Proximity and Physical Navigation in Collaborative Work With a Multi-Touch Wall-Display

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CHI'12, May 5–10, 2012, Austin, Texas, USA.
ACM 978-1-4503-1016-1/12/05.

Abstract
Multi-touch, wall-sized displays afford new forms of collaboration. Yet, most data on collaboration with multi-touch displays come from tabletop settings, where users often sit and where space is a limited resource. We study how two-person groups navigate in relation to a 2.8m×1.2m multi-touch display with 24.8 megapixels and to each other when solving a sensemaking task on a document collection. The results show that users physically navigate to shift fluently among different parts of the display and between parallel and joint group work.

Author Keywords
Large high-resolution display; multi-touch; group work; user study; proxemics

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces—Graphical user interfaces (GUI).

General Terms
Experimentation, Human Factors.

Introduction
Multi-touch, wall-sized displays allow multiple users to provide simultaneous touch input, offer sufficient resolution to allow reading and other work to be carried

out up close, and let users mix closely-coupled and loosely-coupled work at the display. Taken together, these factors afford new forms of collaboration and, in turn, shape collaboration in new ways.

Most of what we know about collaboration using multi-touch displays, however, is from research on tabletops [e.g., 8,9]. This work suggests that partitioning the display space is crucial to efficient collaboration, and that distinct territories may be identified in the spatial layout of information. These findings may not generalize to larger, vertical displays. For instance, orientation of information is crucial on tabletops [8], but appear less relevant on wall-displays. Research suggests that display size influences collaboration [9]; having much more space on a wall-display may therefore profoundly change interaction and performance. Finally, physical movement influences performance with large displays [2] and the relative distance among collaborators also influences their interaction [3]. Yet, most tabletop studies have participants sit down and stay put.

We present an exploratory study of how pairs collaborate on a multi-touch, wall-display (Figure 1). We use a complex problem-solving task that requires sensemaking of a large document collection. The paper focuses on understanding how participants navigate relative to the display and to each other. The main contribution is to challenge findings from earlier studies on tabletops [e.g., 8,9] and from seated interaction with high-resolution displays [e.g., 1,11] by providing empirical data that show how wall-sized displays differ. The intended benefit of the paper is to discuss how notions of territoriality, proximity, and physical navigation may inform design for multi-touch, wall-displays.

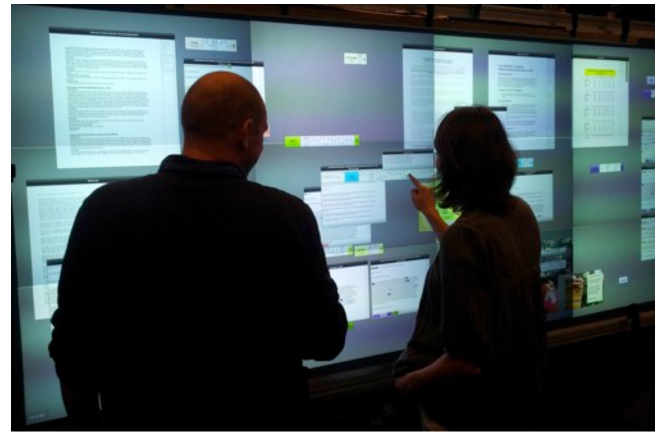


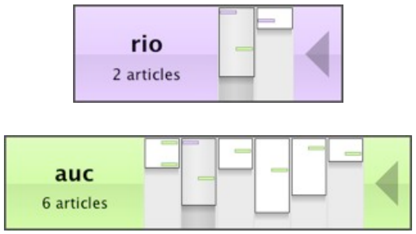
Figure 1. Pair of users working on a sensemaking task.

User Study

Participants worked on the “Stegosaurus” scenario from the interactive session of the VAST 2006 challenge [4], which has also been used in [1,7]. The task scenario involves finding a hidden weapons-smuggling plot. The data set consists of a background document explaining the scenario, 230 news articles, 3 images, 1 map, 1 spreadsheet, and 3 reference documents. Participants must search for and read relevant documents to make hypotheses and gather evidence, filter out irrelevant information, and connect the data. We chose the task because it provides for varied types of collaboration: group members may find it useful to search or read in parallel, while they also need to share information or work jointly to connect evidence.

Participants

We recruited 30 participants (eight female) to take part in the study as pairs. Participants were 18–41 years old (M = 26.3, SD = 6.4). Pairs knew each other well (M =



(a)

(b)

Figure 2. Search bars (a) showing tiles for documents that contain the terms "rio" and "auc". A document containing both terms has been opened (b) and the tile for that document in the search bars is thus shown in a darker shade.

2.3, *SD* = 1.1, on a 7-point scale with 1 being 'very familiar').

