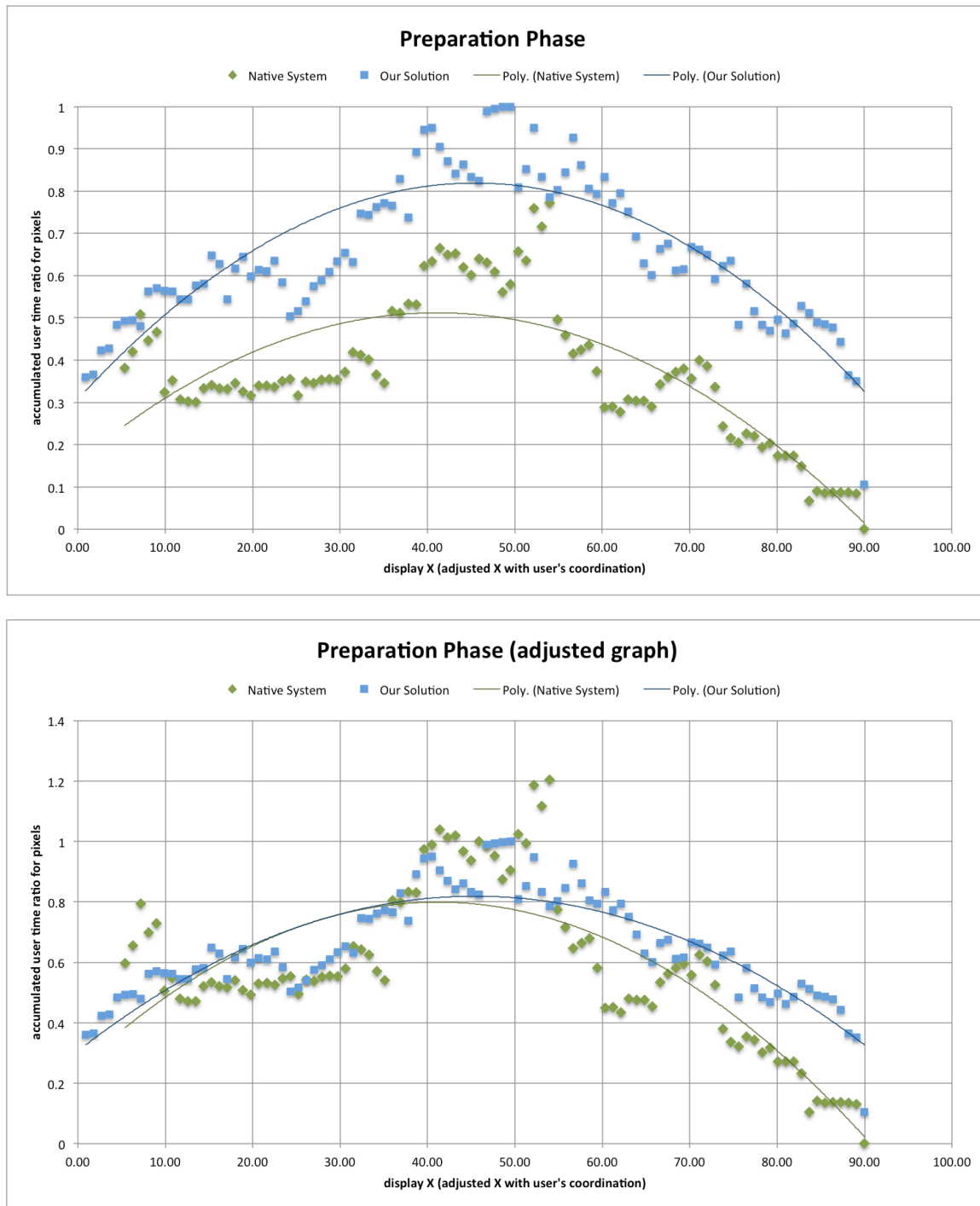
Figure 44. (a-top) Used pixel distribution graph for the analysis phase. (b-bottom) Adjusted graph by duration.

Center

The point with the highest used pixel ratio on the native system is 53.10% (59%), and is 48.60% (54%) on the upgraded version. The center of the focal area on the native system is 47.25% (52.50%), and the center of the focal area on the upgraded version is 47.70% (53.0%). The high used pixel ratio centers for the native system and the upgraded version are located on the right side of the natural center position. On the upgraded version the highest point and center of the focal area are in similar position and also near the natural center point. The highest used pixel point of the native system is more shifted to the right side as Figure 45 shows.

Area

We counted used area that was above average. The native system has 35% of the area of the display, which are above the average 0.38 ratio. The upgraded version has 41% of the area of display with an average 0.65. We checked the area over a 0.5 ratio. The native system shows 22% and the upgraded version shows 79% of the area.

Figure 46 (a) shows the trend pattern during analysis phase and preparation phase on the native system and Figure 46 (b) shows the trend pattern during the analysis phase and the preparation phase on the upgraded version. Each system shows a similar distribution pattern for both phases. Participants on the native system used space on the right side less than on the left side. However the distribution trend line on the upgraded version shows a fairly symmetric curved shape from the 45% point.

7.3 meters in diameter
2.4 meters in height

39%
66%

48 degree

participant

35%
71%

65 degree

participant

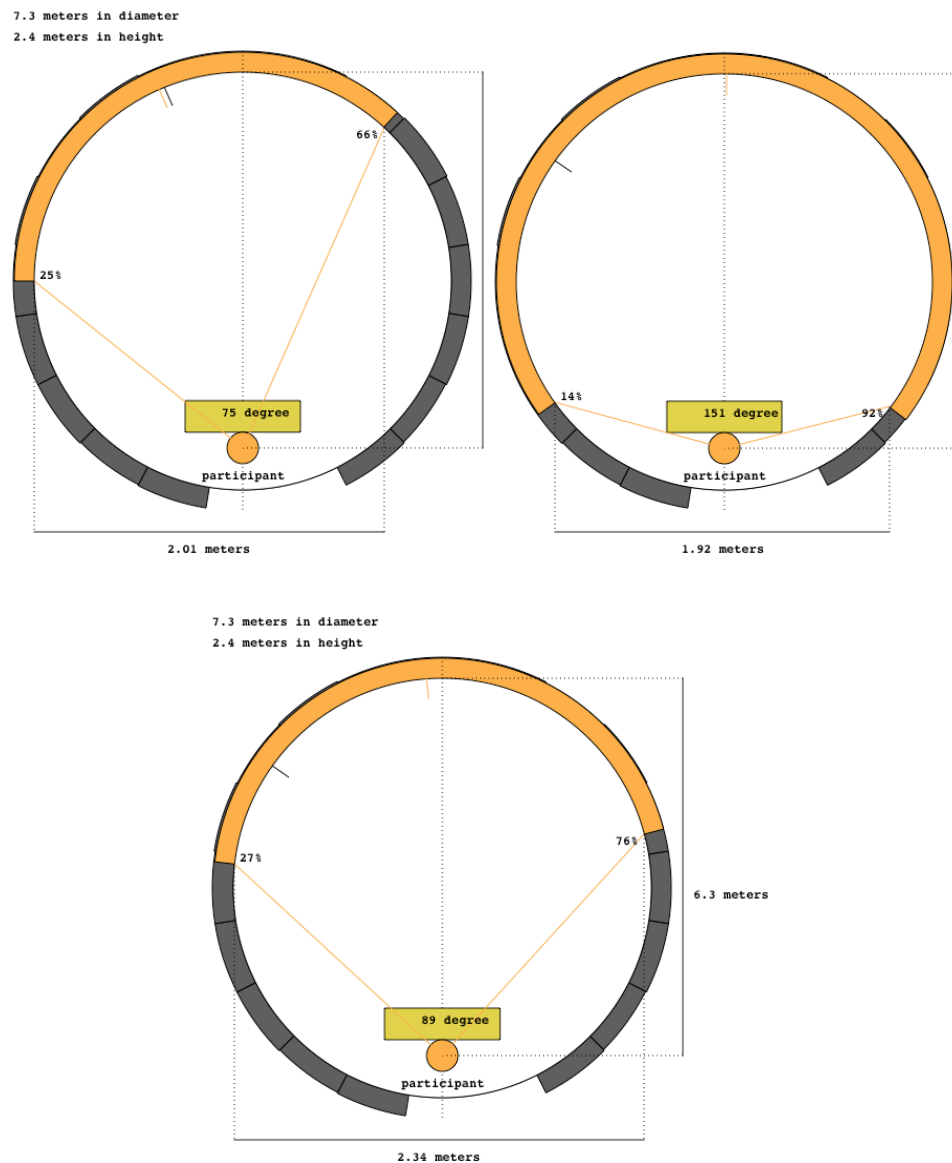6.3 meters

1.65 meters

2.03 meters
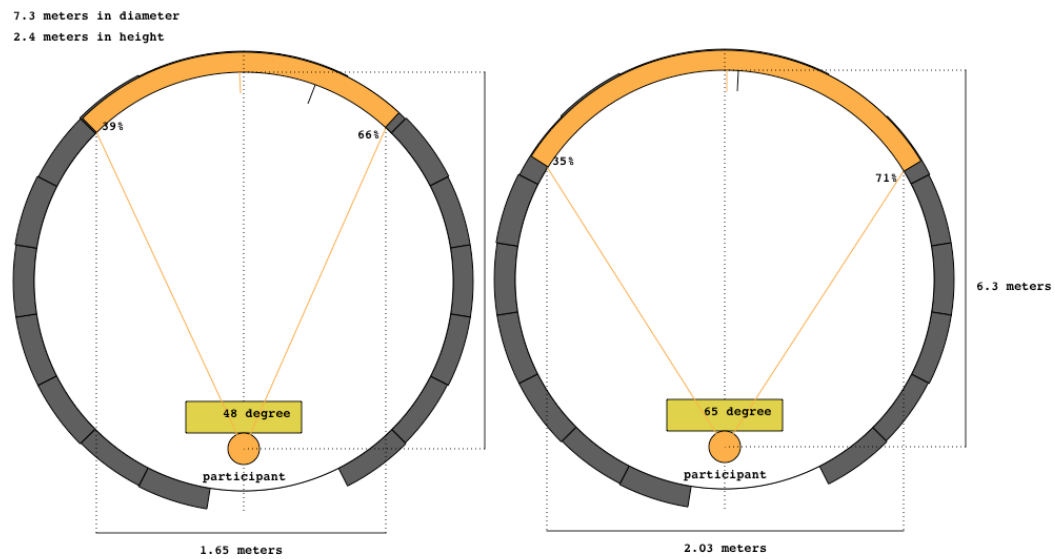
Figure 45. (a- left) Focal area graph on the native system with a 0. 83 ratio. (b-top right) Focal area graph on the upgraded version with a 0.65 ratio. The orange area on display circumference indicates focal area. The orange line from circumference is the center of the focal area, and the black line is the highest ratio point.
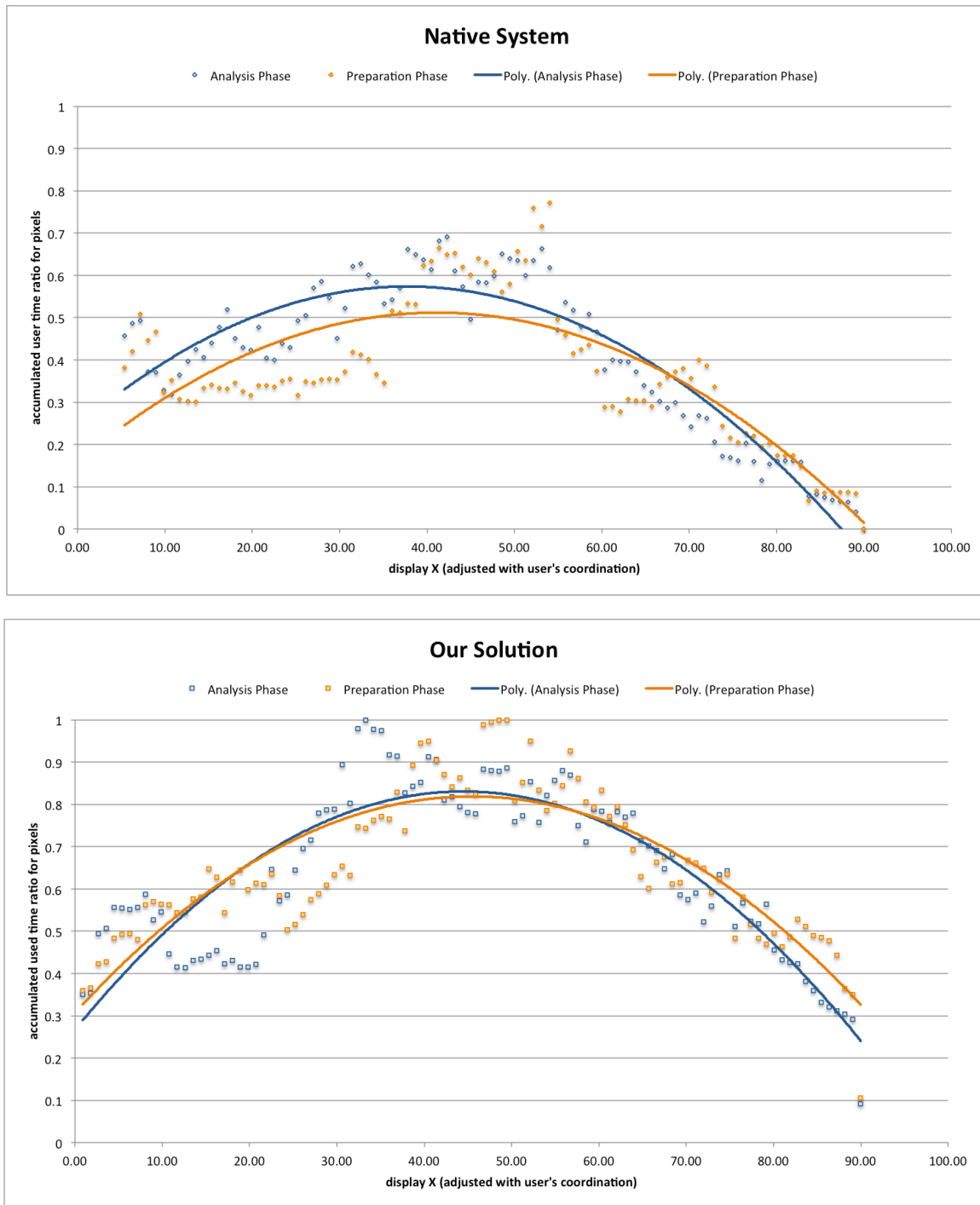
Figure 46. (a-top) Used pixel distribution graph on native system. (b-top) Used pixel distribution graph on upgraded version.

In the analysis phase and the preparation phase users of the upgraded version had a higher average ratio than on the native system, used more space, had wider focal area, had wider focal angle, and used space fairly on left side and right side.
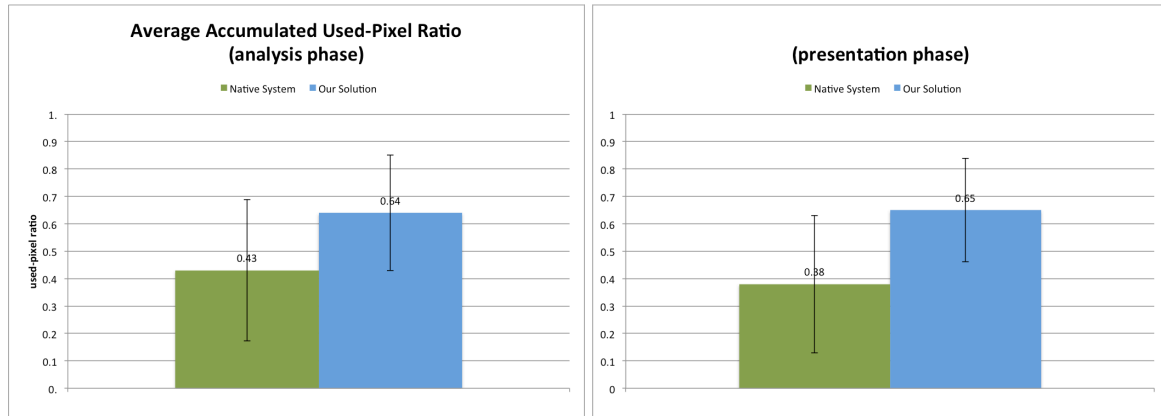
Figure 47. Average accumulated used-pixel ratio.

