Toward Characterizing the Productivity Benefits of Very Large Displays

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Abstract: Larger display surfaces are becoming increasingly available due to multi-monitor capability built into many systems, in addition to the rapid decrease in their costs. However, little is known about the performance benefits of using these larger surfaces compared to traditional single-monitor displays. In addition, it is not clear that current software designs and interaction techniques have been properly tuned for these larger surfaces. A preliminary user study was carried out to provide some initial evidence about the benefits of large versus small display surfaces for complex, multi-application office work. Significant benefits were observed in the use of a prototype, larger display, in addition to significant positive user preference and satisfaction with its use over a small display. In addition, design guidelines for enhancing user interaction across large display surfaces were identified. User productivity could be significantly enhanced in future graphical user interface designs if developed with these findings in mind.

Keywords: Large displays, multiple monitors, user interface design, knowledge work, user study

1 Introduction

The increasing graphical processing power of the PC has fueled a powerful demand for ever larger and more capable display devices. Cathode ray tube or CRT displays are now generally affordable with a 21" diagonal. Flat panel displays can be obtained in such sizes and larger and are becoming increasingly less expensive. Still, most users possess displays whose display surface area is less than 10% of their physical workspace area. How might users cope and benefit with displays having 25% to 35% of their desk area or covering an entire office wall? This question has been an issue of interest for many researchers. To examine this issue, we have tested several models to measure their effectiveness for productivity applications.

One approach to garnering extra display surface is to attach multiple monitors to one computer. Because the ability to work with multiple displays has been supported for some time in several operating systems (OS) and due to the advancements of graphic cards over the past ten years or so, a growing number of computer users take advantage of multiple monitor (multimon) capabilities. Our own survey research indicates that as many as 20% of the Windows™ OS users today run multiple monitors from one PC or laptop. Most users are becoming aware that running multimon is an option. The two top reasons participants in our survey cited for not running multiple monitors were not having enough desktop space and price concerns. Display manufacturers are predicting trends for the price of liquid crystal displays (LCDs), which have smaller footprints, to drop dramatically over the next four years. This price drop has already begun and the average computer consumer can now readily get more pixels by buying dual 17" LCDs than by buying one 21" LCD for approximately the same price. Since all laptop manufacturers also are selling their products with built-in support for multiple monitors, we foresee a dramatic increase in the number of users who will be opting for more screen real estate (pixels) by running multimon configurations.

Grudin (2001) has documented the usage patterns of CAD/CAM programmers and designers running multiple monitors. Even though current operating system support for multimon has its limitations, as described in that research, multimon users clearly love the extra screen real estate and learn to adapt their windows and application layouts optimally for the number, size, orientation and resolution of their displays. Current multimon users claim they would never go back to a single monitor.

Despite these qualitative claims, there are very few empirical investigations in the literature demonstrating real or perceived productivity benefits from using multimon or large displays. We ran an initial study investigating the benefits of using multiple monitor projections to mimic a very large display surface with an eye toward novel software applications that might better support the way information workers multitask between their projects and applications. Though this study is preliminary, it provides a contribution to the field in that the benefits and satisfaction provided by our very large multimon display surface and accompanying software support tools are clearly outlined in comparison to small display benchmark.

2 Related Work

In closely related work, Simmons & Manahan (1999) studied the productivity benefits of using increasingly large displays. In that study, they examined productivity for MS Office tasks (e.g., using Word, Excel, etc.) with four different monitors sizes: 15", 17", 19" and 21" diagonal viewing areas. Resolution was not controlled across the monitor sizes. Significant productivity benefits were reported for the 21" monitor size in terms of task times and overall preference. A few other studies using single, widely available displays sizes have also reported performance benefits such as ease of learning task speed decreases from using the larger display sizes (De Bruijn, De Mul & Van Oostendorp, 1992; Dillon, Richardson & McKnight, 1990; Kingery & Furuta, 1997; Sommerich et al., 1998). Unfortunately, these studies did not examine display sizes larger than a 21" diagonal display.