Display and Interface

Participants used a vertical multi-touch display containing 24.8 megapixels (7680×3240). The active display area measures 2.8×1.2 meters with the bottom edge 89 cm above the floor. The display consists of 12 projectors, each with 1920×1080 pixels, arranged in a 4×3 grid. The display has a resolution around 60 ppi, appropriate for reading at arms length. Touch detection is done with diffused surface illumination. Input from 6 cameras, 640×480 pixels at 30 fps, is analyzed using Community Core Vision and multiplexed to form input for tracking touch points.

Participants used a touch-based interface for exploring the document collection (see Figures 1 and 2). The interface resembles Cambiera [9], a tabletop system for collaborative analysis, but was adapted to a high-resolution wall-display. The interface supports group work by allowing participants to search and read documents in parallel. For instance, multiple views of a document can be open for participants to read in different parts of the display. Also, the interface provides basic brushing features that may help participants link their partner's work to their own.

The interface contains four search buttons located near the bottom of the display. Touching a button opens a *search bar* and an on-screen keyboard. When a search term has been entered, the search bar expands to show each document as a *tilebar*, modified from [6]. The height of each tilebar is proportional to the length of the document (see Figure 2). Colored rectangles indicate locations of search terms; if a document is found by more than one search, its tilebar contains a column for each of the matching search terms. Touching a tilebar in a search bar opens a preview of the document in a window. The preview includes the document's title and publication date, search terms found in the document, and the lines containing the search term of the currently browsed search.

Documents can be opened for reading by dragging a finger up or down from a tilebar whereby the preview window detaches from the search bar; when releasing the preview window, a document window is opened. Documents can be scrolled and search terms are highlighted. When a document is selected, all representations of the document in the interface are highlighted by colored borders.

Finally, holding a finger anywhere on the background for one second opens a note window for entering text.

Data Collection

The main data on proximity and physical navigation come from a camera mounted in the ceiling. The camera captured 640 x 480 pixels at 15 fps and used a wide-angle lens in order to cover the room. Participants wore red and yellow baseball caps that could be detected by a custom program to track their location.

Procedure

Participants were first introduced to the wall-display and the interface. Next, they used 10 min to work on a sample document collection and ask questions about the interface. After the introduction, each participant were handed a baseball cap and the head tracking system was calibrated. Participants were then briefed on the task with reference to a background document, which includes starting points and clues for the task, shown in the center of the display. Then participants began analyzing documents to identify the plot. Participants could break after around 45 min, to sit down if they needed to. After having worked on the task for 1½ hour, participants were asked to summarize their findings, explaining their hypotheses and the data to support them.

Results

On average, pairs spent 79 min (*SD*=9.7 min) on the task and the tracking data comprise 19:46 hours. Below, we examine the participants' proximity to each other and to the display, their sharing of the display, and their physical navigation in front of the display. We based our analysis on participants' location rather than on their interaction with the display, thus providing data for periods where participants did not interact with the display (e.g., while reading).

Proximity

Participants spent 56% of the time (*M* = 44.3 min, *SD* = 12.1) at a personal distance (46–120 cm, as defined by [5]). More surprisingly, participants spent 18% of the time (*M* = 14.3, *SD* = 10.7) at an intimate distance (0–46 cm), even pairs that were not thus related. Participants spent the remaining 22% of the time (*M* = 17.6, *SD* = 9.7) at a social distance (120–370 cm). This shows that participants were working close most of the time, but that they also found it useful to work in parallel on separate parts of the display.

Participants spent the most time up close to the display: 60% of the time (*M* = 47.5, *SD* = 13.0) was spent within a comfortable distance for interacting with the display (<46 cm) and 31% (*M* = 24.2, *SD* = 15.9) within arms length distance (< 76 cm). This is not surprising, since most activity including reading is often best done at a close distance. Participants stepped back from the display for at least five seconds, 43 times in average (*SD* = 20.8). We observed participants back away from the display to read more comfortably, to gain an overview of the display, or to pass behind their partner to a different part of the display. The time spent away from the display varied across participants. One participant, who spent 10% of the time away from the display, said that he liked walking around while thinking; others worked up-close throughout the task.

Location

Participants occupied the center regions more than the left and right side (see Figure 3A), possibly because all participants started working on the task by reading the documents shown in the center of the display.

To help quantify how pairs shared the display over time, we calculated an index of display partitioning (*IDP*). The index is calculated by dividing the area in front of the display into regions, and determining how much longer each region is occupied by one participant (wearing Red hat) relative to the other (wearing Yellow hat):

$$IDP = \sum_{i=1}^{10} |t_{Ri} - t_{Yi}| \Big/ \sum_{i=1}^{10} t_{Ri} + t_{Yi}$$

where t_{pi} is the time spent by participant $p \in \{R,Y\}$ in region i. Table 1 shows the index of display partitioning for all 15 pairs in this study. Two participants occupying separate regions for the entire task would give *IDP* = 1. The median *IDP* = 0.35 suggests that most pairs shared the display quite evenly. The *IDP* varies greatly across pairs, however, ranging from 0.23 for pair 11,

Pair	IDP
1	0.33
2	0.39
3	0.27
4	0.35
5	0.32
6	0.38
7	0.31
8	0.26
9	0.67
10	0.39
11	0.23
12	0.46
13	0.69
14	0.25
15	0.52

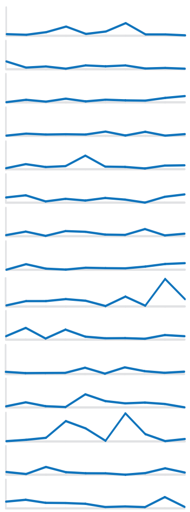


Table 1. Index of display partitioning (IDP) and sparklines showing the relative difference in time spent by each group member for the different regions of the display.

which shared the display the most equally among them, to 0.69 for pair 13, which showed the strongest partitioning of the display.