5.3.3.3 Percentage of Used Space

We calculated how much space was used every second during the analysis phase. Figure 48 shows the average used space percentage per second during the analysis phase. The native system has average of 30.16 % used ($mean = 30.16, SD = 10.74$), the upgraded version has an average of 37.59% used ($mean = 37.59, SD = 8.31$). The native system and the upgraded version might be different, but not significantly ($t(14) = 1.91182, \rho = 0.078$).

The participants who worked on the native system in session 1 used 34.08 percent of the display space per a second ($mean = 34.08\%, SD = 6.78$). With the upgraded version participants used 39.04% of space per a second ($mean = 39.04, SD = 6.35$). In session 2 with the native system participants had an average used space per a second of 27.45% ($mean = 27.45, SD = 12.60$).

Participants on the upgraded version used 33.40 percent of space ($mean = 33.40, SD = 11.21$).
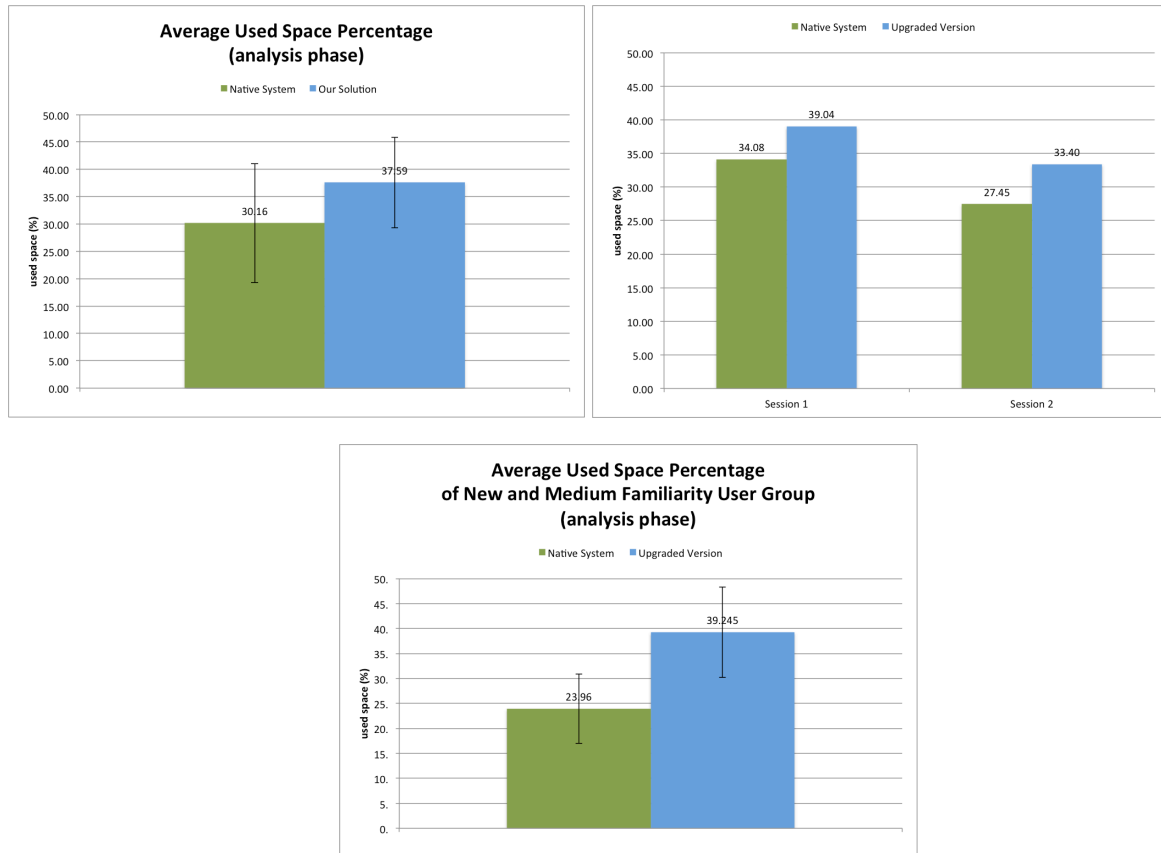
Figure 48. Average used space percentage in analysis phase.

We also checked the average used space with the group of naïve users and the medium familiarity users of large high-resolution displays (see figure 48). The native system shows 23.96 % (SD=6.86), and the upgraded version has 39.245 %(SD=8.84). With this group the native system and the upgraded version show significant difference in average used space percentage per second ($t(7) = 3.90, \rho < 0.01$).

Participants showed higher used space percentage when they used the upgraded version. The

naïve users and medium-level user group were affected more by the difference between the two systems.

5.3.3.4   Distribution of Used Space Percentage

We investigated how the used space percentages are distributed. We drew a distribution graph (see figure 49). The X-axis is the percentage of used space. The basic unit is 10%, and the range is 0 to 100%. 100 % means a participant used all the space without any empty space. The Y value is accumulated time (second). Figure 49 shows that generally 10~20% of display space was used during the analysis phase. The participant did not use space over 40%. This is not the pattern that we prefer. We need to make participants use more space throughout. Therefore the best shape of the graph is to make the bars move toward 100% (right side). This is different from focal range. This is about whether participants waste space or not.
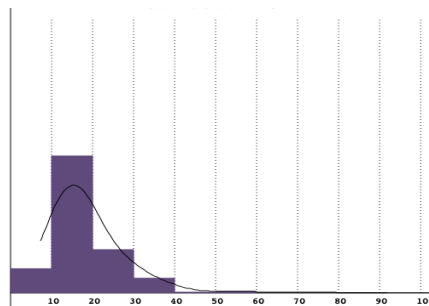
Figure 49. Used Space Percentage Distribution Graph. X-axis is the percentage of space used. Y-axis is the accumulated time.
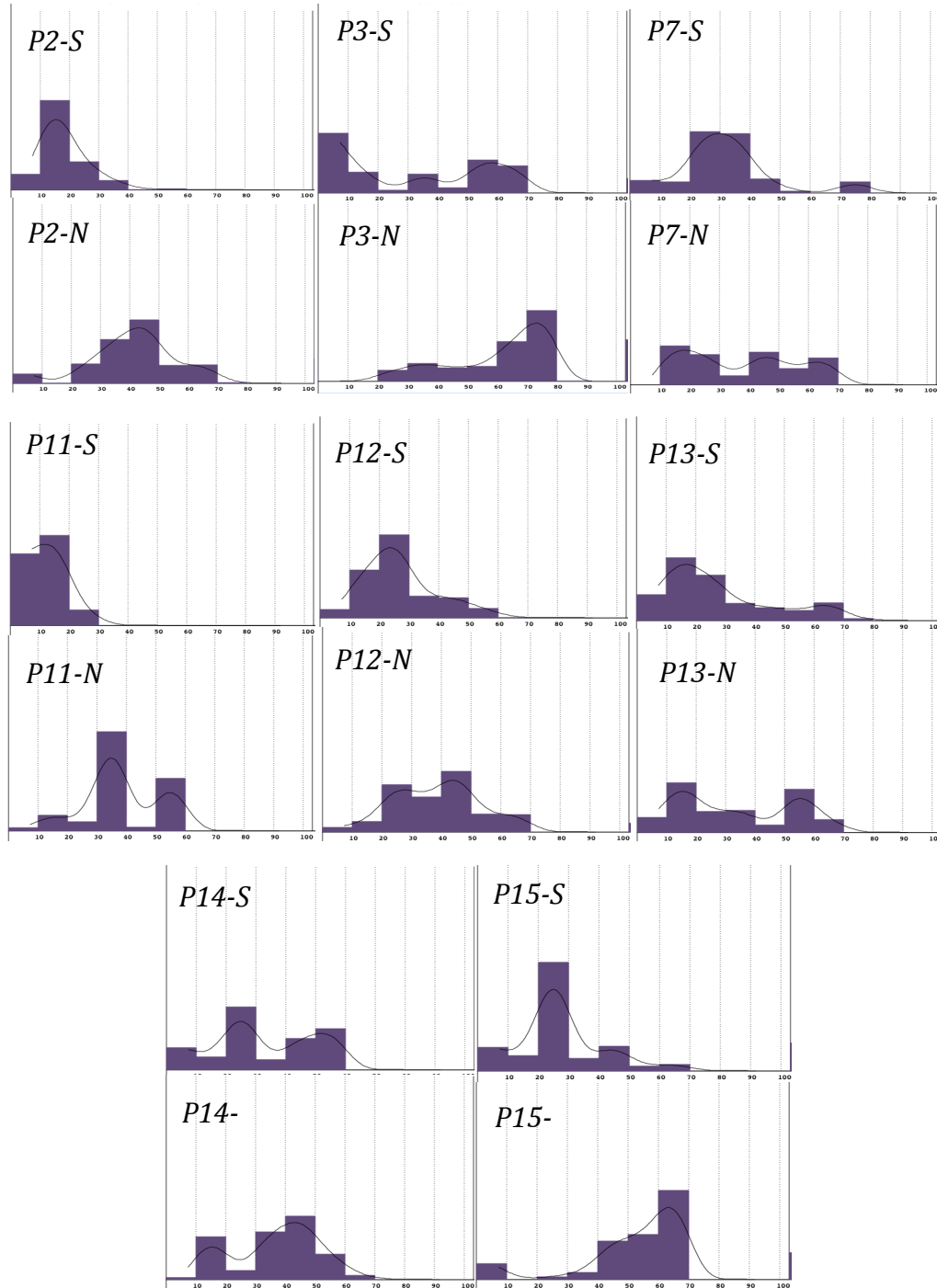
Figure 50. Used Space Percentage Distribution Graphs of the naïve users and the medium-level familiarity group.
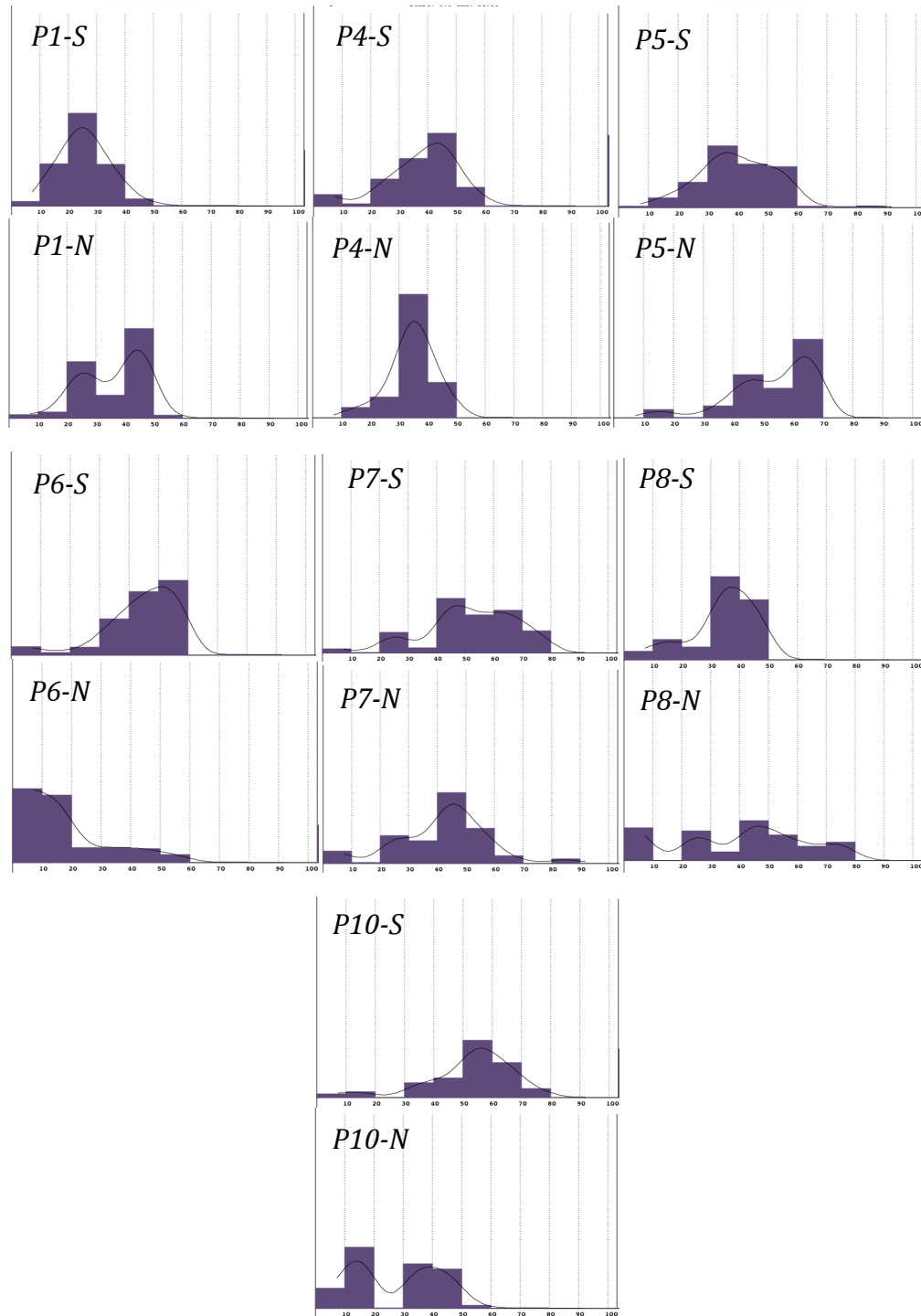
Figure 51. Used Space Percentage Distribution Graphs of the high-level familiarity group

We found that the group of participants who have new or medium familiarity with large high-resolution displays (see figure 50) had their space usage affected more with the upgraded version. Generally the shape of the distribution is shifted towards higher used space percentage or distributed fairly. In Figure 51 for the high-level familiarity group the distribution changes from the native system to the upgraded system vary. Some of them shifted to the right side, but some of them went the opposite way. From the distribution of used space the upgraded version affected members of the naïve and medium-level experience group to reduce wasted space.

