Chapter 2: Literature Review

2.1 Introduction

Researching the use of multiple monitors with geospatial information is at the convergence of two fields: cartography and computer science. Both disciplines have pertinent studies that combine to provide ample background information for this work. First, there is a discussion of the limitations of single monitor displays, followed by an analysis of the implications of human visual fields. The various studies undertaken in cartographic research on visual search add insight on the possible results produced by larger display configurations. Next, computer science research contributes information concerning the rise of multiple monitors, their difference from projectors, and results from usability studies with both office computing tasks and geospatial tasks. Finally, the potential problems of working with multiple monitor displays are addressed.

2.2. Limitations of Single Monitor Displays for Maps and Imagery

Size is a basic element of map design regardless of the medium used. Map size, coverage, and scale are intrinsically related, and the specification of one element limits the available parameters for the others (Figure 1.1a). When map size is fixed, or when the viewing area is fixed as in the case of a desktop monitor, one must evaluate the tradeoff scenarios between coverage area and scale. If a larger coverage area is desired the scale must be reduced, or conversely, if a larger scale is desired the coverage area must be reduced (Lloyd and Bunch 2003). It is usually impossible to obtain desired size, coverage, and scale in one paper map or in one view on the computer screen.

To overcome the fixed size limitation of computer monitors, panning and zooming functions are essential for navigation (Slocum et al. 2005). These tools allow users to alternately capture desired coverage area and scale, providing the ability to quickly cycle back and forth between the two for comparison if they cannot be depicted in one view. Frequent panning and zooming, however, have implications on map perception. Panning around at a large scale creates a loss of context as the entire map cannot be viewed at once, where as zooming out to obtain the full context alters the scale and results in a loss of detail (Brown 1993) (Figure 1.1b).

While the quantity and quality of geospatial data and imagery have greatly increased, the windows to this world have remained relatively the same size. Users are left with a small view into an enormous virtual digital world (Czerwinski et al. 2006), catching only glimpses of large, high-resolution data.

2.3. Visual Fields and Implications for Large Displays

Although larger display sizes might be more useful for viewing maps and imagery, any benefits of their utility hinge on the user's ability to perceive and employ the larger display. Currently, display spaces for most users occupy 10% or less of their physical workspace (Czerwinski, et al. 2006). Considering a predominant number of work tasks are now performed on the computer, it is worthwhile to explore how users would function with displays that occupy larger proportions of their work areas.

Desktop monitors do not seem to take full advantage of our visual capabilities as they only cover approximately 10% of our fixed field of vision (Grudin 2001). The wide angle lens of the eye allows for 60 degrees of viewable area to either side of the focal point (MacEachren 1995), and therefore typical computer monitors ranging from 14" to 21" rarely make use of peripheral vision. It is possible that larger displays can reduce the conflict between map scale and coverage area while also covering a greater portion of our field of vision.

Large, high-resolution displays, however, provide such a dramatic increase in both physical size and resolution that the potential for detrimental effects or hindrances is equally possible. Perception research indicates limits to our information processing capabilities as the presentation of more complex information increases cognitive load, which effectively reduces our functional field of view (Williams 1982). However, Williams (1982) also noted that the functional field of view is not static; it varies depending upon task demand. Berg and Killian (1995) found that collegiate fast-pitch softball players had larger visual fields than non-athletes. The authors attributed this result to the subjects' extensive sport participation because other research had shown that training can affect visual field size. Individuals can be trained to enlarge their visual field in order to improve performance on tasks that demand substantial use of peripheral vision (Berg and Killian 1995). While larger displays could be detrimental due to the load of information they present, complexity also plays a major role in cognitive load and training could aid individuals to adapt to utilizing the increased display area.