The Prairie prototype, a 6 x 3 foot display running at 2400 x 1200 pixel resolution, allowed researchers to explore the design space for very large displays and detail the lessons learned (Swaminathan & Sato, 1997). The authors argue that very large displays could support 3 kinds of context: social, work and navigational contexts. Their design afforded all three contexts, but it became clear that a very large display viewed from approximately 8 feet (which the authors referred to as "distant-contiguous") had disadvantages and advantages. An advantage of this kind of display is that it supports the traditional desktop viewing angle of 20-40 degrees visual angle (users do not need to rotate their necks) and provides a large, continuous drawing surface. The disadvantages discussed by the authors were that this configuration inherently compromises privacy and can lead to eye strain if sustained detail work is required, as in most office computing tasks. To get around this problem, the authors recommended the "desktop-contiguous" large display configuration. This configuration does not have the advantage that the display is at the center of the user's visual field (e.g., the user will have to rotate the neck), but keeps the display at the standard reading distance. The authors recommend this type of display when large amounts of interrelated information need to be displayed, especially if it is likely that the user will need to attend or work closely with any of that information. We chose to design our prototype display as a "desktop-contiguous" display, as we were interested primarily in single user, office computing task support. Sawminathan and Sato also discuss the importance of designing novel input techniques due to the problems inherent in long distance mouse travel, and we also observed similar issues related to mouse movement in our user study.

There have been several investigations around what is commonly referred to as large "focus plus context" displays or visualizations for large displays. Baudisch et al. (2002) present one of the few reports of empirical studies demonstrating the significant performance benefits of a very large display used for maintaining a lower resolution context, with a smaller, central focal display region of very high resolution. We wondered if productivity benefits could also be observed with larger display surfaces without the high contrast focus region during normal office productivity work.

In related work, Tani et al. (1994) described the Courtyard system to support the operation of complex real-world systems. Multiple users cooperate in monitoring and controlling large amounts of information by integrating an overview on a shared large screen and detail on individual screens. Two aproaches were used to obtain this level of integration. First, an implicit method of transferring mouse and keyboard control between the shared and individual screens was provided. Secondly, the association between the overview on the shared screen and the per-user detail on individual screens was supported. One elegant feature of the Courtyard system allowed a user to move a mouse pointer between the shared and individual screens as though they were on one shared display surface. In addition, detailed information on a user's individual screen could be accessed simply by pointing to an object on the shared screen. The authors claimed that the integrated approach resulted in an interface that was as easy to use as a single screen, without being distracted by information intended for others. Unfortunately, no user studies were reported for how beneficial this approach was from a productivity point of view.

Guimbretiere, Stone and Winograd (2001) investigated the interaction techniques that might enable better productivity with wall-sized displays. Design goals followed in this work included the integration of high resolution materials (such as web content and digital camera images) on a wall sized display, with a clean, uncluttered screen, and natural, fluid interaction techniques. A pilot study with IDEO designers using the display with very little training revealed that many of these design goals had been accomplished. Flow menus, an adaptation of marking menus (Kurtenbach & Buxton, 1991) helped reduce the interference from menubars and toolbars, and window scaling via dragging to special regions of the screen further reduced clutter. While many of Guimbretiere's design ideas and informal user accounts are compelling, measurable benefits to using the large display and accompanying interaction techniques were not provided.

Elrod et al. (1992) reported on the Liveboard, a large interactive display system. The focus of the Liveboard was to carry out research on user interfaces for group meetings, presentations and remote collaboration. The Liveboard had nearly one million pixels and used a cordless pen, similar to Guimbretiere's display. The authors did perform qualitative surveys of their users which indicated there was some perceved benefit to using the large display in meetings. In a related line of research, an electronic whiteboard application called Tivoli (Pederson et al., 1993) was designed to support informal workgroup meetings and targeted to run on and augment the capabilities of the Liveboard for informal meetings. For both Liveboard and the Tivoli application, it was unclear if productivity benefits were found over time using the large display and interaction techniques.

A multiple-device approach for supporting group meetings using a digital whiteboard was designed and reported by Rekimoto (1998). The author, like Guimbretiere et al. and Pederson et al., discussed how the large display surface of the whiteboard makes traditional GUI design ineffective. Rekimoto proposed the use of a hand-held computer for each participant for accessing tool palettes and data entry palettes for the larger display. No user studies were reported on the pallette approach's efficasy for increasing productivity while using the large display.

An interactive wall with an active area of 4.5 meters width, 1.1 meters height, and 3072x768 resolution, using pen, finger and hand gesturing was developed by Geissler (1998). Users could shuffle display objects around, throw them to other users standing at the opposite side of the wall, and objects could be taken from the wall and placed elsewhere. Once again, no user study demonstrating the producitvity benefits of these novel interaction techniques was presented.