5.3.4   Task Performance

Average completion time for the analysis phase is similar in both sessions and two systems-native system and upgraded version. In session 1 participants on the native system took an average of 29 minutes (SD=3.89), and participants who worked on the upgraded version took an average of 30 minutes (SD=0.89). In Session 2 participants on the native system took an average of 28 minutes (SD=1.74), and on the upgraded version participants took 27 minutes for the analysis phase (SD=2.80).
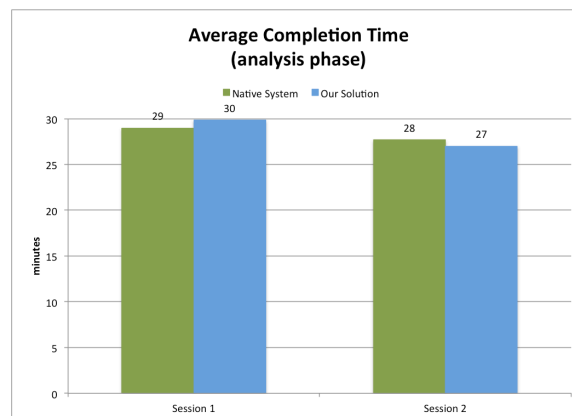
Figure 52. Average Completion time for the analysis phase.
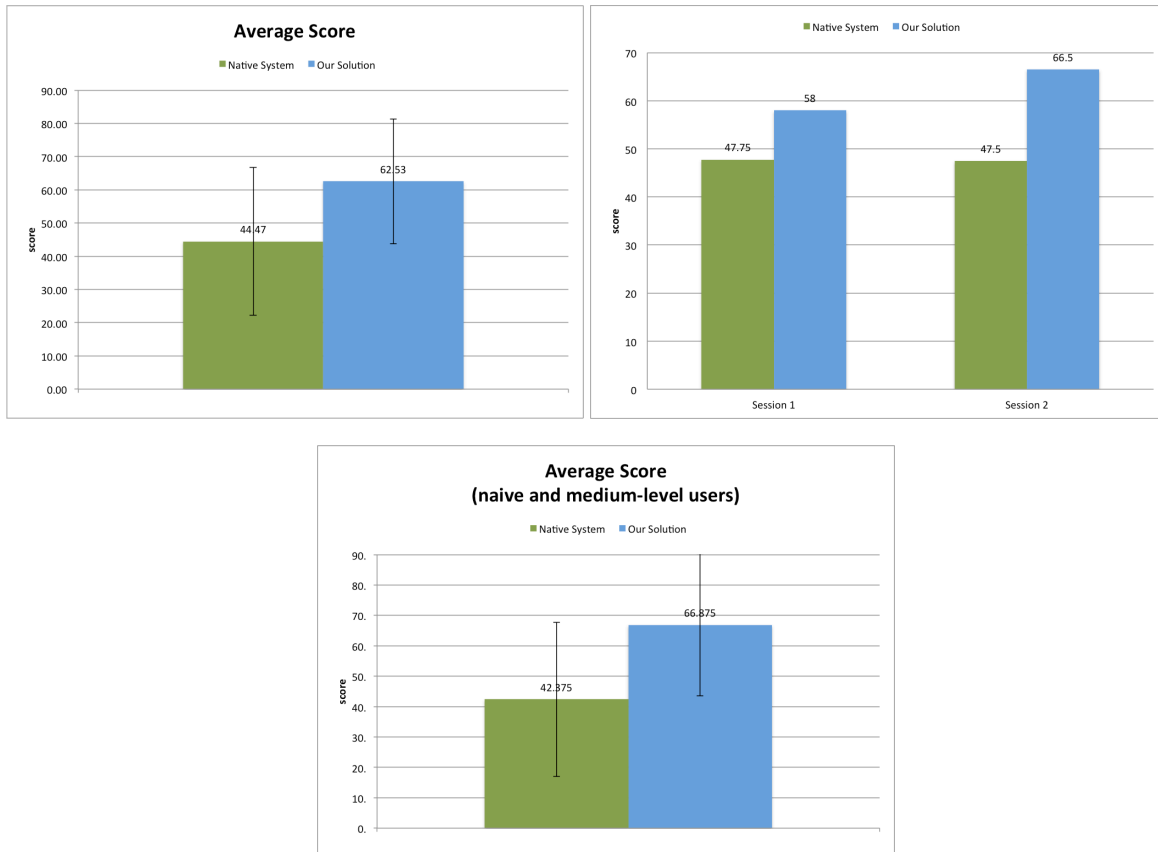
Figure 53. Average Score.

We scored the items that the participants reported during the presentation phase. We scored each answer from the questions which we had provided to participants. Each item found was worth 1 point. If participants showed the evidence on display, they received another 1 point. If the item was selected from co-relation evidence, they received additional points that multiplied by the correlation factors. The average score for both systems is shown in Figure 53. Participants had average 44. 47 score on the native system (SD=22.06), and they had average 62.53 score on the upgraded version (SD=18.89).

From the t-test, the two system were significantly different (t(15)=3.04248, p < 0.01). From the different sessions, the score distribution for both systems is shown in Figure 53. In session 1, the average score on the native system was 47.75 (SD-15.8), and the average score on the upgraded version was 58.0 (SD=18.5). In session 2, the average score on the native system was 47.5 (SD=21.19), and the average score on the upgraded version was 66.5 (SD=17.05). We also checked the score for the naïve and medium experience user group. The group had an average of 42.38 (SD= 25.25) on the native system, and an average of 66.88 (SD=23.23) on the upgraded version. The result of the t-test is t(7) =2.70263, p < 0.031 between the two systems with this group.
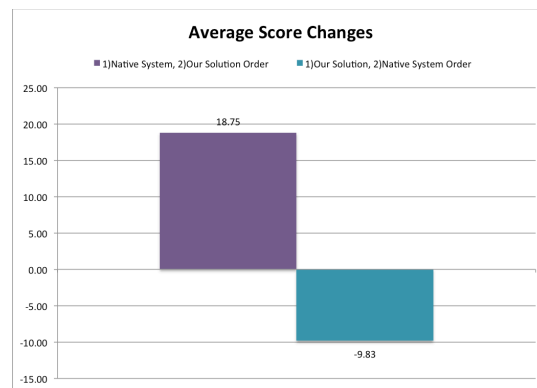
Figure 54. Average Score Changes.

We looked at whether order in which the systems were presented affected to performance. We made two groups. The first group is for participants who ran the native system first, and then worked on the upgraded version. The second group is for participants who ran the upgraded version first, and worked the native system in session 2. Figure 54 shows the performance difference. The average performance of the first group (native system -> upgraded version) increased by 18.75 (SD=13.60). The average performance of second group (upgraded version -> native system) decreased by 9.83 (SD=27.45). We also compared these two groups. T test results showed that the two groups are

significantly different (t(12)= 2.58, p < 0.025).
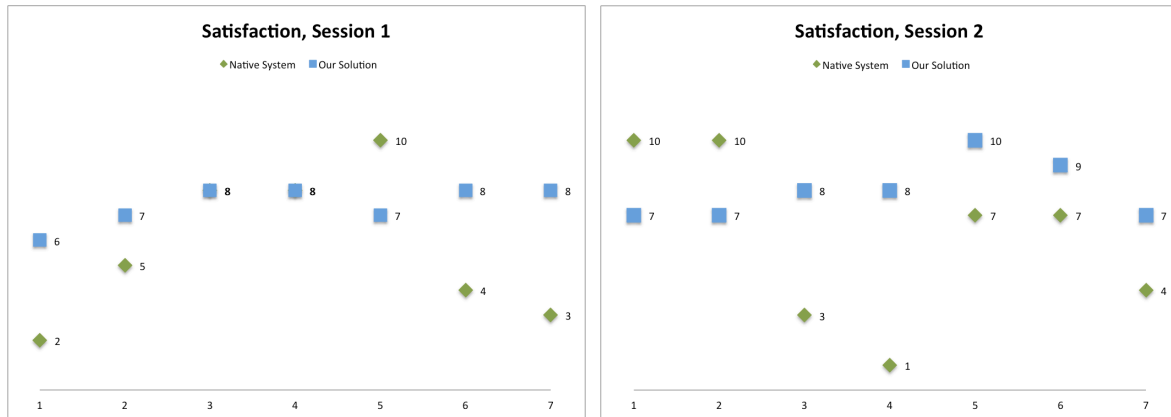
Figure 55. Satisfaction reported by participants.

Participants reported their satisfaction of their presentation results in their sessions - 1 being "very disappointed" and 10 being "very satisfied". Figure 55 shows the results. Participants with the native system in session 1 are same participants using the upgraded version in session 2. Average satisfaction reported on the native system is 5.87 (SD=3.11), and is 7.71 on the upgraded version (SD=0.99). T-test results t(14)=2.13, p < 0.05. The distribution trend lines on the upgraded version are more flat shaped than with the native system. If we make a big cloud with points in Figure X, the points not in the cloud are from the native system.

Analytic score was higher and reported satisfaction of analytic result was higher on the upgraded version.

5.4   Qualitative Observations

This section presents our observation on how participants used the available space to analyze the Chicago crime data, and how the participants reacted to some of issues.

5.4.1   Focal Area: Working space

All participants had a specific region to explore the data. It is matched with focal area mentioned in previous section. Participants kept this area as a focal area. The focal area is generally the central area and working space. Participants put new data into the focal area. They cleaned up after making observations or they kept the graph. If the data was important, participants looked for a new space to put the data. Sometimes they created a new section for the data. Figure 56 shows the case of focal area.

5.4.2   Section

We wondered how users would start their session, whether participants would start by dividing the space into sections first, or loading data first. Even though we informed the participants that they could still use sections with the native system before session 1 began, no participants using the native system started by creating sections in session 1. 71.43 % of participants working on the upgraded version started to create sections first it session 1. In session 2, 71.43 % of participants started with section division first on both systems.

5.4.3   Sitting or Standing Observation

Some of Participants preferred to sit. Some of participants preferred to stand and stood close to display. They still kept the focal area in the center.

5.4.4   Interruption by long interaction

Participants did not like long interaction times during the analysis phase. P11 said that he forgot what he wanted to do because of long interaction times.

5.4.5   Losing Cursor Issue

We added cursor marker at the bottom of the display. It was not helpful. When participants lost track of the cursor they started to move the pointer left to right continuously to try and find it. Adding the cursor marker did not help the user in finding the lost cursor.

5.5   Discussion

The results support our first hypothesis H_1 about window manipulation improvement. We found evidence to support our second hypothesis H_2, which is about effective use of space. We could partially confirm our third hypothesis H_3, that our design solution provides guidelines for how to effectively use space on large high-resolution display environments. We discuss these results in more detail and talk about observed changes on user interaction next.

5.5.1   Improvement window management

Our results show improvement in window management, which was our first hypothesis. First, the average length of window manipulation per a window was reduced. During the analysis phase participants spent 47% less time on average with our solution. During the preparation phase participants took 20% less time for window manipulation. If there is more data to analyze the difference will be larger, and the difference could affect work performance significantly. Additionally we confirm this decrease with the behavior transition diagram. We found that the average number of transactions for space organization activities was reduced by 60 % with our solution. Clearly participants spent less time on space organization activities, and more time in analyzing their data. Participants spent 17% more time on average in the analysis activity. This could potentially affect the average number of cycles during the analysis phase. Participants could have 20% more cycles on average. The behavior transition diagram also shows subtly different flows with our solution. Our
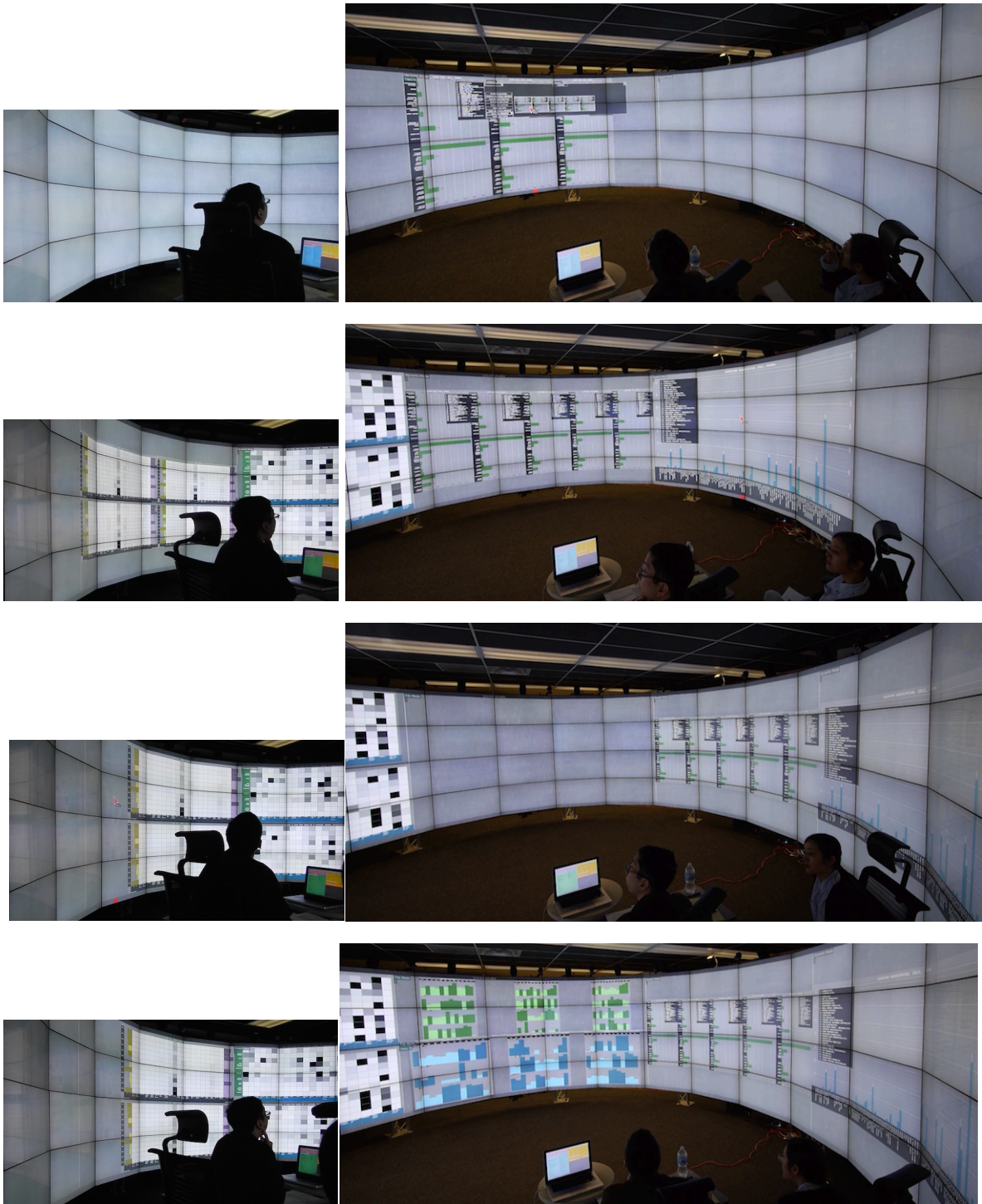
Figure 56. From top to bottom, pictures captured at 2:05, 9:14, 19:22, 21:55.

solution provided more chance to have a cycled loop that flows between data search and analytic activity. Task performance is increased 40% on our solution. This could be caused by several complex combined reasons. However one potential reason we could consider is that the users have more cycles of analytic activity. Why participants had more cycles could be from fewer transitions in space organization states. Why participants had fewer transitions on average is from automatic operations on space organization. Basically, one potential reason is that participants spent less time manipulating windows. If automatic operations are involved participants could have a negative impression. We checked their satisfaction of their analyzed results. Participants reported 31% higher points on average with our solution. Even if they might have a negative impression, the negative impression might be covered by quality of their analytic result. For general preferences about tool, 93% of the participants selected our solution. Therefore, our conclusion is that our solution provided an overall improvement window manipulation to participants.

5.5.2 Effective Use of Space

Our results strongly support effective use of space, which is our second hypothesis. We focused on the user behavior pattern in analysis phase.

During this phase participants used 27% more space on average. For naïve users and medium-level users, the average used space percentage was 64% higher. Generally, participants used more space with our solution.

We checked the distribution of used space on the display area. From the accumulated window heatmap and used pixel distribution graph, the average used pixel ratio is 49% higher with our solution. This shows that our solution promoted overall distributed usage of the display. We checked areas over a 0.5 ratio. Participants used 105% more area with our solution. The shape of distribution

also shows us how participants used all of that display area. Since the center area acted as focal area the shape of the distribution looked curved. The participants used the left and right sides of display fairly on our solution.

As we mentioned earlier, participants had a focal area, which is their working area. We defined the focal area as the continuous area with above average usage from the center. Participants had 20% more space and 19% wider viewing degrees as their focal area with our solution. If we apply the same average value for both environments (lower average = average ratio on native system), participants had 90% more space and 100% wider viewing degree.

The definition of the effective use of space could vary. Here we considered effective space has the following aspects.

- Use more space every time.
- Use overall display
- Have wider focal area, which is the working area.

We assumed that participants set their focal area according to their perception range. If participants were uncomfortable with the size of focal area, they probably then adjusted the focal area.

Our results strongly support the above aspect. We conclude that participants could use space more effectively. In addition, the results partially support our third hypothesis H_3, which is to provide guidelines to the users. Our solution encouraged the users to change their space usage pattern. This means that our solution lead participants to use space more effectively.