Physical display size is not the only quality relating to vision and perception. Resolution is another aspect of multiple monitor displays associated with a user's ability to utilize the new display configuration. Ware (2004) explored the efficiency of displays by comparing the ratio between brain pixels (retinal ganglion cells that transmit retinal information to the brain) and screen pixels, with the ideal being a one-to-one ratio. With low-resolution displays, there are multiple brain pixels per screen pixel, so the brain is receiving redundant information. While a projector increases display size, the resolution of the display is not enhanced, and thus the larger image is not providing the brain with any new information. To enhance the effectiveness of larger displays, there should be a concurrent greater number of pixels so that more information is included in the display.

Understanding visual fields and their relationship to task performance also provides design implications to incorporate in display layouts. While difficult tasks have been shown to reduce visual fields by approximately 14%, they also change the shape of visual fields (Rantanen and Goldberg 1999). Increasing task load created a reduction of the vertical axis of the visual field, but less change horizontally. The results were visual fields that were horizontally elongated. This concept can be used to design displays by arranging features more horizontally than vertically on the display and configuring displays themselves to be wider than they are tall.

2.4. Cartographic Research on Visual Search and Visual Field Size

Although no cartographic research has handled multiple monitor displays as of yet, the field does provide complementary studies regarding the use of peripheral vision, extent of visual fields, and visual search techniques. These findings help to form hypotheses for how users might utilize maps and imagery on large, high-resolution displays. Some studies have addressed a minimum map size or visual angle necessary for clear understanding and information processing, but cartographic research has yet to specifically address increasingly larger map size implications or a maximum size threshold. Lloyd and Hodgson (2002) speculated about the implications of geographic scale on visual search, hypothesizing that small photographs may produce longer reaction times due to the detailed information to process, while large photographs may also create longer reaction times due to the eye movement necessary view the entire image.

Peripheral vision improves performance in map search tasks when the aperture through which an individual views the map is increased to encompass one's area of useful peripheral vision (AUPV) (Phillips 1981). Single monitors restrict use of peripheral vision as the bezels of the monitor restrict the user's viewing aperture. Larger displays can incorporate greater peripheral vision, potentially aiding the process of knowing where to look next on a map.

Research involving aerial photograph classification has also explored the idea of appropriate image size for viewing. Lloyd et al. (2002) had subjects categorize land use using different sizes of aerial photographs while scale was maintained. In this study, when the display area was increased, the coverage area increased as well, providing more information to viewers. Both accuracy and confidence increased with the use of larger photographs, leading to the conclusion that a reduction in scale or the concealing of neighboring information increases task difficulty. Pertaining to this research in particular, if users complete work at a certain scale, a larger display size is beneficial because it provides more information and context.

Many map reading studies incorporate eye fixation measurements to gauge processing time and visual search techniques. Unlike the research for this thesis in which the amount of information stays the same while only the display size increases, Dobson (1980) increased the density of information shown while simultaneously increasing the visual spread of information. By tracking eye fixations, Dobson found that the accuracy of responses decreased and processing time increased when information density and visual angle were greater. There were both more eye fixations and longer fixations with the high density, high angle condition. This result supports the previously mentioned visual research that found that more difficult tasks or complex displays can hinder vision and perception. Perhaps the most pertinent previous research for this thesis topic is the oldest study in this literature review. Enoch (1959) directly explored the relationship between display (aerial map) size and map tasks. He found that eye fixations were centrally concentrated and thus objects located near the edge of a map or display were less likely to be discovered. This assertion is supported by more recent research confirming faster target acquisition when targets are located centrally on a map (Lloyd 1997). This indicates possible pitfalls of larger displays, as information located peripherally may be overlooked. In a follow-up study to Enoch's work, Wood (1993) found that the number of eye fixations increased as image size increased. Wood (1993) also noted that the proportion of fixations falling within the image increased with image size, concluding that larger maps make better use of eye fixations since more fixations fall within the area where information is being presented. However, although their research generated many implications for large map displays, Enoch (1959) and Wood (1993) both focused on the small end of the map size spectrum, making recommendations for minimum map sizes to be used for presenting information, but not pursuing a maximum size recommendation.