Patrick et al. (2000) described a comparison of head-mounted displays, large projection displays and desktop displays. An empirical study investigated differences in spatial knowledge gleaned while navigating a virtual environment between the three display conditions. Participants were required to generate a cognitive map of the virtual environment after following predetermined routes. The head-mounted display and large projection screen conditions were significantly better than the desktop viewing condition, and not different from each other. The authors concluded that a large projection screen may be an effective, inexpensive substitute for a very immersive experience. Similarly focusing on immersive navigation, Czerwinski et al. (2002) and Tan et al. (2001) explored gender effects observed when wider fields of view were available on very large display surfaces during 3D navigation tasks. In a series of studies, it was observed that females benefited significantly more from the wider fields of view accommodated by larger displays than males, although the wider fields of view also helped males to a smaller degree. The studies demonstrated that when users navigate with large displays and wider fields of view, the typically observed gender difference between females and males is ameliorated. All of these studies are intriguing in that they demonstrate benefits of large displays in immersive, 3D environments. However, the complementary user studies of normal office computer productivity work in 2D applications are lacking.

In summary, research on larger displays is beginning to gain critical mass, but there are still few empirical studies that show advantages to using very large displays to perform typical information work. In addition, though many novel interaction techniques have been designed for large display interaction, few user studies have been carried out to demonstrate the value of these novel designs. It is our goal in the research presented here to begin to outline the productivity benefits provided by interacting with very large displays for typical computing tasks. Along the way, it may be possible to document what aspects of current graphical user interfaces do not scale well across large display surfaces, in addition to gaining some insight as to what novel software solutions might need to be developed.

We next present a user study aimed at understanding if there are indeed productivity benefits to using very large displays. It is our hypothesis that there must be an advantage to having additional screen real estate—both a cognitive load advantage as well as a reduction in the need to perform window management. If there are indeed measurable benefits, this study will provide the HCI community with the contribution of revealing the magnitude of the effect, and that these benefits can emerge during daily office computing task contexts. We close with some thoughts about what novel software user interface solutions might enhance very large multimon display user interaction.

Figure 1. User working on experimental Dsharp display.

3 User Study

A study was designed in order to examine the productivity benefits of the larger display surface over and above a standard, 15" flat panel display for complex, multi-application computer tasks. This study compared a 15" display with a novel 42" wide surface, called DSharp (see Figure 1), created by using three XGA DLP projectors at 1024 x 768 resolution onto a curved Plexiglas panel for an equivalent of a 3072 x 768 resolution display. "DSharp" (which arose from an acronym, viz. Display System implementing High Aspect Ratios with Projection) is the current code name for the display technology. This combination yields a screen having an area of about 12 inches high by 48 inches wide comprising a 4:1 aspect ratio. Rather than have a very wide flat display (which we refer to as "billboard mode") and its attendant perspective distortion, the desire was to have the display curve around the user. The display is nearly seamless; the seam between each of the three projectors is visible but extremely small (less than 1/32"). By comparing the 15" flat panel display to the much larger DSharp display, we have chosen two ends of the continuum in terms of display surface in this pilot study. The goal of the study was to determine if there was a significant performance advantage inherent in performing productivity tasks on the larger display. Such displays are expected to be increasingly useful in producing more visually pleasing environments as well as improving the quality of the work.

A fairly complicated sequence of web and Microsoft Office task steps was constructed in order to replicate the large amount of task switching and multitasking we have observed for real information workers in the field.. We cautiously hypothesized that users would perform the tasks faster using the large display surface due to less windows management. It was not clear whether we would in fact observe this benefit, given that the Windows XP™ operating system and Office XP™ applications used in the study do not optimally support multiple monitors, and since the participants were not familiar with such large display surfaces for carrying out their work.

3.1 Participants

Fifteen volunteers (7 female) from the greater Puget Sound area were recruited from the Microsoft Usability database to participate in the study. The average age of the participants was 38.25 (range was 23 to 50 years old). The participants were screened to be intermediate to expert Windows and Office users, as per validated internal screening tools. All participants had normal or corrected to normal vision, and none of them had previously used multiple monitors either at work or home.

3.2 Tasks

Each participant carried out 12 isomorphic tasks on each display, the first two of which were considered practice and not included in the performance data analyses. Each task involved the following, 8-step sequence:

1. A phone number was presented which had to be remembered throughout the trial.
2. A web page target (title and summary description) was presented to the user upon removal of the phone number, and the user was to come up with 3 search terms for searching for this target before continuing.
3. Alta Vista's search page was presented and the participant was to type in the 3 search terms.
4. The best match from the search list was to be selected.
5. The participant was to determine who designed the web page (a computer science student, a small software company or an upscale design firm).
6. The URL from the web page was to be copied and pasted accordingly into a Word document containing the 3 design categories.
7. An image of the web page was to be captured (using Alt + PrintScreen) and pasted into an empty PowerPoint slide deck (empty slides were already prepared for this task).
8. The participant pressed a button to conclude the task trial, and then had to type in the phone number from memory.