5.5.3 Change of Interaction

Additionally, we could see interaction behaviors changed. Participants performed fewer dragging

operations but more multi-touch interactions. Some of the dragging interactions were replaced with multi-touch interactions as we expected. Participants used more right-clicks in our solution. This is also an expected interaction behavior change. However we did not expect more double-clicks on the native system. There were two use cases we observed with double-clicks. The first one was to make the window larger to see its contents. The other case was for moving a window to the center. We saw some participants used the maximize operation to make the window move to the center, which would be their potential focal area. The participants did not like dragging to move the window, and they found an easier way to move the window to the center area, which was the double-click maximization action. After the window appeared in center area, participants moved it to some other place where they wanted to place it. We observed this behavior only on the native system.

Our observation on interaction changes is more evidence that our solution could make users change their behaviors easily. The evidence suggests that the participants adopted our solution.

5.5.4 <u>Limitation</u>

We explained the data and the new operations for 15 minutes in the training session. After that the participants tried to use the new operations and ran data analysis for 30 minutes by themselves. Some of participants pointed out that 45 minutes was too short a training time for learning the complex scenario and new operations. From observation of the analysis activity we could see that participants learned fast and adapted very well. However participants might feel that they could perform better with more training.

6   EVALUATION- MEETING SPACE

In the previous chapter, we discussed our user study and evaluation. The study was focused on workspace, specifically for data exploration and analysis work. As we mentioned before, large high-resolution display environments can work as meeting spaces, presentation spaces, and workspaces. Currently these displays work primarily as presentation spaces, so here we performed another user study for the meeting space.

This chapter provides observations of our designed environment as a meeting space. In this chapter we describe user study scenario and experimental environment. Then we present the results of our user study.

6.1   <u>Scenario</u>

We used a real meeting case. The Korean government encourages young people to open their business ventures with good ideas. This is the "Smart Creation Center" program. The government receives proposals, selects good ideas, and provides funds. To win the funds people need to form a team and submit a proposal with their idea. After the first review they might get a chance to present their idea to the reviewers. If they pass then they get funds. For six months they have to develop their idea. We found undergraduate students who wanted to compete in this program. Our study began at the beginning of this process, which was the brainstorming step. We observed the students for approximately four months in which they had eighteen meetings. During this time, we could observe them   in   all   phases,   which   are   brainstorming,   proposal   preparation,

presentation preparation, software design, and development phase.

6.2   Experimental Methodology

Here we describe apparatus, participants, procedure and data gathering for the study. Our hypotheses are also presented.

6.2.1   Apparatus

We setup a 10.39 megapixels, 5x1 LCD tiled-display (see figure 57). Participants sat at distance of 0.8 meters from the display. The experimenter watched them through video conferencing. The participants used remote mouse pointer to interact with the display.

6.2.2   Participants

One volunteer team was recruited which has 5 team members. They all were computer science undergraduate students and all women. The average age range was 21.4 $(SD = 0.45)$. Two of participants participated our preliminary study, so they had worked on large high-resolution displays. The other three participants were new to large high-resolution displays.

6.2.3   Procedure

Participants sat at a distance of approximately 0.8 meters from the display (see figure 57). The chair was an office chair. Individual participants used their laptop to interact with the display, so 5 laptops were connected to display.

We observed them for approximately four months. Eighteen meetings were held during this time. The average meeting length was 58.14 minutes $(SD = 34.41)$. We did not control the length of the meeting.

Participants held meetings for brainstorming, proposal preparation, presentation preparation, software design, and development.
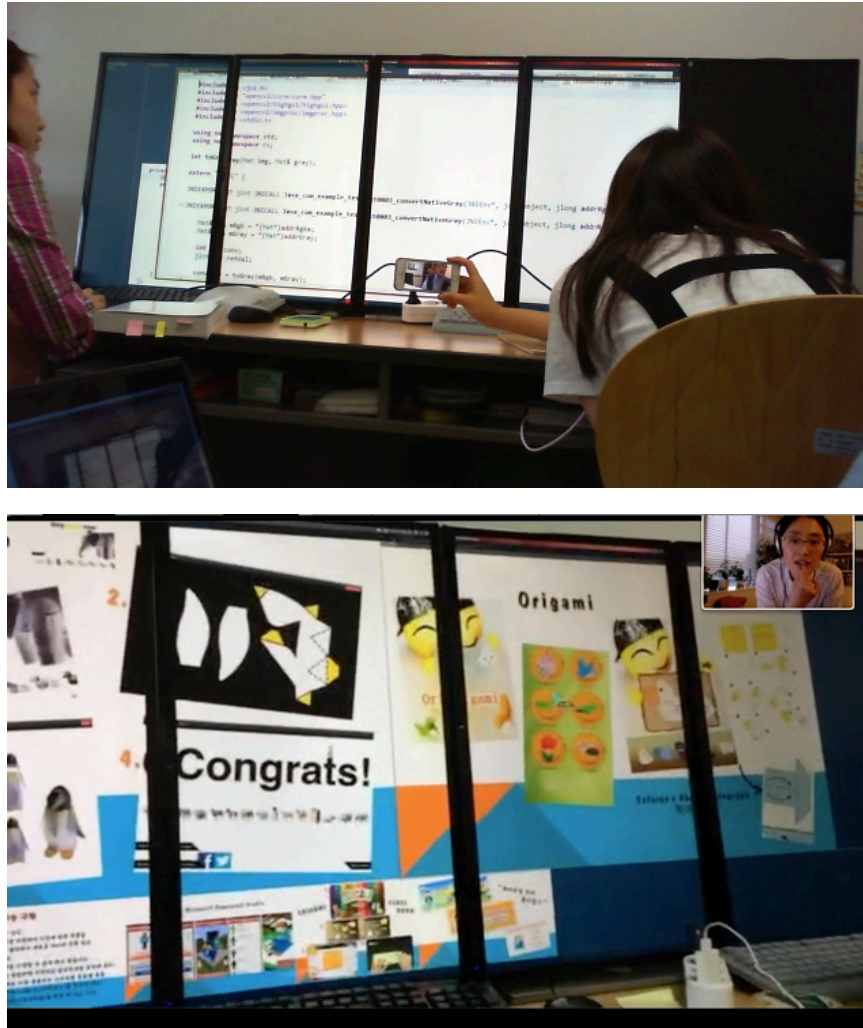
Figure 57. Apparatus. (a-top) Technical discussion meeting. Participants looked at the code that had issues. (b-bottom) Brainstorming meeting- The view is from experimenter. The experimenter was watching the user study through video conferencing.

6.2.4   Data Gathering

We recorded two videos. One camera faced the display, and the other camera recorded participants. All activity on display except for pointer movement was recorded in the display log file. Pointer movement was recorded on the laptop. The pointer movement log was merged with display log later.

6.2.5   Hypotheses

Our hypotheses for this study were:

- H_3: We hypothesize that the participants would learn how to use space on the large high-resolution display with our space organization design solution as our solution provides guideline to the participants.

- H_4: We hypothesize that the primary usage of the large high-resolution display would move from presentation space to collaborative workspace.

6.3   Observations

The first to fourth meetings were for the brainstorming phase, the fifth and sixth meeting were for proposal preparation. The next two meetings were for presentation preparation. After that participants had software design meetings and technical discussion meetings. Figure 58 shows a design meeting and a technical discussion meeting. We will look at the use of space and sections, and then we present an activity analysis.
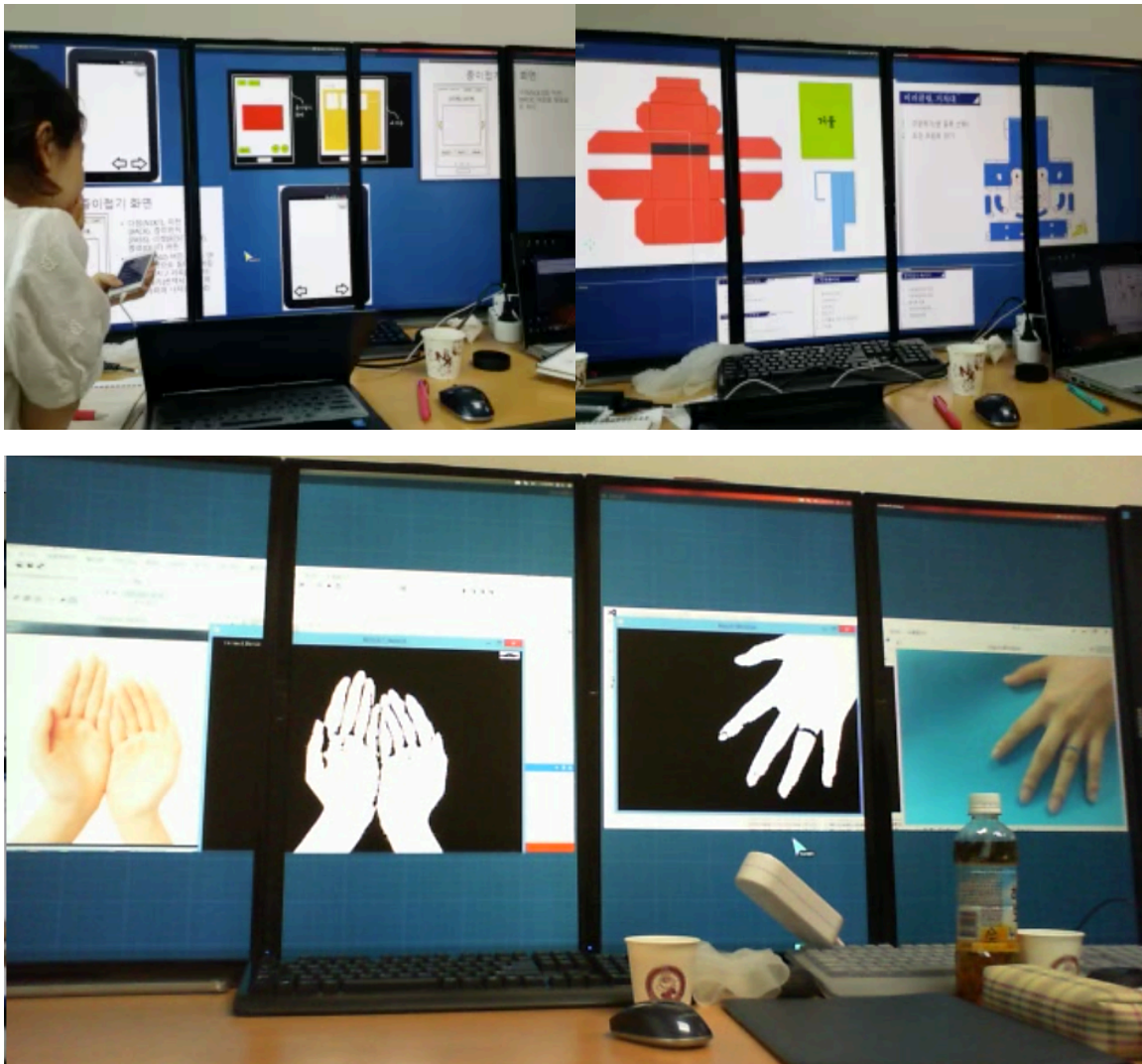
Figure 58. (a-top) Software design meeting. Participants were discussing their UI design. (b-bottom) Technical discussion meeting. A participant was showing intermediate results to others.

6.3.1   Activity Analysis

Figure 59 shows the mouse pointer activities of the participants. Multiple participants were interacting at the beginning of the meeting. Sometimes multiple participants also interacted at the end of meeting. At other times individual participants lead the meeting for a certain time.
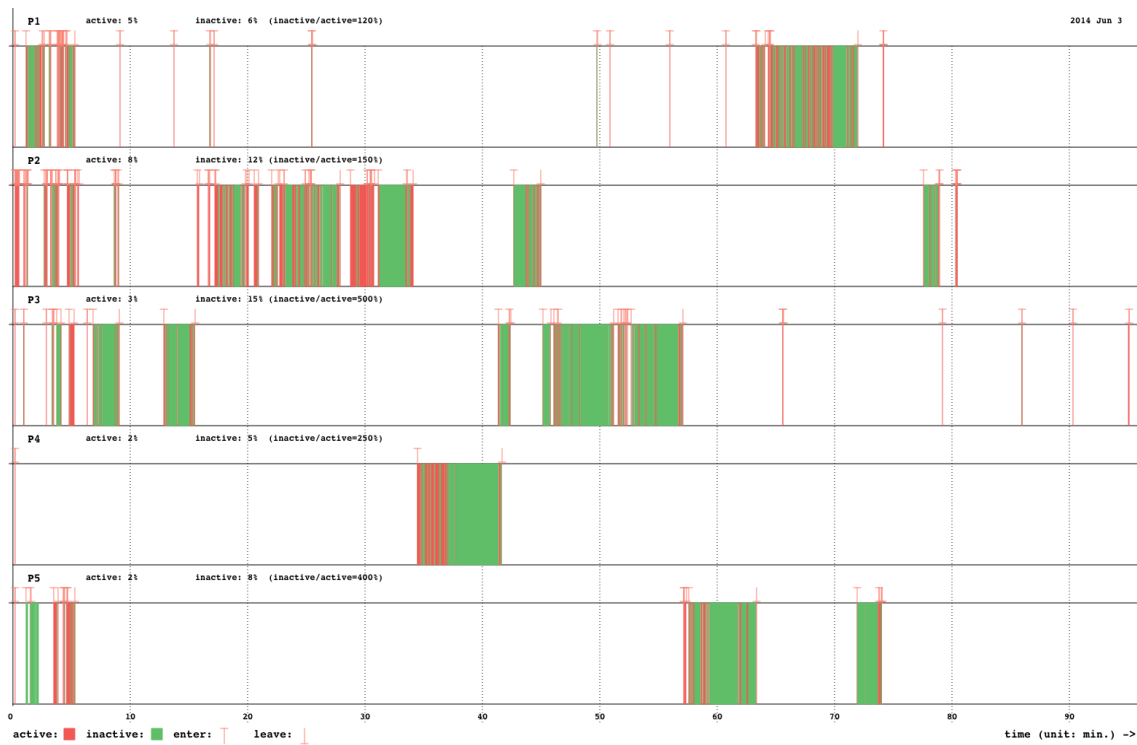
Figure 59. Mouse pointer state graph. Red color indicates that the participant moved the mouse pointer. Green color means that the pointer is on display, but the participant did not move the pointer.

