EVALUATING THE BENEFITS OF TILED DISPLAYS FOR NAVIGATING MAPS

Robert Ball, Michael Varghese, Bill Carstensen*, E. Dana Cox, Chris Fierer, Matthew Peterson, and Chris North
Department of Computer Science
Department of Geography*
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061
email: {rgb6,north}@vt.edu

ABSTRACT
Maps are used by almost everyone in society during the course of their lives. However, when maps are used with computers they are almost always used with small, low pixel count displays, such as desktop monitors. We performed two experiments involving map usage with various tiled display configurations (one monitor, four monitors, and nine monitors). The first experiment focused on basic map navigation tasks and the second experiment focused on how to maximize the effectiveness of the details-on-demand interactive technique with large, high pixel count displays. We conclusively found from the experiments that finding objects and route tracing in maps was performed on average twice as fast on the nine monitors as the one monitor. We also found that participants on the nine monitor configuration had 70% less mouse clicks, 90% less window management, and a general accuracy and performance improvement over the one monitor. This indicates improved insight for large, high pixel count displays.

KEY WORDS
high resolution, maps, navigation, usability

1 Introduction

In everyday life almost everyone in all aspects of society uses maps during their lives. However, when using maps with computers most people use conventional monitors with limited physical size and pixel count.

The motivation behind this experiment comes from evaluating the effectiveness of using large, high pixel count displays when navigating maps. Essentially, our research questions were:

- Does the use of large, high pixel count displays help navigate maps more efficiently?
- Can the higher pixel count that comes with tiled displays be used to improve performance with navigation techniques such as details-on-demand?

To answer our research questions we conducted two experiments involving large, high pixel count displays with maps. For each of the two experiments we used three monitor configurations: one, four, and nine tiled monitors. Figure 1 shows a person using the tiled display. The two experiments we used were: Navigating large maps and using details-on-demand for strategic planning.

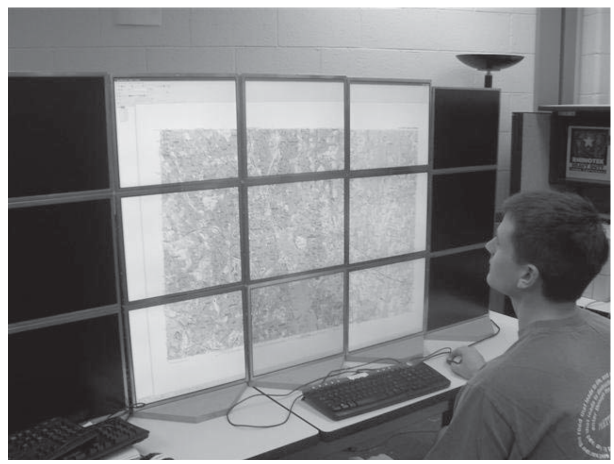

Figure 1. Example of navigating a large map on nine tiled monitors at a resolution of 3840x3072.

This paper is based on the results from Ball and North [3] which show that higher pixel counts positively affects basic navigation tasks with a static view. They show that people do not always perform better at higher pixels counts. Using one, four, and nine monitor configurations, they showed that if the target size is large enough people can zoom out to get an adequate overview of the visualization. However, they show that as the target size gets smaller users are not able to use zoom to get an adequate overview, thus necessitating a more detailed view. As the target size gets smaller, larger pixel count (the more monitors used) causes better performance.

However, where their study had images that were the same size as their largest display, our first experiment used a map that was 50% larger than the largest display. For our second experiment we used a map that could be used at a variety of pixel counts. The second experiment only had tasks directed towards the overview of a map, therefore, it used a ”best-fit” overview for each monitor configuration without the need to zoom.

Ball and North’s results also were dependent on non-optimal image viewing software. using basic pan and zoom techniques. As a result we used top of the line GIS software that has much better navigation techniques.

We wanted to know if other navigation techniques besides pan and zoom allowed for similar increases in performance. We chose a details-on-demand navigation technique as details-on-demand is fundamentally different from the pan and zoom technique. Our first experiment involved using maps for normal, everyday use. Tasks used in the experiment were routine tasks that people may encounter during their lives dealing with maps.

Our second experiment was directed more at strategic planning. Using a details-on-demand interactive technique it focused more on military, strategic planning. The purpose of the second experiment was to evaluate the effectiveness of details-on-demand for large, high pixel count displays and to test whether higher pixel counts can be used more effectively with details-on-demand.