3.3 Design and Equipment

Two displays, each on a separate personal computer, were used for this study. The first display was a 15" flat panel display from Sony Corporation, running at 1024x768 resolution. The second display was the DSharp display, running at 3072x768 resolution. For both workstations, a Microsoft natural keyboard and Intellimouse were used as the input devices. Microsoft Internet Explorer v. 6.0 and Microsoft Office XP Professional applications were used for the tasks, and system performance on the Dell P610 PCs was equated, as measured by internal clock speed for web searching and windowing behaviors.

Pairs of users carried out two practice tasks each at one of the displays, and then carried out 10 experimental trials, taking approximately one hour. After all tasks were completed on one display, the users would complete a satisfaction survey, then move to the alternate display, and carry out the same process, counterbalancing display order. In addition, the tasks, although created to be isomorphic, were alternated between pairs of users so that the tasks were used equally often on the large and small displays, in order to counterbalance for any potential task set differences. A 5 minute deadline procedure was utilized, so that if a participant did not complete all the task steps within the 5 minute timeframe, they moved on to the next task. Total session time lasted approximately 2 hours (one hour per display), and users were provided with a software gratuity.

3.4 Results

Phone Number Memory. The percent correct for the memorized phone number was slightly higher, on average, in the large display condition (average of 3.5 numbers memorized correctly on the large display v. 3.0 on the small display), but this difference was not statistically significant, $t(14)=-0.79$, $p=.22$. Memory for the phone number digits could be reflective of the amount of cognitive resources available for the secondary phone memorization task.

Task Times. The average task times were significantly faster on the large display than on the small display, $F(1, 13)=7.0$, $p=.02$. Tasks were completed in 116 seconds, on average, on the large display, compared to 127 seconds, on average, on the small display. This amounts to just over a 9% increase in productivity on the larger display. This performance improvement might not seem so large to the casual observer, but in our experience it is extremely difficult to get performance improvements of this magnitude using existing user interfaces for these types of tasks. In addition, this significant benefit emerged despite the fact that it was clear that the Windows graphical user interface features and functions did not scale well to the very large surface. We discuss this in more detail in the next section. The task time data are shown in Figure 2.

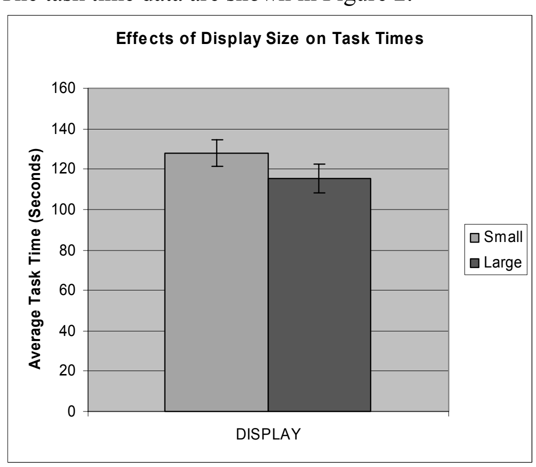

Figure 2. Average task times for 15" LCD v. DSharp.

Usability Issues. We did observe several usability issues for both display size conditions. For the small display, there were many problems observed in terms of managing the level of complexity on the small screen, including losing files by accidentally closing them, wasting time resizing for each stage of a task, moving windows so that they weren't occluding key information, etc. From our windows event monitoring software, we observed that users on the small display wasted time bringing windows back to the front when occluded, resizing and repositioning them. In addition, small display users spent extra time accidentally opening and closing documents they did not intend to because the taskbar aggregated window items by application (i.e., all open web pages would collapse to one tile on the taskbar, with a numeric indicator of how many items were being represented by that tile). In all, users performed over 300 more window "focus" events (i.e., bringing the window to the top of the z-order for input) on the small display than they did on the large display.

For the large display, brightness of the display was mentioned as an issue by several users. Also, some users thought that they were forced to sit "too close" to the display, and they wanted to be able to back up and interact with it from a distance. In terms of windows design for the very large display, users mentioned the amount of navigation required and the problem of losing the cursor on the display were the two most onerous problems. In addition, a few users pointed out that the Start Menu and Task Bar should be positioned closer to the area of attentional focus. Users mentioned that incoming notifications that might appear in the primary display (the only display with the Task Bar) would be an issue if there were not working on that display. In terms of any egregious effects of the display bezel, around half of the users purposefully aligned windows up with the seams in the display projections; another half did not appear to even notice the seams and laid their information right across them. Users had trouble remembering that they needed to click on a window to bring it into focus, even though it was open and not occluded (this was only true for some Office applications used in our tasks, such as Word and PowerPoint), and this reduced productivity slightly in the large display condition.