Figure 60 shows how long each participant put their mouse pointer on the display. We assumed that if they put their mouse pointer on the display that they actively wanted to participate the meeting. P2 was team leader, and P3 was deputy team leader. Their mouse pointers spent more time on the display. We accumulated the active mouse pointer time length percentage for all users in each meeting. It is shown in figure 61. The trend line shows that the value is increasing gradually.
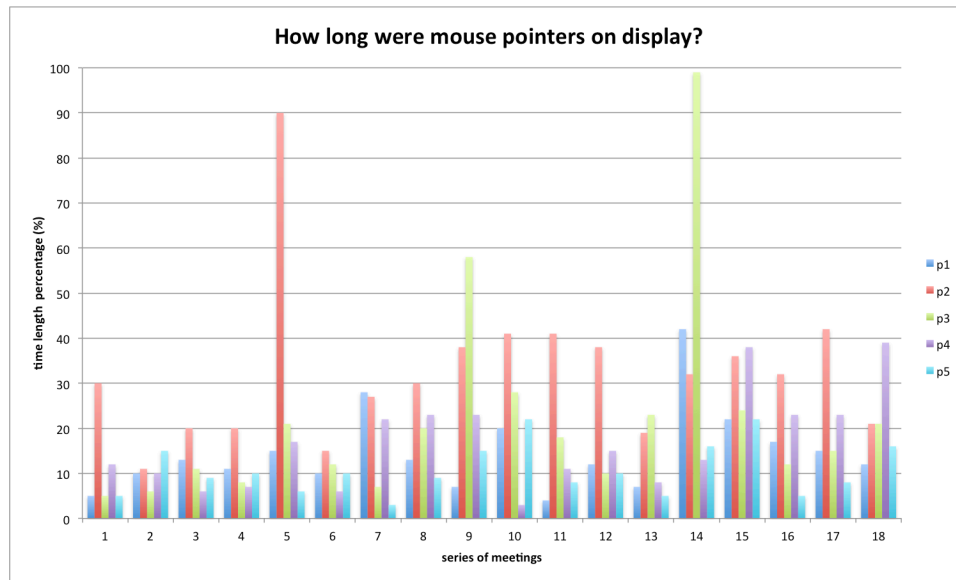
Figure 60. The chart shows how long mouse pointers of each participant were on display.
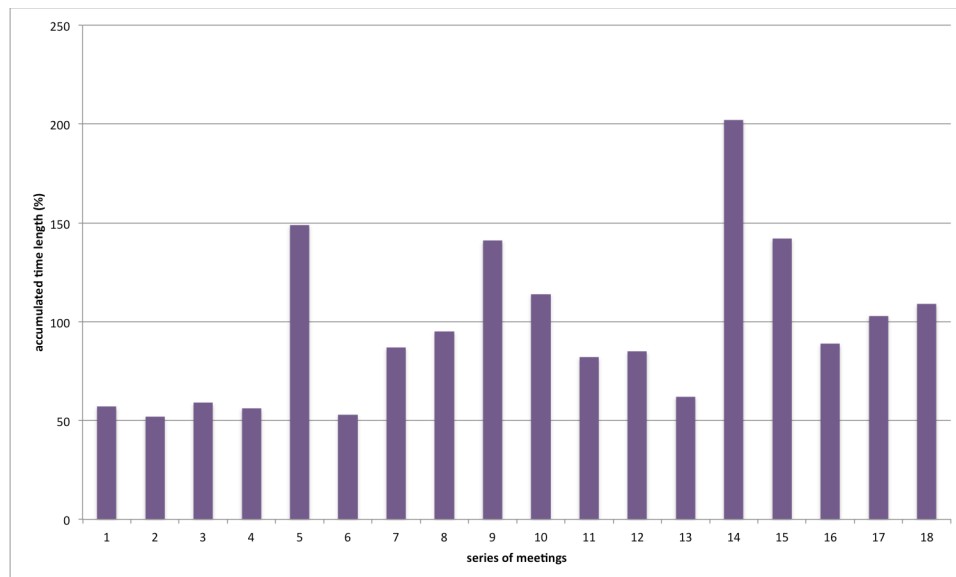
Figure 61. The chart shows accumulated active mouse pointer time length percentage for all users in each meeting. The trend line gradually increases.

6.3.2 Use of Space

We briefly investigated the use of space. Figure 62 (b) shows the distribution of used pixel graph for 18 meetings. The detail description of the graph is in chapter 5.3.3. The distribution shape is almost symmetrically curved. The accumulated ratio in left area of the display was 54.09% and in the right area of the display it was 45.91% (see figure 62 (c)).
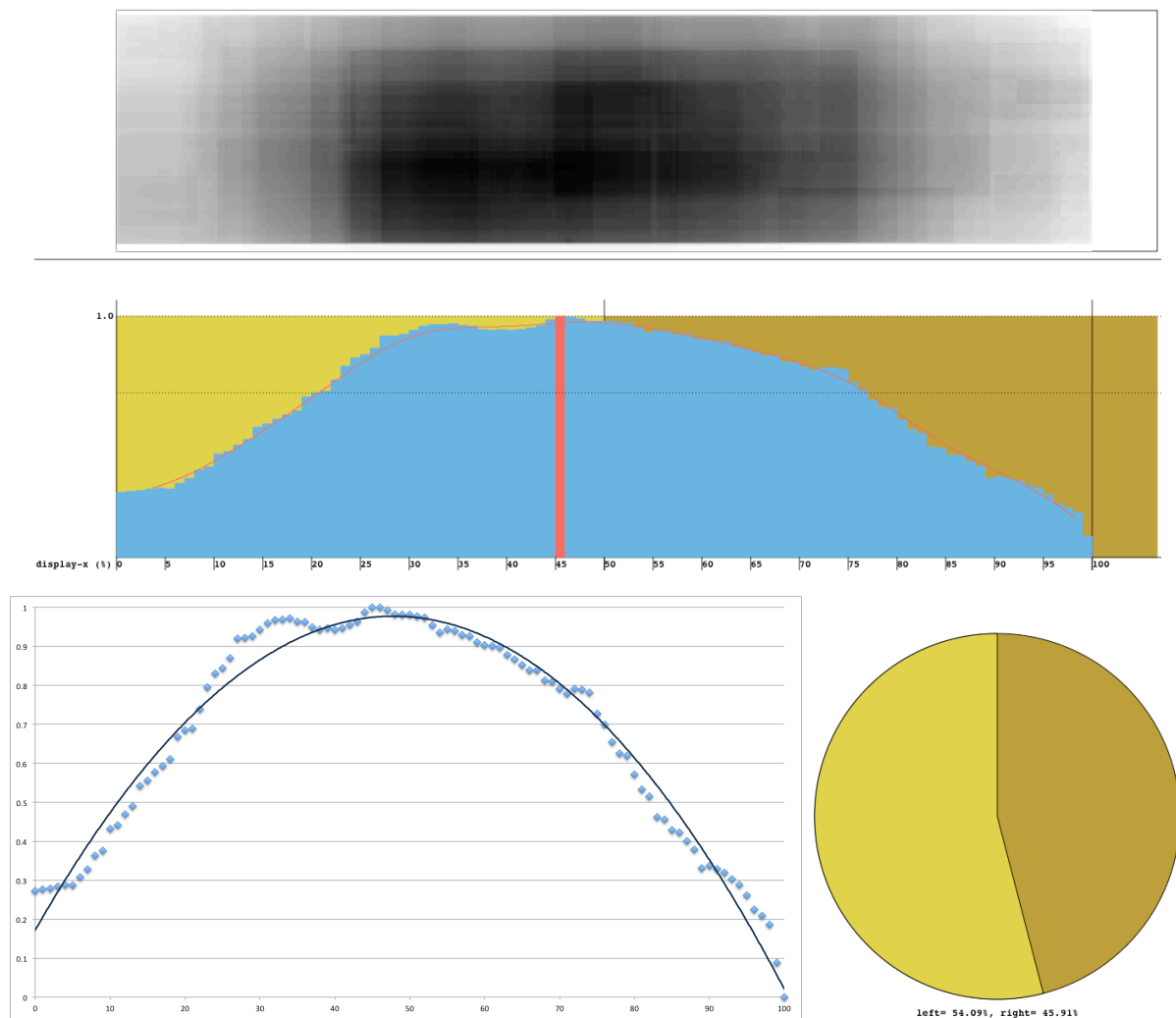
Figure 62. . (a-top) Windows Heatmap. (b-bottom left) Distribution of used pixel graph. (c-bottom right) distribution of used pixel pie chart for under and over 50% of display x.

We checked the average used space percentage per second during the 18 meetings. We accumulated the time (in seconds) if the used space percentage was over 50%, and divided by the total length of the meeting. Figure 63 shows the percentage of how often the participants used space over 50%. In the chart, it increased at beginning, and kept the time portion around 80% of meeting length.
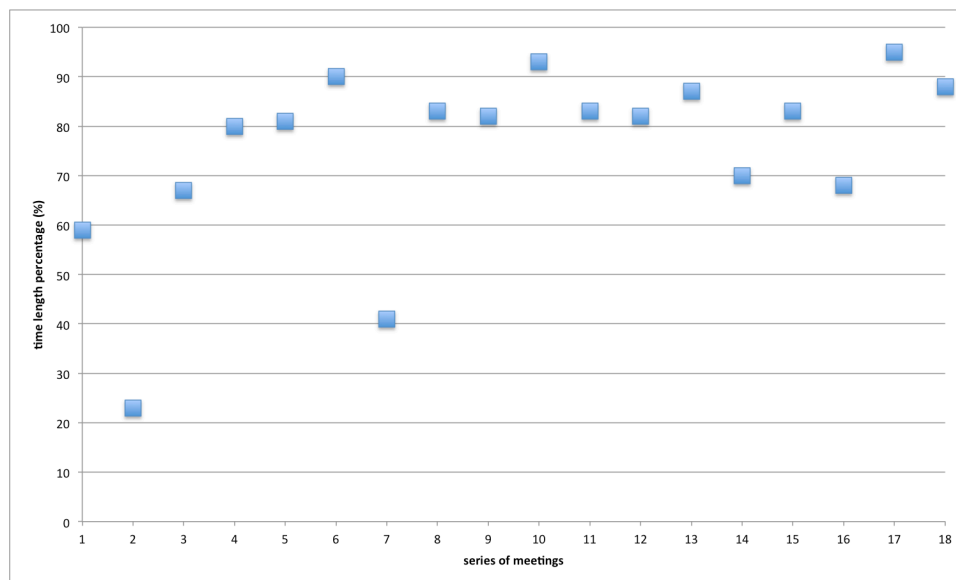
Figure 63. Percentage of time when over 50% of the space was used over the 18 meetings.

6.3.3 Use of Section

The average number of sections created during the meeting was 11.56 ($SD = 6.26$). Figure 64 (a) shows the number of sections for the 18 meetings. Figure 64 (b) also shows number of windows ($mean = 43.44, SD = 26.13$). We could not find a correlation between the number of sections and number of windows.
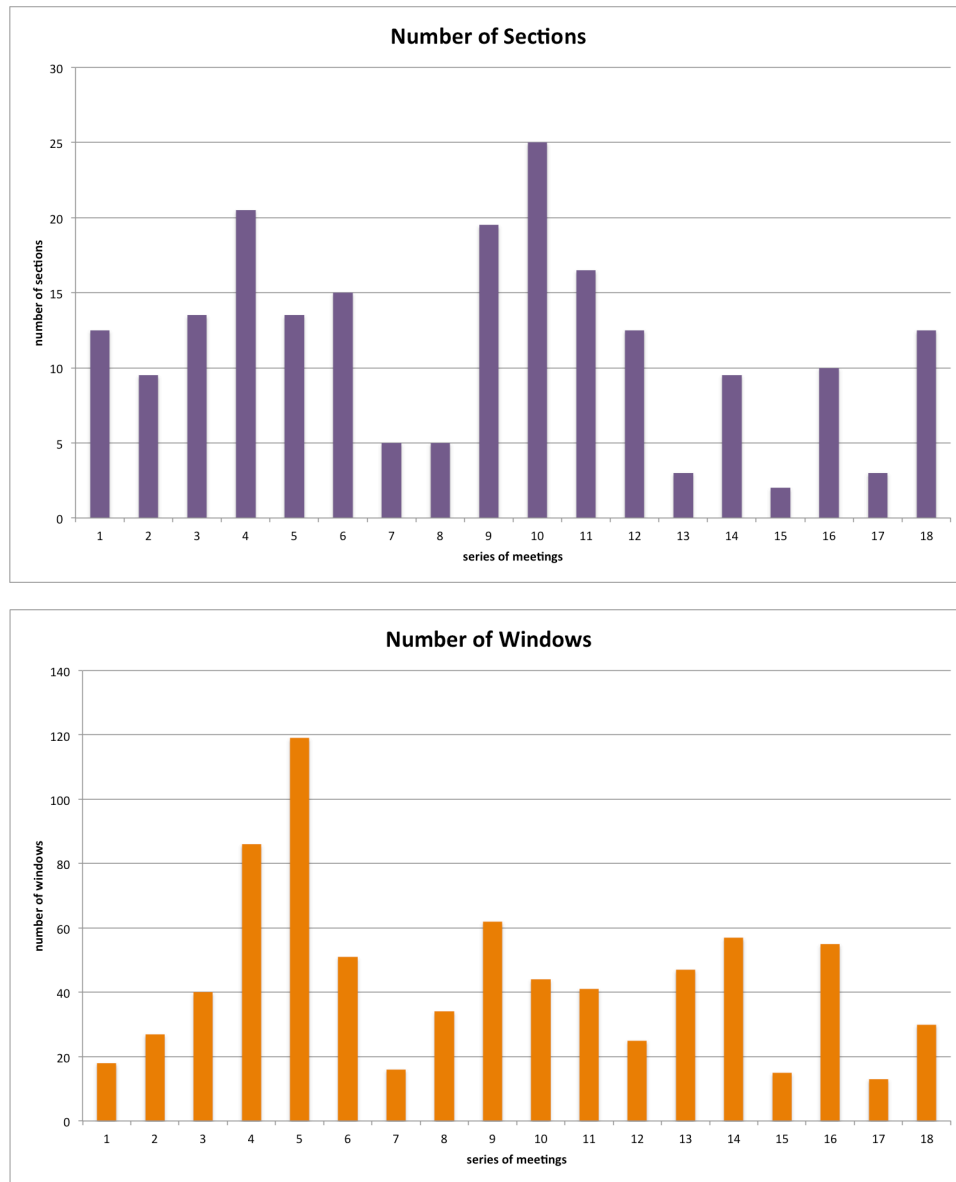
Figure 64. (a-top) Number of sections during 18 meetings. (b-bottom) Number of windows. X-axis are 1-4: brainstorming, 5-6: proposal preparation, 7-8: presentation preparation, and 9-18: software design and technical discussion.

All participants used explicit sections. We observed that each participant had a preferred section layout. One common layout was a central focal area. Participants created a waiting area on left, right,

bottom, or top side of display. Sometimes participants had several waiting sections. They put relevant windows in a section. Sometimes participants made one section for their final conclusions.
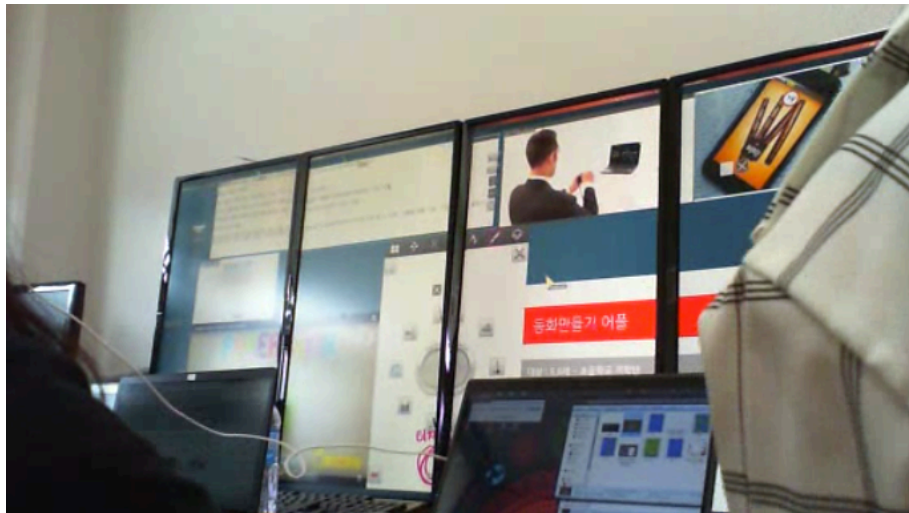
Figure 65. Software design meeting. They had six sections- left top, left bottom, middle top, middle bottom (focal area), right top, right bottom section. They kept dynamic mode as the space organization policy.