2 Previous Work

Different studies have been performed on large screens and multiple screens to compare their effectiveness to that of small or single screens. As mentioned above, the paper that most relate to this work is from Ball and North [3]. Other papers include generally usability of high pixel count displays from Ball [2] and Czerwinksi [7]. Another similar paper which focuses on dynamic real-time maps and high pixel count displays from Ball is [4].

Several studies have suggested that the increase of the physical size of a screen helps with memory. Lin, et al. [10] suggests that an increase of one’s field of view increases one’s sense of presence and memory. Tan, et al. [17] also show how retention can be increased by using extra screen space to display different images in the user’s peripheral to help recall more from a particular task session.

Tan et al. show how performance on a large screen can be better than a conventional screen even at the same resolution. They show that with the same visual angle participants in a study were able to perform better on a large screen compared to a single monitor for both spatial performance [15] and 3D virtual navigation [16]. Large low pixel count screens have the problem that they can only show the same amount of data as small screens because they tend to have similar resolutions. As a result, what occurs is that the data on the screen is simply enlarged.

Some studies have also shown that gender can have an affect with spatial performance with screens. Some recent studies by Czerwinksi, Tan, and Robertson show that the affects of an increase of field of view can offset the gender bias [8] [14]. Their findings point that women need a wider field of view than men to achieve the same performance. Other related studies have focused more on characterizing any benefits that one might receive from larger screens. These studies tend to focus on multi-tasking using current applications.

In a unique study, Baudisch et al. [5] performed an experiment studying the affects of having a high resolution screen embedded in a low resolution screen. In effect, they created a focus plus context screen without any distortion. They conclusively showed that participants were able to perform better using their high/low resolution screen than on a standard monitor.

A few interaction techniques developed on multiple displays include pen-based approachs[9], mouse-based approaches [12][6], and head-tracking approaches [11].

3 Hardware Used

We assembled nine monitors that all run off one computer. We used a Dell Optiplex GX270 at 2.66 GHz with 2 GB of ram running Windows XP. By using plug and play video cards and monitors we were able to create a 3x3 matrix of monitors with minimal effort. We also removed the plastic bezels that surrounds each monitor to reduce the distance between monitors.

Figure 2. The monitor configurations were one, four, or nine monitors with a resolution of 1280x1024, 2560x2048, and 3840x3072 respectively.

Figure 2 shows three different monitor configurations used with the experiments. The pixel count varied in that the one monitor had a resolution of 1280x1024, four monitors had a total resolution of 2560x2048, and nine monitors had a total resolution of 3840x3072.

3.1 Participants

All volunteers for the two experiments were screened prior to participation. All participants were required to have normal to corrected-normal vision, no color blindness, no familiarity with traveling/navigating through the state of Rhode Island (all maps used were from the state of Rhode Island), and no prior experience with large displays.

All participants were undergraduate students between the ages of 18 and 24. For the navigating large maps experiment twenty-four people participated. They were all male computer science undergraduate students who received extra credit for their participation. For the details-on-demand strategic planning experiment thirty-six participants were used. Twelve participants were female and twenty-four were male. Participants were 78% undergraduate computer science or computer engineering majors while the rest was a mix of different types of undergraduate majors. Sixty-six percent of the participants did the strategic planning experiment for extra credit.

4 Navigating Large Maps

Maps are used for a variety of reasons. More common usages include route tracing to more complex tasks such as deciding where building should be erected. As a result, our tasks included six different tasks:

- Three find tasks (e.g. Find Brown University on the map)
- Two route tracing tasks (e.g. Find the shortest path between two locations)
- Two counting tasks (e.g. Count how many bodies of water are named)
- Five comparison tasks (e.g. Which destination is closest)
- Three intermediate tasks (e.g. Find the deepest water in Providence River)
- Four advanced understanding task (e.g. Why is this area not developed?)

Each participant performed the set of tasks on the same map with only one of the monitor configurations (between-subject design). All participants used the same map of Providence, Rhode Island. Performance time and accuracy were recorded as the dependent variables. Each participant was randomly assigned to a monitor configuration.

Each participant was given a brief five to ten minute tutorial on how the software worked using a map of Roanoke, Virginia prior to the actual experiment. The tutorial taught the user how to use the different navigation features of the software.