User Satisfaction. Users answered 4 user satisfaction questions after carrying out the 12 tasks on each display, and then provided us with their overall preference. The large display received significantly higher ratings on all questions at the p=.05 level, and was preferred by 14 out of 15 participants, significant via a binomial test. The user satisfaction data is shown in Table 1.

Satisfaction Question	**Avg. Rating—Large Display**	**Avg. Rating—Small Display**
The web and Office tasks were easy to perform on this computer.	4.4	3.4
I had some trouble managing multiple windows to perform the tasks.	1.9	3.3
It was hard to go back and forth between my various windows and applications.	1.8	2.9
I was satisfied with how easy was to lay out my windows and move between them.	4.5	2.9

Table 1. Average user satisfaction ratings after using each display for 12 tasks.

Representative User Comments:
User1: I would be far more productive at my job if I had a setup like this. I could see how I could save time by being able to see more full size application screens at the same time.

User 2: I do like having multiple screens open at once, with more room.

User 3: I love this screen; sign me up for beta testing!

User 4: It was nice to be able to have everything laid out in front of me. I like the large screen for that reason. it is easier to do multiple tasks. I would like to be able to sit back a distance from the screen.

User 5: It was much easier to use the large screen for multiple tasks. It made the job go much faster.

3.5 Discussion

This study demonstrated that there is a significant performance advantage to using very large, multiple monitor display surfaces while carrying out complex, cognitively loaded productivity tasks on the computer. Although we originally hypothesized a benefit, it is a somewhat controversial finding, given that our current graphical user interfaces (Windows in this case) are not optimally designed for navigating very large surfaces, and since the idea of "bringing windows into focus" is not as intuitive on larger screens, where windows may already be open and not occluded. We were intrigued by this finding, and wondered how much further we could push the benefits of larger displays with better task and window management support in the user interface, something our future research and UI designs will focus on. For instance, given a larger display surface, perhaps the Start Menu needs to be located wherever the user's focus of attention is. Likewise, important notifications may need to be presented closer to the user's focus as well. It is clear that the Task Bar should stretch across all the monitors, but it is not immediately obvious how the window "tile" representations in the Task Bar should align with their corresponding windows on the display surface (e.g., should tiles show up on the monitor where the corresponding window is open?). We believe, based on this study, that improvements to the cursor visualization are needed as the user travels longer display surface differences, enhancing the cursor's presence. Other novel input mechanisms, allowing the user to target various items on screen without large arm movements, are clearly needed. Finally, with as much display area as the Dsharp display provided, it may not be necessary to minimize windows into a bar on the edge of the screen. Larger amounts of screen real estate should allow users to leave larger, more meaningful representations of windows open for peripheral monitoring.

4 Conclusion

An initial study attempted to demonstrate that users are significantly more productive and more satisfied when carrying out complex, multiple window tasks across larger display surfaces. In the user study reported, users carried out multiple-step, cognitively loaded tasks on both a 15" and a 46.5" display (using triple projections). Users were significantly faster working on the large display. In addition, all but one participant preferred carrying out the tasks on the larger display surface, and user satisfaction measures were significantly better for the larger display. Despite these positive findings, it was clear that software could be better designed for multiple monitors, as a number of usability issues were observed. It is our intention to work to improve software user interface design for larger display surfaces, based on these observations.

We believe that this paper provides a contribution to the HCI community as one of the few descriptions of the magnitude of productivity benefits offered by a very large multimon display over a smaller display. We have also indicated a variety of user interface redesign ideas for the traditional GUI desktop that would better support large display surface users, including designs that leave windows layouts open and available to the user, and better cursor "travel" and visualization techniques. It is our intention to further refine our ideas and studies around these issues, including novel window and task management software UI ideas.

Despite these observations and ideas, much more needs to be known about the current state of productivity benefits from multiple monitors, especially for the more likely scenario of dual monitors. Other caveats to the current findings are that we did not examine collaborative work, nor work that is heavily oriented toward multitasking across several different projects. In addition, we did not explore differences in resolution or viewing distance in this study, as again we were primarily interested in a desktop-contiguous multimon configuration in comparison to a single monitor for single user office computing tasks. We intend to explore these alternative design questions and contexts in future studies.

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