During the proposal and presentation preparation time they divided the display top and bottom. The bottom section was the focal area. They put data into the focal area. Each window was large enough for everyone to see. When someone wanted to talk about something they maximized it. If everyone agreed then they moved it to the top or bottom section. There were many different reasons to make a section. Since participants could easily and quickly manage space organization, they had more sections (see figure 65). We believe that the enhanced section operations encouraged participants to use sections more. Figure 66 shows a variety of the section layouts. We selected several different section layouts. At the beginning of the series of meetings the participants tried different section layouts. Later the participants had their own preferred layout for specific cases.
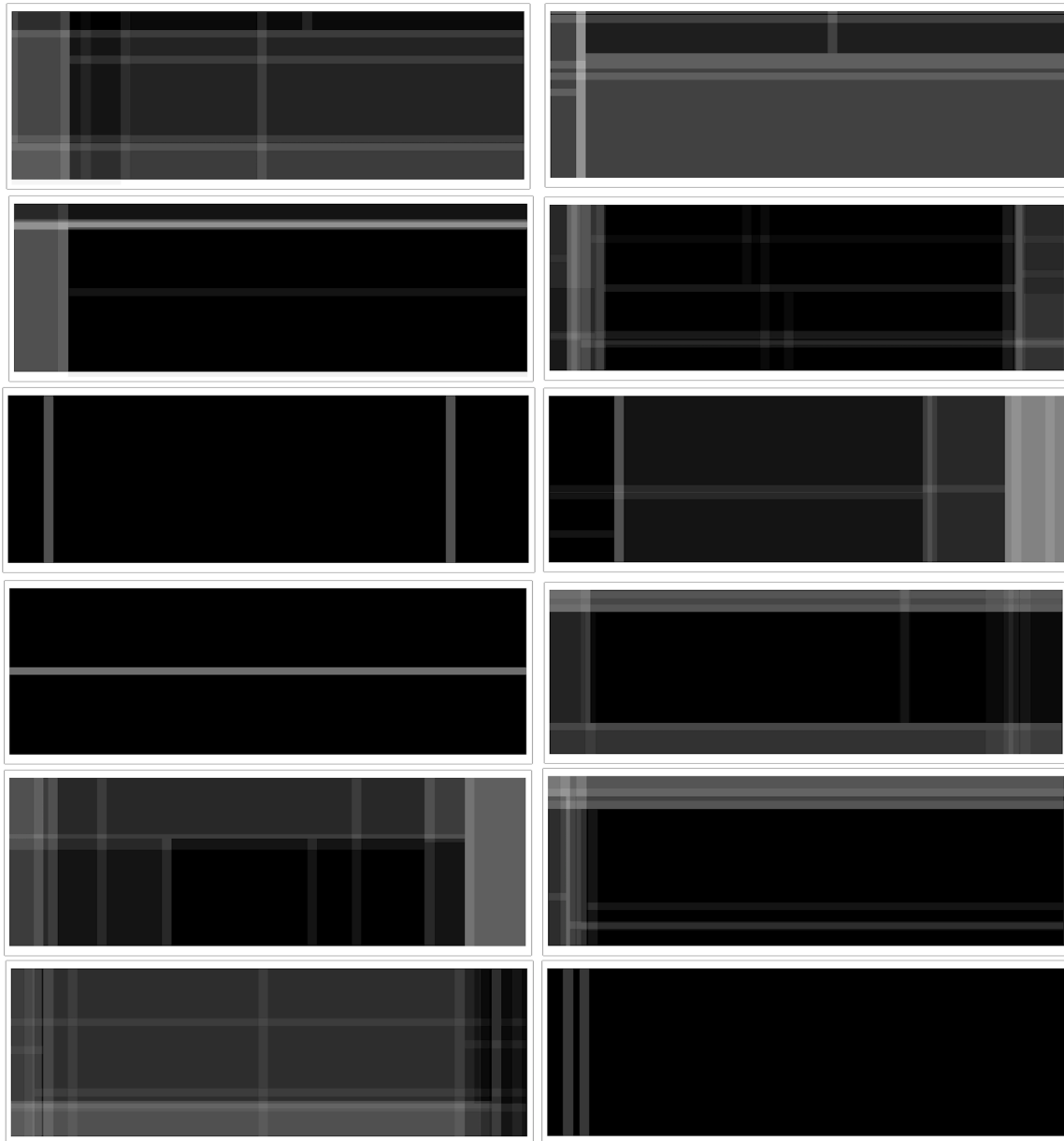
Figure 66. Section Heatmaps.

.

The participants used primary data-in, clear, apply, swipe motions, flocking operation to organize

space. The default space organization policy was dynamic mode. They kept this mode until they felt

something did not work. For example when windows had different aspect ratios. With dynamic mode all windows were close to each other to use as much space as possible. Alignment is not important in dynamic mode. If participants felt alignment was important in some cases, they changed to tile mode. In that case some of window sizes might become smaller.

During brainstorming (1st to 4th meeting), they used voting operation to share and keep their opinions. Participant were confused by the automatic position change. If the priority of a window is change then, window size is changed, but also the position is changed. The window with highest priority moves to left bottom side. However they recognized this as a kind of sorting activity. Then they accepted and adjusted.

6.4   Discussion

The results indirectly support our third hypothesis H_3, in which our design solution provides guidelines on how to use space on large high-resolution display environments. We could indirectly see the possibility for a fourth hypothesis H_4, which is about how the use case could extend to collaborative meeting space on large high-resolution displays.

Next we discuss these results in more detail and the limitation of our user study for small group meeting space.

6.4.1   Effective space organization

Generally the participants used sections. We could see that enhanced sections encouraged the users to use partition more. With our preliminary study (5 times meeting use case), participants prepared materials, but they did not use sections. At our preliminary study the participants used the native system, which also supported section and tiling. Figure 64 (a) shows how many sections were

used for the meeting. We could not find any evidence of changes with number of sections, We could see participants had a preferred section layout. They had a focal area in common. The other sections are filtering areas- to finish, to wait, selected, to express ownership and so on. Each participant had set of section layouts as their preference after several trials. They chose the layout according to the state of the work. Section layout could be representative of windows layout. While creating a section layout, the participants explicitly created their workflow for the meeting. This means that our design solution provided a tool that actually changed the users' behavior. It promoted section layout, and space organization encouraged the user to think about workflow. We suggest that this could be evidence of guiding the user in how to use large high-resolution displays for their work. Therefore, H_3 is indirectly supported.

Participants adapted their meeting work on the large high-resolution space. They found a preferred layout for certain phases and situations. They also used the voting operations to help make decisions. The time that their mouse pointers appeared on the display was gradually increased, so there was more time where multiple participants worked together. This indirectly shows the possibility of a collaborative workspace use case, which can support H_4.

6.4.2   Limitation

We wanted to look at a real small group meeting. Even though the observation period was four months, this was not enough. They had a fixed schedule to start some tasks and deadlines to meet.

7   CONCLUSION

These days vast amounts of information are continuously being created. By analyzing these data we could help solve current issues that we are faced with, and we might have a better ability to predict the future. Large high-resolution displays can support increasing the amount of data displayed. Therefore, large high-resolution environments have the potential to provide affordable infrastructure to maximize insight for exploration and analytic work of large and complex data. Unfortunately the current usage of large high-resolution environment has been limited to presentation, demonstration, or user studies due to usability issues on large high-resolution displays. User behavior analysis researchers have found that it became more difficult and time consuming to access and manipulate information as screen size increased, users were easily frustrated and confused when they changed environments, users wasted more space on large high-resolution displays, and users felt guilty about the wasted space. These usability issues can hinder the user from concentrating on their task and data. These are serious issues in moving beyond the current usage of large high-resolution display environments. As display size increases, the degree of these usability issues will also increase.

This dissertation focuses on space organization design to solve usability issues. Space organization design can impact how users can effectively make use of large high-resolution display. First, we observed user behaviors in different use cases on large high-resolution displays. We introduced design principles driven from these observations. Our design principles for space organization in large high-resolution displays are the following.

- Reduce repeated operation steps
- Spend less effort to organize space and more time on task
- Provide methods for effective use of space
- Support effective workflow
- Provide easy, fast, and correct interaction

We have proposed space organization design. First, our design solution provides four space organization policies; Free, Dynamic, Tile, and Tile per display. Second, our design solution consists of new enhanced techniques with multi-touch interaction; Apply, Data-In Section, Flow Section, Swap the Position of Window in Section, Move to Other Section, Flock, Expand, Push-Expand, Vote, Clear All Windows in Section, Set Center, Global Maximize, and New. Last, our design solution includes multi-touch interaction for distance users. Multi-touch interaction as distance interaction can assist dragging with automated operations and directional motion. To evaluate the proposed design we conducted a comparative user study in data exploration and analytic workspace, and a case study in small group meeting space.

In this chapter, conclude this dissertation with our contribution and future work.

7.1   Contributions

This dissertation was driven from the following four research questions.

- How can we provide improved window manipulation on large high-resolution displays?
- How can we guide the user to use space effectively on large high-resolution displays?
- How can we help the user avoid being frustrated and confused? Is there way to provide implicit guidelines to the user on making use of large high-resolution displays?
- How can we support creating a collaborative workspace on large high-resolution displays?

Based on these question and analysis of use cases, we proposed an effective space organization design which supports enhanced section operations. We summarize our contributions related to these questions.

7.1.1 Effective Activity Transitions with Improved Window Manipulation

We have observed activity transitions in data exploration and analysis workspace. Activities are divided into analysis activities and organization activities. Additionally, the data loading activity is involved in this activity transition. We suggested some improvements to the data loading activity, which also could save time by removing repeated actions. However, here we focused on organization activity and the analysis activity. By analyzing use cases we found activities that could be automated based on a repeated series of actions. We applied these activities into our space organization design. This allowed the user to reduce the number of transition activities, and save time for the analysis task.

Time is an important resource. Spending a certain amount of time for space organization is an important activity as well. However duplicated or meaningless activities give the user negative effects. One of participants in our user study specifically mentioned that he interrupted his task by doing repeated tedious organization operations. In the activity transition diagram, a loop to the same state could cause an interruption of the thought process. It makes user pay less attention to the work, and do more extra organization work.

Our user study shows an improvement in window manipulation with our solution. This is also a reason that our solution provides effective analysis transition.

- Less time for window management, so more time for the analysis activity
- Affected work performance

Additionally, we adapted multi-touch interactions with automation. Multi-touch interaction involved directional meaning. Therefore we could provide one action involving two intentions. The combination of automated operation and multi-touch interaction improved window management.

By improving window management, we could provide effective activity transitions to the user. Effective activity transition could affect task performance. This is our potential contribution, and it gives answers for the first and fourth questions.

7.1.2   Effective Space Usage

Space is an important resource in large high-resolution displays. The reason we build and use large high-resolution displays is to have access to more space. The user will have a large space. How to effectively use the space is another question for the user. We are used to working on desktop computer based environments. Everyone has their own preferred space usage pattern on a desktop environment. It might not work to bring these patterns to a large high-resolution display. Common operations might feel too tedious with space organization on a large high-resolution space. In this thesis we wanted to help the user use space on large high-resolution displays, and investigate what is the most effective way to utilize that large space. Therefore we provided different organization policies which were driven from analysis of use cases. Additional enhanced organization operations that helped control the space were created, for example, where to put data in, setting automated flow and so on.

Our user study shows that our solution

- Used more space every time
- Used the overall display

- Had wider focal area, which is the working area

This implies that our solution provided effective space usage to the users. In addition our second user study confirmed that enhanced solution for sections encouraged the users to use sections with more meaning. Users considered their workflow, made a plan, and then applied it to the section layout. This indirectly shows the possibility that this behavior might affect their work performance as well. This is another contribution from this thesis. This is also an answer for the second, third, and fourth question.

7.1.3   Future Research Directions

Even though the cost to build large high-resolution is decreasing, large high-resolution display environments are still expensive environments. If a company, research center, or school spends money to build something they expect improvement or expect to have a positive affect. At Argonne National Laboratory a scientist said: "Our Science Information Wall is important. We could advertise ourselves to VIPs on the high technology display. We believe that it affects to funding". They primarily used this large high-resolution display as a presentation space. If we wanted to extend its use case toward workspace usage on large high-resolution displays, we have to provide clear reasons for the users to invest their money and their effort. Large high-resolution display environments are good for comparing scenarios with complex and large data. However it is hard to convince people to move their workspace to large high-resolution displays.

As future work, we would like to work on qualitative analysis of user behavior based on quantitative results. In this dissertation we focused more on quantitative analysis than qualitative analysis. Qualitative results are as important as quantitative results. We plan to make an improved interview session at end of each study. Since we already have the activity and space quantitative

evaluation tool, we can immediately show the quantitative results to individual participants at end of the study. We can ask specific questions based on the participant's analyzed behavior pattern. This will connect the quantitative results and the qualitative result, and give us deeper explanations of the user's behaviors.

APPENDICES

Appendix A

USER STUDY DOCUMENTS

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
1737 West Polk Street
Chicago, Illinois 60612-7227

Exemption Granted

August 25, 2014

Hyejung Hur, MS
Computer Science
851 South Morgan
Room 1120, M/C 152
Chicago, IL
Phone: (312) 996-3002 / Fax: (312) 413-7585

RE: Research Protocol # 2014-0641
     "Evaluating Organization Design for the Large, High-Resolution Display
Workspaces"

Sponsors: None

Dear Hyejung Hur:

Please be reminded of the need to address institutional approval requirements at Duksung Women's University (Seoul Korea).

Your Claim of Exemption was reviewed on August 25, 2014 and it was determined that your research meets the criteria for exemption. You may now begin your research.

Exemption Period:	**August 25, 2014 – August 25, 2017**
Performance Site:	UIC
Subject Population:	Adult (18+ years) subjects only
Number of Subjects:	30

The specific exemption category under 45 CFR 46.101(b) is:
(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

Please note the Review History of this submission:

Receipt Date	Submission Type	Review Process	Review Date	Review Action
07/07/2014	Initial Review	Exempt	07/23/2014	Modifications Required
08/13/2014	Response to Modifications	Exempt	08/25/2014	Approved

You are reminded that investigators whose research involving human subjects is determined to be exempt from the federal regulations for the protection of human subjects still have responsibilities for the ethical conduct of the research under state law and UIC policy. Please be aware of the following UIC policies and responsibilities for investigators:

1. Amendments You are responsible for reporting any amendments to your research protocol that may affect the determination of the exemption and may result in your research no longer being eligible for the exemption that has been granted.

2. Record Keeping You are responsible for maintaining a copy all research related records in a secure location in the event future verification is necessary, at a minimum these documents include: the research protocol, the claim of exemption application, all questionnaires, survey instruments, interview questions and/or data collection instruments associated with this research protocol, recruiting or advertising materials, any consent forms or information sheets given to subjects, or any other pertinent documents.

3. Final Report When you have completed work on your research protocol, you should submit a final report to the Office for Protection of Research Subjects (OPRS).

4. Information for Human Subjects UIC Policy requires investigators to provide information about the research protocol to subjects and to obtain their permission prior to their participating in the research. The information about the research protocol should be presented to subjects in writing or orally from a written script. When appropriate, the following information must be provided to all research subjects participating in exempt studies:

   a. The researchers affiliation; UIC, JBVMAC or other institutions,
   b. The purpose of the research,
   c. The extent of the subject's involvement and an explanation of the procedures to be followed,
   d. Whether the information being collected will be used for any purposes other than the proposed research,
   e. A description of the procedures to protect the privacy of subjects and the confidentiality of the research information and data,
   f. Description of any reasonable foreseeable risks,
   g. Description of anticipated benefit,
   h. A statement that participation is voluntary and subjects can refuse to participate or can stop at any time,
   i. A statement that the researcher is available to answer any questions that the subject may have and which includes the name and phone number of the investigator(s).
   j. A statement that the UIC IRB/OPRS or JBVMAC Patient Advocate Office is available if there are questions about subject's rights, which includes the appropriate phone numbers.

Please be sure to:

→ Use your research protocol number (2014-0641) on any documents or correspondence with the IRB concerning your research protocol.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact the OPRS office at (312) 996-1711 or me at (312) 355-2908. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Charles W. Hoehne, B.S., C.I.P.
Assistant Director
Office for the Protection of Research Subjects

cc: Robert Sloan, Computer Science, M/C 152
       Andrew Johnson, Computer Science, M/C 154

University of Illinois at Chicago
Consent for Participation in Research
"Evaluating Organization Design for the Large, High-Resolution Display Workspaces"

Why am I being asked?

You are being asked to be a subject in a research study about Large, High-Resolution display workspaces conducted by Computer Science PhD candidate *Hyejung Hur* at the University of Illinois at Chicago. You have been asked to participate in the research because you are not a minor and 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 or your grade in any UIC courses. If you decide to participate, you are free to withdraw at any time without affecting that relationship.

Why is this research being done?

Large, High-Resolution displays are becoming increasingly common. However, the current usage of these displays is limited to presentation and visualization demonstration. Many researchers believe that these displays have more potential beyond the current usage. Usability issues of these displays prevent users concentrating on their task, so we expect that usability issues cause usage limitation. As screen size increases, it becomes more difficult and time consuming to access and manipulate information. This is one of main usability issues. It is important to develop techniques for improving it. Organization design can help solving the problem. The development of better organization design has the potential to extend use cases for these displays.