2.5 Computer Science Research with Large Displays

2.5.1 Introduction

Large display research is a recent development in the discipline of computer science. Researchers specializing in human-computer interaction are seeking out new visualization opportunities through different hardware and software configurations. Studies have progressed from simply comparing different sizes of computer monitors and using standard projectors to multiple monitor configurations and tiled rear-projection displays. The goal of computer science research is twofold: 1) determining the hardware and software requirements needed to construct such displays (Li et al. 2000; Wei et al. 2000), and 2) studying user interaction and performance with the displays as discussed below.

2.5.2 Larger Monitors and Projectors

Initial studies within computer science based on display size and task performance did not involve multiple monitors. Simmons (2001) compared performance of office computing tasks on individual monitors ranging from 15” to 21” in size. Results revealed enhanced productivity on 21” monitors for tasks involving large database searches. Another study conducted by Tan et al. (2003) found that spatial orientation task performance using a wall display was 26% better than task performance on a desktop monitor, even with the visual angle maintained between both conditions. This improvement came solely from an increase in display size as resolution was unchanged. These findings provide extra motivation for exploring large, high resolution display options because improvement already occurs with small display increases (Simmons 2001) and with display area increases without resolution increases (Tan et al. 2003).

2.5.3 Progression to Multiple Monitor Displays

To make research as widely applicable as possible, the display types utilized need to be affordable and attainable for a wider audience. Acquiring a single, large, high-resolution monitor is both extremely expensive and difficult to find since most monitors or display screens are either small and high-resolution or large with low-resolution. Computer design trends, however, have provided a way around this expensive and difficult road block. First, several computer operating systems support working with multiple displays and advancements in graphics cards supports this ability as well (Czerwinski et al. 2003). In addition, thin, flat screen liquid crystal displays (LCDs) with small footprints are replacing previously bulky desktop monitors and LCD prices are predicted to drop continuously. Already it is estimated that the average consumer can acquire 25% more pixels for the same price by buying two 17” LCDs instead of purchasing just one 21” LCD (Czerwinski et al. 2006). With this price trend and the fact that even laptop computers now also support multiple displays (Czerwinski et al. 2003), the use of multiple monitor displays will likely grow in the future. Already large displays are enjoying more widespread use in homes, public places, and office spaces (Hutchings et al. 2004a).

2.5.4 Difference from Projectors

It is important to stress the difference between using multiple monitors to increase display space versus using a projector. The major component difference between the two is not just size, but also resolution. A projector takes the resolution of the computer screen, for example 1280 by 1024 pixels, and casts that image and its original resolution over a larger space. While the initial version of the image on the computer may be 17” diagonally with a resolution of 1280 x 1024, the diagonal of the projected image may be 3 times greater or more, but the resolution remains unchanged. Multiple monitor designs increase both size and resolution of the display. Again, the initial image on one monitor may be 17” diagonally and 1280 x 1024 pixels, but the same image on a 9 monitor display (3 x 3 configuration) would be 51” diagonally with the resolution increased to 3840 x 3072 pixels. With the increase in resolution, high-quality imagery can be examined up close on the multiple monitor display without losing detail or encountering heavy pixilation as you would on a projected image (Bezerianos and Balakrishnan 2005a).

2.5.5 Multiple Monitor Research with Non-Geospatial Tasks

A large portion of multiple monitor research has logically focused on typical office computing tasks such as email, word processing, writing code, computer-aided design (CAD), and formatting presentations, undertaken by most users as part of their everyday work routine. Grudin (2001) conducted research using two and three monitor configurations used by participants in their workplaces over an extended period of time. Bezels were found to be used as dividers for multiple applications, separating primary tasks from supporting tasks, with users rarely placing windows across two monitors. This differs from this research in which additional monitors will be used for enlarging a single application. In general, users preferred the multiple monitor designs and the ability to have more active windows visible. Another longitudinal study that monitored users' typical computing activity focused on window visibility and use of display space (Hutching et al. 2004b). Over three weeks, these researchers found that large multiple monitor users averaged 6.8 visible windows at a time while single monitor users averaged only 3.5. Concerning the use of display space, single monitors had no available empty space 48% of the time while large multiple monitors were entirely full only 14.3% of the time. This suggests that single monitor users are pressed for space while multiple monitor displays provide free screen space more often. Additionally, 80.8% of the time, the large multiple monitor arrangements had less than one-fifth of display space empty; although users had the large multiple monitor displays full less often than single monitor displays, they were using a vast majority of the display space most of the time. Despite the obvious drawback of monitor bezels interrupting the display space, this visual discontinuity does not always hinder results. Tan and Czerwinski (2003) found that subjects' performance of proofreading and monitoring tasks using a two monitor display were not hindered by the central bezels and half of the participants indicated a preference toward placing their tasks across the bezels.