To better understand how pairs shared the display, we visualized the time participants occupied each region of the display. Figure 3 shows visualizations for the pairs with lowest and highest *IDP*: participants of pair 11 occupied different regions for a comparable amount of time (Figure 3B), whereas participants in pair 13 mostly spent time in front of their respective parts of the display (Figure 3C). These visualizations also show how participants were mostly located in front of particular regions of the display (i.e., for pair 13, "red" mostly was in region 4 while "yellow" was in region 7). These visualizations are compressed to the sparklines that are shown for all pairs in Table 1. Variations in how pairs partition the display are noticeable: both members working in separate concentrated regions  (e.g., pairs 1, 10, 13); more complex patterns of one member working in a concentrated region while the other uses more regions  (pairs 9, 12, 15).

Another way of looking at how participants partitioned the display is whether participants stayed on one side of their partner. Half of the pairs spent 69% or more time with their partner on one side. Some spent almost an equal amount of time on the left and right sides of their partner, whereas for instance pair 13 "red" spent 83% of the time to the left of "yellow" (see Figure 3C).

Movement

All participants navigated by moving in front of the display. We analyzed the head tracking data, using a modified Douglas-Peucker algorithm to compensate for jitter. The results show that participants moved 329 m

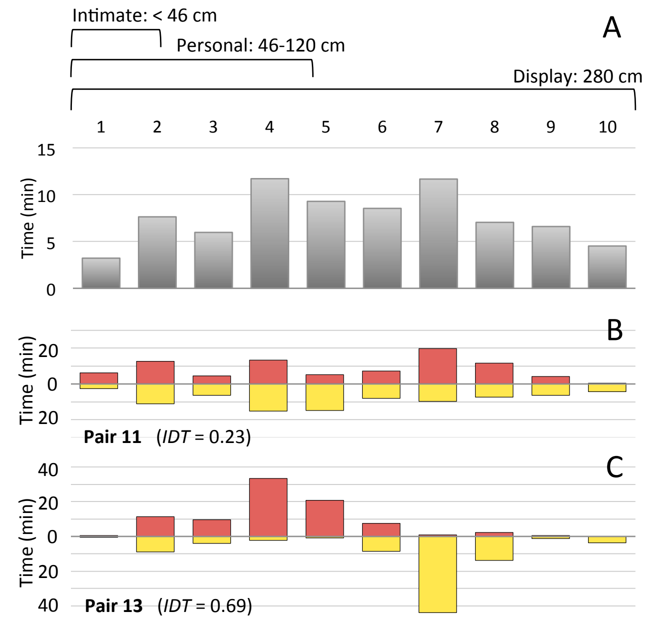


Figure 3. Time spent (y-axis) in the different regions of the display (x-axis): (A) in average across all participants; (B, C) divided among the participants with red and yellow hats of pair 11 and 13.

in average (*SD* = 82 m). Moreover, participants moved past their partner, for instance to access another part of the display, 53 times in average (*SD* = 33.7). This indicates that although participants worked more in some areas of the display or more to one side of their partner, they often found it useful to move in front of the display.

Discussion

One clear difference to studies of seated interaction with large high-resolution displays [1,11] is that the wall-display allowed the participants to navigate effectively through physical navigation rather than virtual navigation, which can improve performance [2].

Moreover, our findings contrast tabletop research [7,8,9] and claims that sharing of large vertical displays requires explicit space partitioning [10]: the wall-display allowed participants to work in parallel without explicit negotiation for space. Many groups shared the display evenly; if those groups made use of personal territories, the territories were much more transient compared to the partitioning of space found for groups of users that are fixed in seated positions [9].

Our findings also have implications for the design of large display interfaces. Despite the abundance of space, pairs worked physically close much of the time. One benefit of working closely is that documents can be easily shared and group members can monitor each others work. Still, participants worked in separate parts of the display for 1/5 of the time, which emphasizes a need for interfaces that help users monitor group work that is distributed across the display. Also, wall-sized displays require new mechanisms for easily moving data or tools between different parts of the display when users move as much as they did in our study.

In follow-up work, we examine users' interactions with the display and relate collaborative interactions around multi-touch wall-displays to established types of collaboration [e.g., 7]. More work is also needed to understand how collaboration and up-close interaction with wall-displays relate to task type and group size.

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