What is the purpose of this research?

We expect that Large, High-Resolution displays are one of potential future displays used in a broad range of areas, such as finance, entertainment, education, and scientific research. To achieve this future, usability issues on these displays must be resolved. One of main usability issues is accessing and manipulating information because of large display size. The purpose of this research study is to understand users' general organization patterns to make automatic scheme. Result from this study will allow us to devise guidelines for creating interface for Large, High-Resolution displays.

What procedures are involved?

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

- You will be asked to move/resize windows and make similar layout with different organization schemes. Each time, organization scheme will be changed. Organization

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

- when 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

- when 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. If photographs, videos, or audiotape recordings of you will be used for educational purposes, your identity will be protected or disguised. 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.

- All identifying data, including images, recordings, and questionairs will be kept under lock and key at the Electronic Visualization Laboratory for the duration of the study. Access to this data will be restricted to the prinicipal investigator, *Hyejung Hur*, and his co-investigators.

- All other information that might identify you, such as response times, will be labeled with a numerical identifier to maintain your anonymity. The index of study participant names and numbers will be kept under lock in the Elecronic Visualization Laboratory.

- We will reguest additional consent from you if we desire to use identifying images or recordings of you in a publication or for public presentation.

- All identifying images, recordings, and questionnaire results will be destroyed once the data has been fully analyzed or within one year, whichever comes first.

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.

Who should I contact if I have questions?

The researcher conducting this study is *Hyejung Hur*. You may ask any questions you have now. If you have questions later, you may contact him at:
Phone: 312-662-8867 Email: hhur2@uic.edu

The faculty sponsor of this research is Associate Professor *Andrew E. Johnson*. You may contact him at:

schemes will not apply in same order to subjects. The order will be automatically generated. In addition, you will undertake an example dataset exploration. The description of the scenario will be provided to you along with a list of questions about the data. Your task is to try to answer one of those questions. There are no 'right' and 'wrong' answers.

- Follow a short training on how to use the tool.

- Use the tool to perform arrangement between different schemes and explore the provided dataset and answer a question. The maximum durarion for this part of the study will be 2 hours.

- Undertake a short interview after you finish the task.

- During the study, you will be video and audio taped. We also ask that you try to keep talking out loud while trying to solve the task. Try to say anything that goes through your head.

- If you have questions during the study, please feel free to ask the researcher at any time. You may also take breaks at any time during the study.

Approximately 30 subjects may be involved in this research at the University of Illinois at Chicago.

What are the potential risks and discomforts?

The research has no foreseeable risks to you as a participant. Your information will remain confidential, and is not linked to your performance with the University of Illinois at Chicago.

Are there benefits to taking part in the research?

You will not directly benefit from participation in this study. By participating in this research, however, you will also be contributing to the field of user interfaces for Large, High-resolution Displays.

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

You will not be reimbursed or compensated for your participation in this research.

What are the costs for participating in this research?

There is not cost to you for participating in this study.

What about privacy and confidentiality?

Phone: 312-996-3002 Email: ajohnson@uic.edu

What are my rights as a research subject?

If you have any questions about your rights as a research subject, you may 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 affect 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 (or someone has read to me) 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.

_____ _____
Signature   Date

_____
Printed Name

_____
E-mail address

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

University of Illinois at Chicago
Consent to Use Identifying Media from

"Evaluating Organization Design for the Large, High-Resolution Display Workspaces"

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

We would like to use images, video, or audio recordings of your participation in the study for publication or presentation. We seek your consent to use this media in unaltered form that may allow others to identify you. We ask that you read this form and ask any questions you may have before giving consent.

Your decision to give this consent is voluntary. Your decision whether or not to give consent will not affect your current or future relations with the University or your grade in any UIC courses.

<u>**What will this media be used for?**</u>

We wish to use images, video, or audio recordings that include your likeness in a publication about the results of our study. This may also lead to opportunities to present the results of the study in a conference setting. The media selected with your likeness or voice has not been altered to prevent others from identifying you. The media will only be used to support arguments regarding the hypothesis of our study within the publication or at the presentation. The media will not be used to convey any personal information about your individual mannerisms, personality, or behavior traits.

<u>**Can I review or edit the media before they are used?**</u>

You have the opportunity to review the images, video recordings, and audio material bearing your likeness at this time. You may decline to give your consent for individual media items if you so desire. Once you have reviewed the media items and signed this consent agreement, you will not have another opportunity to edit or review the images, video, or audio content before publication or conference presentation.

<u>**Who should I contact if I have questions?**</u>

The researcher conducting this study is *Hyejung Hur*. You may ask any questions you have now. If you have questions later, you may contact him at:
Phone: 312-996-3002, Email: hhur2@uic.edu

The faculty sponsor of this research is Associate Professor *Andrew E. Johnson*. You may contact him at:
Phone: 312-996-3002, Email: ajohnson@uic.edu

What are my rights as a research subject?

If you have any questions about your rights as a research subject, you may call the Office for Protection of Research Subjects at 312-996-1711.

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 (or someone has read to me) 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.

_____   _____
Signature   Date

_____
Printed Name

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

Evaluating Organization Design for Large, High-Resolution Display Workspaces

Hypothetical scenario: Exploratory analysis of crime patterns in Chicago

The City of Chicago has been witnessing a steady decline in crime rate over the last decade. However, in the last two years, there has been a resurgence of crime in some areas.

The City of Chicago has asked for your help to analyze crime pattern, and suggest strategies to reduce crime rate for central area of Chicago Police. Strategies include what they need to focus on- which crime type(3), which location(2), which beat area(2), which month of year, which day of week, which time of day*? The central area of Chicago Police consists of two districts-the 1st and 18th district. The city has given access to the graphs for the crimes happened in 2009 ~ 2013.

Please explore and analyze the crime patterns, and present what you like to suggest for the district of Chicago Police.

Training) The Commander of the **12th district –near north- of Chicago Police** want your expertise to help characterize crime patterns of UIC area in 12th district. The area includes Beat #1223-1225, 1231, and 1232 (5 beats).

Session-1) The Commander of the **1st district –central- of Chicago Police** want your expertise to help characterize crime patterns of 1st district. The 1st district is in charge of Beat #0111-0114, 0121-0124, 0131-0133 (11 beats).

Session-2) The Commander of the **18th district –near north- of Chicago Police** want your expertise to help characterize crime patterns of 18th district. The 18th district is in charge of Beat #0811-0814, 0821-0124, 0831-0134 (12 beats).

Time of day: (a. late night-early morning) 12 am–6 am, (b. morning) 6 am–12 pm, (c. afternoon) 12 pm – 6 pm, (d. evening) 6 pm-midnight

덕성(德性)을 갖춘 창의적 지식인 육성

덕성여자대학교

수신자: 이주영교수(컴퓨터학과)
참　조:
제　목: 생명윤리위원회 심의면제대상 연구에 대한 승인 통보

　　　　　생명윤리및안전에관한법률시행규칙(보건복지부령제180호) 제13조 및 제33조에
따라 심의면제대상에 해당하는 연구는 생명윤리위원회의 심의가 면제됩니다. 아래와 같이
심의면제대상 연구에 대하여 승인을 통보합니다.

- 아　래 -

　　　1. 연구과제명 : Large High-resolution Displays의 용이성을 증대시킬 수 있
는 인터렉션에 대한 연구

　　　2. 연구유형 : 인간대상연구

　　　3. 연구책임자 인적사항
　　　　가. 성명 : 이주영
　　　　나. 소속 : 컴퓨터학과
　　　　다. 직위 : 교수

　　　4. 심의면제사유 : 본 연구는 침습적 행위가 개입되지 않는 연구이며, 신체적
변화가 초래되지 않는 마우스와 키보드와 같은 단순 입력장비와 디스플레이의 사용을 관찰
하는 연구로서 심의면제에 해당

Duksung Women's University

Suh, Bo Sun
Email: matrix@duksung.ac.kr
Phone: +82-2-901-8740 / Fax: +82-2-901-8630

Exemption Granted

Professor Juyoung Lee
Computer Science Department
33 Samyangro 144-Gil, Cha-Mirisa Bld. #334,
Dobong Gu, Seoul, 132-714, Korea
Email: jylee@duksung.ac.kr
Phone: +82+901+8344 / FAX: +82-2-901-8642

You Claim of Exemption was determined that your research protocol meets the criteria for exception as defined in Korean Ministry of Health and Welfare Regulations 180 (13 and 33) for the protection of Human Subjects. Your Research is approved to begin.

1. Title: Research about interaction to improve usability of Large High-Resolution Displays

2. Research Type: Human Subject Research

3. PI.

   a. Name: Juyoung Lee

   b. Department: Computer Science

   c. Position: Professor

4. Reason: This research does not involve in any invasive actions, and physical changes. Research involves interview procedure, or observation for usage of input devices and displays.

* Co-PI written in Exception Application : Hyejung Hur

Appendix B

PERMISSION TO USE THIRD PARTY MATERIAL

Permission to use Figure 6
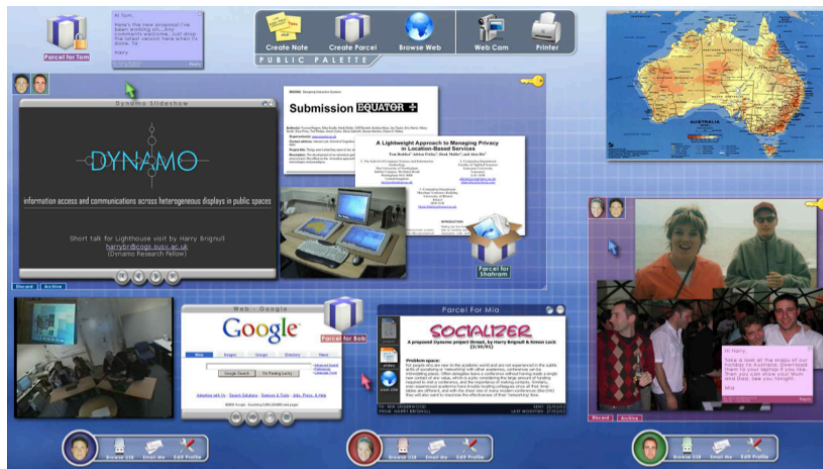
Shahram Izadi <██████@microsoft.com>   12/1/14

to me ▼

Yes of course. Good luck with your dissertation.

Shahram

Sent from my Windows Phone

From: Hyejung Hur
Sent: 30/11/2014 08:52
To: Shahram Izadi
Subject: Permission to use Picture

Dear Dr. Shahram Izadi,

I am writing my PhD dissertation on the enhanced space organization on large high-resolution display environment. I came across your Dynamo project, and found the examples to be very compelling.

I was wondering if it would be OK to use one of your picture(attached) in my dissertation document. Of course, I would add citation and credit.

Thank you very much.

Best Regards,
Hyejung Hur

CITED LITERATURE

[Andrews and North, 2013] Andrews, C. and North, C.: The impact of physical navigation on spatial organization for sensemaking. In Visualization and Computer Graphics, IEEE Transactions on, 19(12), pages 2207–2216, 2013.

[Andrews and North, 2012] Andrew, C., North, C.: Analyst's Workspace: An Embodied Sensemaking Environment For Large, High-Resolution Displays. In Proceedings of VAST, pages 123-131, IEEE, 2012.

[Andrews et al., 2011] Andrews, C., Endert, A., Yost, B., and North, C.: Information visualiza- tion on large, high-resolution displays: Issues, challenges, and opportunities. In Information Visualization, 10(4), pages 341–355, 2011.

[Andrews et al., 2010] Andrews, C., Endert, A., and North, C.: Space to think: large high- resolution displays for sensemaking. In Proceedings of CHI'10, pages 55–64, ACM, 2010.

[Ball et al., 2007] Ball, R., North, C., and Bowman, D.: Move to improve: promoting physical navigation to increase user performance with large displays. In Proceedings of the SIGCHI conference on Human factors in computing systems, pages 191–200, ACM, 2007.

[Ball and North, 2005] Ball, R. and North, C.: Analysis of user behavior on high-resolution tiled displays. Human-Computer In Interaction-INTERACT 2005, pages 350–363, 2005.

[Baudisch et al., 2006] Baudisch, P. , Mike, S. , and Andrew, W.: Soap: a pointing device that works in mid-air. In Proceedings of the ACM symposium on User Interface Software and Technology, pages 43-36, ACM, 2006.

[Baudisch et al., 2004] Baudisch, P. , Edward, C. , Ken, H. , and Robert, G.: Mouse ether: accelerating the acquisition of targets across multi-monitor displays. In Proceedings. of CHI'04, pages 1379-1382, ACM, 2004.

[Baudisch et al., 2002] Baudisch, P., Good, N., Bellotti, V., and Schraedley, P.: Keeping things in context: a comparative evaluation of focus plus context screens, overviews, and zooming. In Proceedings of the SIGCHI conference on Human factors in computing systems, pages 259–266, ACM, 2002.

[Beaudouin, 2001] Beaudouim, L.: Novel interaction techniques for overlapping windows, In Proceedings of UIST'01, page 153-154, ACM, 2001.

[Bell and Steven, 2000] Bell, B., and Steven Feiner.: Dynamic space management for user interfaces. In Proceedings of the ACM symposium on User Interface Software and Technology. Pages 239-248, ACM, 2000.

[Bezerianos and Balakrishnan, 2005] Bezerianos, A., and Balakrishnan R.: The Vacuum: Facilitating the Manipulation of Distant Objects. In proceedings of CHI'05, pages 361-370, ACM, 2005.

[Bi et al., 2010] Bi, X., Bae, S., and Balakrishnan, R.: Effects of Interior Bezels of Tiled-Monitor Large Displays on Visual Search, Tunnel Steering, and Target Selection. In Proceedings of CHI'10, pages 65-74, ACM, 2010.

[Bi and Ravin, 2009] Bi, X., and Ravin B.: Comparing usage of a large high-resolution display to single or dual desktop displays for daily work. In proceedings of CHI '09, pages 1005–1014, ACM, 2009.

[Bierbaum et al, 2001] Bierbaum, A., Just, C., Hartling, P., Meinert, K., Baker, A., and Cruz-Neira, C.: VR Juggler: A Virtual Platform for Virtual Reality Application Development. In proceedings of VR'01, page 89, IEEE, 2001.

[Blanch et al., 2004] Blanch, R., Guiard, Y. , and Beaudouin-Lafon, Y.: Semantic pointing: improving target acquisition with control-display ratio adaptation. In Proceedings of CHI'04, pages 519-526, ACM, 2004.

[Bly and Rosenberg, 1986] Bly, S., and Rosenberg, J.: A Comparison of Tiled and Overlapping Windows. In Proceedings of CHI'86, pages 101-106, ACM, 1986.

[Cao and Ravin, 2003] Cao, X., and Ravin B.: VisionWand: interaction techniques for large displays using a passive wand tracked in 3D. In proceedings of UIST '03, pages 729-729, ACM, 2003.

[Czerwinski et al., 2006] Czerwinski, M., Robertson, G., Meyers, B., Smith, G., Robbins, D., and Tan, D.: Large display research overview. In proceedings of CHI'06, pages 69–74, ACM, 2006.

[Czerwinski et al., 2003] Czerwinski, M., Smith, G., Regan, T., Meyers, B., Robertson, G., and Starkweather, G.: Toward characterizing the productivity benefits of very large displays. In proceedings of Interact 2003, volume 3, pages 9–16, 2003.

[Defanti et al., 2009] DeFanti, T., Leigh, K., Renambot, L., Jeong, B., Verlo, A., Long, L., Brown, M., et al.: The OptIPortal, a scalable visualization, storage, and computing interface device for the OptiPuter. In Future Generation Computer Systems, 25(2), pages 114–123, 2009.

[Doerr, 2011] Doerr, K.: CGLX: A Scalable, High-Performance Visualization Framework for Networked Display Environments. In IEEE Transaction on Visualization and Computer Graphics, 17(3), pages 320-332, IEEE, 2011.