Using increasingly larger displays for controlled experiments provided further insight into user behavior and performance. Czerwinski et al. (2003) compared task performance on a 15" flat panel displays versus a 15" x 42" wide curved display produced by 3 projectors. Although this study was not specifically with multiple monitors, it did provide interesting large display usage results. Concerning productivity, task completion was significantly faster on larger displays despite the unsuitability of the graphical user interface for the larger configuration (Czerwinski et al. 2003). Ball & North (2005a) incorporated a larger 3 x 3 monitor configuration (17" monitors with 3840 x 3072 pixels) and argued that greater concentration is maintained with large, high-resolution displays because less virtual navigation is required. This finding is a key advantage in relation to the use of such displays for viewing maps because users can maintain a more stable sense of the overall context, especially if there is specifically less panning and zooming. However, in additional work, Ball and North (2005b) noted that larger displays require more physical navigation. High-resolution displays were found to be particularly effective in improving performance times in search and comparison tasks of relatively smaller targets (Ball and North 2005b), which may contribute to increased efficiency in analyzing digital imagery sources that involve fine detail.

2.5.6 Multiple Monitors and Map Reading

Since large display research falls into the domain of computer science, research with maps and geospatial information has not been heavily pursued. The increasing prominence of GIS and use of aerial photography has increased interest for such uses on large displays has increased. Ball et al. (2005) used a map-based experiment to evaluate navigational performance. Results showed that users of a 3 x 3 monitor configuration (17" monitors, 3840 x 3024 pixels) vastly outperformed those on a single monitor. On the multiple monitor display, search and route tracing tasks were performed twice as fast with 70% fewer mouse clicks and 90% less window management (Ball et al. 2005). While these most recent studies have been done utilizing maps, the experiments were designed from a human-computer interaction perspective, leaving the implications specific to map reading and cartography relatively neglected.

2.5.7 Potential Problems with Using Multiple Monitors

When making the switch from working on a single display to utilizing the same software and hardware for multiple displays, users can encounter a number of problems including, but not limited to: losing track of the mouse cursor, image distortion due to bezels, accessing information on distant portions of the display, managing windows, and configuration problems (Czerwinski et al. 2006). Such difficulties can be expected during the initial switch to a new display technology format, but they are unlikely to remain as permanent problems as researchers develop tools specifically for multiple monitors. For example, for the problem of losing the mouse cursor on large displays, new mouse designs can be suited specifically for multiple monitors to overcome current user issues (Benko and Feiner 2005; Bezerianos and Balakrishnan 2005b; Robertson et al. 2005). Bezel issues are avoided by making screens seam-aware (bezel locations taken into account) to avoid image misalignment (Mackinlay and Heer 2004). Software is also under development that can aid window and task management, making both more efficient on large displays (Robertson et al. 2005). While user problems with large, multiple monitor displays are an issue for this research at this point in time, future development and implementation of tools and software designed specifically for multiple monitors will make these problems less significant.

2.6 Summary

Although the use of multiple monitor configurations with geospatial information is a relatively new development, there is a wealth of pertinent previous research from cartography and computer science. The work in these fields has revealed the limitations of single monitor displays, the capacity of human vision and visual search techniques, and the usability of multiple monitor displays for work performance. This research builds an excellent foundation for understanding the possible benefits of large, high-resolution displays for geospatial tasks, as well as potential problems of working with multiple monitor systems.

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