[Eilemann et al., 2009] Eilemann, S., Makhinya, M., and Pajarola, R.: Equalizer: A Scalabla Parallel Rendering Framework. In IEEE Transaction on Visualization and Computer Graphics, 15(3), pages 436-452, IEEE, 2009.

[Endert et al., 2012a] Endert, A., Fiaux, P., and North, C.: Semantic interaction for visual text analytics. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pages 473–482, ACM, 2012.

[Endert et al., 2012b] Endert, A., Fox, S., Maiti, D., and North, C.: The semantics of clustering: analysis of user-generated spatializations of text documents. In Proceedings of the International Working Conference on Advanced Visual Interfaces, pages 555–562, ACM, 2012.

[Endert et al., 2012c] Endert, A., Bradel, L., Zeitz, J., Andrews, C., and North, C.: Designing Large High-Resolution Display Workspaces. In proceedings of AVI'12, pages 58-65, ACM, 2012.

[Endert et al., 2011] Endert, A., Han, C., Maiti, D., House, L., Leman, S.C., and North, C.: Observational-level interaction with statistical models for visual analytics. In proceedings of VAST'11, pages 121-130, IEEE, 2011,

[Grossman et al., 2005] Grossman, T., and Ravin B.: The bubble cursor: enhancing target acquisition by dynamic resizing of the cursor's activation area. In Proceedings of CHI '05, pages 281-290, ACM, 2005

[Grudin, 2001] Grudin, J.: Partitioning digital worlds: focal and peripheral awareness in multiple monitor use. In Proceedings of CHI '01, pages 458–465, ACM, 2001.

[Haller et al., 2010] Haller, M., et al. The NiCE Discussion Room: Integrating Paper and Digital Media to Support Co-Located Group Meetings. In proceedings of CHI'10, pages 609-618, ACM, 2010.

[Henderson and Card, 1986] Henderson, D., and Card, S.: Rooms: The Use of Multiple Virtual Workspaces to Reduce Space Contention in A Window-Based Graphical User Interface. In ACM Transactions on Graphics, 5(3), pages 211-243, ACM, 1986.

[Humphreys et al., 2002] Humphreys, G., Houston, M., Ng, R., Frank, R., Ahern, S., Kirchner, P., and Klosowski, J.: Chromium: a stream-processing framework for interactive rendering on cluster. In Proceedings of SIGGRAPH'02, pages 693-702, ACM, 2002.

[Hutchings and Stasko, 2007] Hutchings, D. and Stasko, J.: Consistency, Multiple Monitors, and Multiple Windows. In proceedings of CHI'07, pages 211-214, ACM, 2007.

[Hutchings et al., 2004] Hutchings, D. R., Smith, G., Meyers, B., Czerwinski, M., and Robert- son, G.: Display space usage and window management operation comparisons between single monitor and multiple monitor users. In Proceedings of the working conference on Advanced Visual Interfaces, pages 32–39, ACM, 2004.

[Hutchings and Stasko, 2004] Hutchings, D. and Stasko, J.: Revisiting Display Space Management: Understanding Current Practice to Inform Next-generation Design. In proceedings of Graphics Interfaces, pages 127-134 , ACM, 2004.

[Hutchings and Stasko. 2002] Hutchings, D. and Stasko, J.: QuickSpace: New Operations for the Desktop Metaphor. In proceedings of CHI,'02, ACM, 2002.

[Izadi et al., 2003] Izadi, S., Brignull, H., Rodden, T., Rogers, Y., and Underwood, M.: Dynamo: a public interactive surface supporting the cooperative sharing and exchange of media. In proceedings of UIST'03, pages 159-168, ACM, 2003.

[Jagodic, 2011a] Ratko J..: Collaborative Interaction And Display Space Organization In Large High-Resolution Environments. Ph.D. dissertation, Dept. Computer Science, University of illinois at Chicago, 2011

[Jagodic et al., 2011b] Jagodic, R., Renambot, L., Johnson, A., Leigh, J., and Deshpande, S.: Enabling multi-user interaction in large high-resolution distributed environments. In Future Generation Computer Systems, 27(7), pages 914–923, 2011.

[Jeong et al., 2006] Jeong, B., Renambot, L., Jagodic, R., Singh, R., Aguilera, J., Johnson, A., and Leigh, J.: High-performance dynamic graphics streaming for scalable adaptive graphics environment. In proceedings of SC '06, pages 24, IEEE, 2006.

[Jiang et al., 2006] Jiang, H., Eyal O., Neema M., and Yuanchun S.: Direct pointer: direct manipulation for large-display interaction using handheld cameras. In Proceedings of CHI '06, pages 1107-1110, ACM, 2006.

[Johanson et al., 2012] Johanson, P., Abram, D., Westing, B., and Navrtil, P. et al.: DisplayCluster: An Interactive Visualization Environment for Tiled Displays. In Cluster Computing, pages 239-247, IEEE, 2012.

[Kandogan and Shneiderman, 1997] Kandogan, E., and Shneiderman, B.: Elastic Windows: Evaluation of Multi-Window Operations. In proceedings of CHI'97, pages 250-257, ACM, 1997.

[Khan et al., 2009] Khan, A., Matejka, K., Fitzmaurice, G., Kurtenbach, G., Burtnyk, N., and Buxton, B.: Toward the Digital Design Studio: Large Display Explorations. Journal of Human-Computer-Interaction, pages 9-47, 2009.

[Khan et al., 2005] Khan, A., Justin, M., George, F., and Gordon K.: Spotlight: directing users' attention on large displays. In proceedings of CHI '05, pages 791-798, ACM, 2005.

[Kirsh, 1995] Kirsh, D.: The intelligent use of space. Artificial Intelligence, 73(1), pages 31–68, ACM, 1995.

[Kopper, 2011] Kopper, R.: Understanding and Improving Distal Pointing Interaction. Ph.D. dissertation, Dept. Computer Science, Virginia Polytechnic Institute and State University, 2011

[Leigh et al., 2013] Leigh, J., Johnson, A., Renambot, L., Peterka, T., Jeong, B., Sandin, D., Talandis, J., Jagodic, R., Nam, S., Hur, H., et al.: Scalable resolution display walls. Proceedings of the IEEE, 101(1), pages 115–129, IEEE, 2013.

[Leigh et al., 2008] Leigh, Jason, and Maxine Brown.: Cyber-commons: merging real and virtual worlds. In Communications of the ACM, 51(1), pages 82-85, ACM, 2008.

[Leigh et al., 2006] Leigh, J., et al.: The Global Lambda Visualization Facility: An International Ultra-High-Definition Wide-Area Visualization Collaboratory. In Future Generation Computer Systems, 22, pages 964-971, 2006.

[Mayers, 1988] Mayers, B.: Window Interfaces: A Taxonomy of Window Manager User Interfaces. In IEEE Computer Graphics and Applications, 8(5), pages 65-84, IEEE, 1988.

[McCallum and Irani, 2009] McCallum, D., and Irani P.: ARC-Pad: absolute+relative cursor positioning for large displays with a mobile touchscreen. In proceedings of UIST '09, pages 153-156, ACM, 2009.

[Park and Cho, 2005] Park, K., and Cho, Y.: Designing Display-Rich Environments for Collaborative Scientific Visualization. In LECTURE NOTES IN COMPUTER SCIENCE, pages 52-60, Springer, 2005.

[Rashid et al., 2011] Rashid, U., Kauko, J., Hakkila, J., and Quigley, A.: Proximal and distal selection of widgets: designing distributed UI for mobile interaction with large display. In proceedings of MobileHCI'11, pages 495-498, ACM, 2011.

[Ringel, 2003] Ringel, M.: When one isn't enough: an analysis of virtual desktop usage strategies and their implications for design. In proceedings of CHI'03, pages762-763, ACM, 2003.

[Roberts, 2007] Roberts, J. C.: State of the art: Coordinated & multiple views in ex- ploratory visualization. In Coordinated and Multiple Views in Exploratory Visualization, pages 61–71, IEEE, 2007.

[Roberson et al., 2005] Roberson, G., Czerwinski, M., Baudisch, P., Meyers, B., Robbins, D., Smith, G., and Tan, D.: The Large-Display User Experience. In IEEE Computer Graphics and Applications, 25(4), pages 44-51, ACM, 2005.

[Robertson et al., 2004] Robertson, G., Horvitz, E., Czerwinski, M., and Baudisch, P.: Scalable Fabric: A Flexible Representation for Task Management. In proceedings of Advanced Visual Interfaces, pages 85-89, ACM, 2004.

[Rogan et al., 2012] Rogan, E., Endert, A., Bowman D., and Quek, F.: How Spatial Layout, Interactivity, and Persistent Visibility Affect Learning with Large Displays. In proceedings of AVI'12, 2012.

[Seifreid et al., 2012] Seifried, T., Rendl, C., Haller, M., and Scott, S.: Regional Undo/Redo Techniques for Large Interactive Surfaces. In proceedings of CHI'12, pages 2855-2864, ACM, 2012.

[Szwedo et al., 2006] Szwedo, M., North, C., and Ball, R.: Dynamic size and speed cursor for large, high-resolution displays. Technical Report TR-06-16, Computer Science, Virginia Polytechnic Institute and State University, 2006.

[Wallace et al., 2009] Wallace, J., Stacey, D., Taryn, S., Tricia, E., and Kori, I.: Investigating teamwork and taskwork in single- and multi-display groupware systems. In Personal and Ubiquitous Computing, 13(8), pages 569–581, Springer, 2009.

<div align="center">**VITA**</div>

<div align="center">Hyejung Hur</div>

EDUCATION

Ph.D. Candidate, University of Illinois at Chicago, 2007 - present

M.S., Computer Science, Duksung Women's University, Seoul South Korea 2001

B.E., Computer Science, Duksung Women's University, Seoul S Korea 1999

ACADEMIC EXPERIENCE

Research Assistant, Electronic Visualization Laboratory, 2007 – 2014. 12

Intern, Argonne National Laboratory, 2012, 2010, 2009 Summer

Intern, Samsung Electronics, June 2008 – August 2008

Intern, Lemont-Doherty Earth Observatory of Columbia University, May 2008

PROFESSIONAL EXPERIENCE

Researcher, Institute for Graphic Interface, February 2005 – August 2006

Senior Software Developer, RealTimeVisual Inc., November 2001– January 2005

TEACHING EXPERIENCE

Adjunct professor, digital media department of SangMyung University, March 2005 – Feb. 2006

Lecturer

- *Design and Analysis of Algorithms, Mar. 2004 ~ Jun. 2004, Duksung Women's University, Seoul South Korea*
- *Computer Programming/C++, Sep. 2003 ~ Dec. 2003, Duksung Women's University*
- *Computer Graphics, Mar. 2003 ~ Jun. 2003, Duksung Women's University*
- *Multimedia Communications, Sep. 2002 ~ Dec. 2002, Duksung Women's University*

ACTIVITIES

URP from Korea Foundation for the Advancement of Science and Creativity, 2012 May ~ 2012 November

CSCW 2012, Seattle, WA. – Student Volunteer.

UIST 2011, Santa Barbara, CA. – Student Volunteer.

AAAS 2009, Chicago, IL. – Demonstrated TacTile, a 52" LCD-based multi-touch table.

Supercomputing 2008, Austin, TX. – Demonstrated "Global Visual-casting", streaming of 4K and HD video, audio and visualizations among several international research sites, to create a sustained global teleconference environment.

Supercomputing 2007, Reno, NV. – Demonstrated LambdaTable, a 24-Megapixel tabletop system, accompanied by a tiled display wall to form a collaborative, distributed, high-resolution table+wall environment.

MEMBERSHIP

Student member, ACM, 2011 – present

Student member, ACM SIGCHI, 2011 – present

Student member, IEEE, 2014 – present

PATENT

"Wireless Interactive Input Method and Device for VR/AR" filed by The Korean Intellectual Property Office, 2005

PUBLICATIONS

Hur, H., Lee, J.: Contents Sharing Model in Distributed Collaboration Environment. Journal of The Korea Society of Computer and Information. Vol. 19, No. 5, May 2014.

Hur, H., Lee, J.: Improved Tracking System and Realistic Drawing for Real-time Water-Based Sign Pan. Journal of The Korea Society of Computer and Information. Vol. 19, No. 2, February 2014.

Leigh, J., Johnson, A., Renambot, L., Peterka, T., Jeong, B., Sandin, D., Talandis, J., Jagodic, R., Nam, S., Hur, H., Sun Y.: Scalable Resolution Display Walls. Proceedings of the IEEE. 101(1), pages 115-129, 2013

Lee, J., Hur, H., Park, M., Lee, S., Suh, M., Yu, J.: Drawing Tool with Inexpensive Vision-Based Tracking System. Conference of Korea Society of Computer Information. 20(2), pages 295-296, 2012, Best Paper Award

Jeong, B., Leigh, J., Johnson, A., Renambot, L., Brown, M., Jagodic, R., Nam, S., Hur, H.: Ultrascale Collaborative Visualization Using a Display-Rich Global Cyberinfrastructure. IEEE Computer Graphics and Applications. 30(3), pages 71-83, 2010

Chen, Y., Hur, H., Lee, S., Leigh, J., Johnson, A., Renambot, L.: Case study: designing an advanced visualization system for geological core drilling expeditions. Proceeding of CHI Extended Abstracts, pages 4645-4660, 2010

Renambot, L., Jeong, B., Hur, H., Johnson, A., Leigh J.: Enabling high resolution collaborative visualization in display rich virtual organizations. Future Generation Comp. Syst. 25(2), pages 161-168, 2009

Chen, Y., Lee, S., Hur, H., Leigh, J., Johnson, A., Renambot L.: Design an interactive visualization system for core drilling expeditions using immersive empathic method. Proceeding of CHI Extended Abstracts, pages 2671-2674, 2009

Chen, Y., Hur, H., J., Leigh, J., Johnson, A., Renambot L., Ito, E., Morin, P., Higgins, S., Reed, J.: The CoreWall Project – Core Visualization, Stratigraphic Correlation and Rich Media Distribution. Workshop on "The Future of Continental Scientific Drilling, a US Perspective", June 2009, Denver, CP.

Leigh, J., Renambot, L., Johnson, A., Jagodic, R., Hur, H., Hofer, E., Lee, D: Scalable Adaptive Graphics middleware for visualization streaming and collaboration in ultra resolution display environments. Proceedings of the Workshop on Ultrascale Visualization, pages 47-54, 2008

Leigh, J., Johnson, A., Renambot, L., Sandin, D., Defanti, T., Brown, M., Jeong, B., Jagodic, R., Krumbholz, C., Svistula, D., Hur, H., Kooima, R., Peterka, T., Ge, J., Falk, C.: Emerging from the CAVE: Collaboration in Ultra High Resolution Environments. Proceedings of the First International Symposium on Universal Communication, 2007

Hur, H., Fleisch, T., Kim, T., On, G.: AICI-Advanced Immersive Collaborative Interaction Framework. Korean Society of CAD/CAM Engineers Conference, 2006

Lee, J., Hur, H.: Analyzing Educational Effect with VR Application in the Aerospace Museum. Korean Information Science Society HCI, 2005

Hur, H., Woo, I., Park, S.: The Integrated M&S Framework for Engagement and Mission Effectiveness Analysis in Development Phase of Air Weapon Systems. AeroSpace Weapon System Development Seminar, 2004

Hur, H., Chung, W.: Visual Concurrent Programming based on Extension State Transition Graph. Journal of Korean Information Processing Society, 2000

Hur, H., Lee, J., Lee, J.: Algorithm for Orthogonal Drawing without bending in Planar Binary Trees. Conference of Korean Information Science Society, 2000

Hur, H., Kim, S., Lee, J.: Algorithm for Level Drawing in Planar Trees. Conference of Korean Information Science Society, 2000

Hur, H., Lee, J., Lee, S.: The Algorithm for Optimistic Channel Assignment in Cellular Network. Conference of Korean Information Science Society, 1999

Hur, H., Chung, W.: Visual Concurrent Programming based on Extension State Transition Graph. Conference of Korean Information Processing Society, 1999