4.1 Navigation Techniques

For this experiment, we used pan and zoom as our interactive technique. The software that participants used to navigate around the map was ArcView: a full-featured GIS software program for visualizing geographical data by Environmental Systems Research Institute (ESRI). Participants were filtered to ensure no prior experience using ArcView previous to the experiment.

ArcView allows users to navigate images using a range of tools. Zooming and panning in ArcView is similar to Adobe Acrobat's navigation features. Participants were able to transfer knowledge learned from using Acrobat to ArcView's pan and zoom techniques as they are fundamentally the same.

Zooming is performed by zooming in or out at specific locations by using a cursor that looks like a magnifying glass. The area that one clicks to zoom in or out is centered in the user's view and zoomed in or out. ArcView also employs a bounding box zooming technique. Panning is performed by placing a cursor of a hand on the map and "moving" the map around as one does a piece of paper on one's desk without picking it up. A best-fit feature was also used during the experiment. The best-fit button changes the view of the map to show the full overview of the map.

4.2 Large Map Quantitative Results

All statistical analyzes for this paper were performed in SAS's JMP using standard ANOVA techniques.

The finding and route tracing tasks were statistically significant. The find tasks showed statistical significant ($p = 0.0077$) with differences between the one and four monitor configuration and between the one and nine monitor configurations. Looking at figure 3 one can see that the finding task was performed more than twice as fast on the nine to the one monitor configuration.

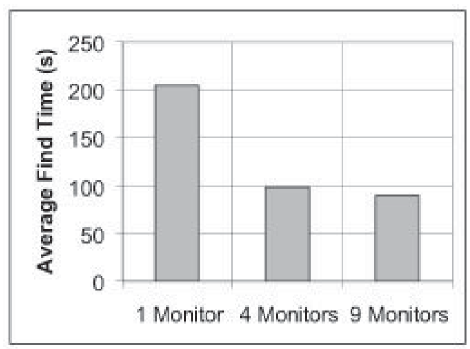

Figure 3. Average time in seconds for a participant to find a particular object or location on the map at different monitor configuration sizes.

The route tracing tasks was also statistically significant ($p = 0.0070$) with differences between participants using one monitor compared to nine monitors. Participants were instructed to trace a route from a source location to a destination location. Once again, the nine monitor configuration was more than twice as fast as the one monitor configuration. Figure 4 shows the same trends as figure 3; participants were able to trace routes more than twice as fast on the nine monitor configuration compared to the one monitor configuration.

One reason for the increase in performance times would be the fact that participants on the larger monitor configurations navigated less with the map. In effect, as participants could see more of the map at a time, less navigation was required and consequently more time could be spent on the task at hand.

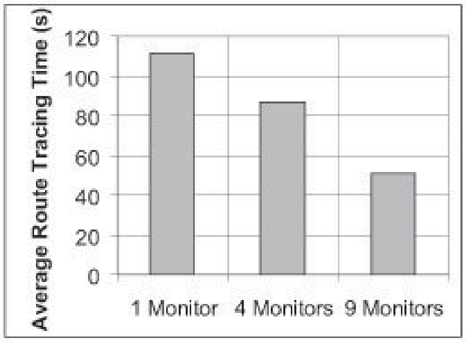

Figure 4. Average time in seconds for a participant to trace a route on the map at different monitor configuration sizes.

The counting, comparison, intermediate and advanced tasks were not statistically significant. One reason for this could be that the participants used were not map experts. The participants used generally only had experience with route tracing and finding tasks with maps.

4.3 Large Map Qualitative Results

Several interesting things were observed among the participants. Only the most common ones are reported here.

Although bezels are generally considered a distraction, we observed that participants used bezels to their advantage. A bezel is the border between monitors. A bezel is the limiting factor of how close two monitors can be together. When using the four and nine monitors participants would use the bezels to segregate the map into portions. By dividing the map into parts they were able to better keep track of which part of they map they had previously searched.

Similar to [3], we observed that participants did not in general like to zoom in. If possible, participants would use the bounding box zoom rectangle to clip out all unnecessary parts of the map for the task. Then participants would often squint at the overview to try to gain as much detail as possible without having to actually zoom in any further and lose context of the entire overview.

This was especially noticeable with the route tracing task. Participants using nine monitors were able to see more detail from the best-fit view than participants using one or four monitors and rarely zoomed in. However, they were able to see enough detail to complete the task correctly. On the other hand, with the four monitor configuration, participants often thought that they could see enough detail and would report a less efficient route. On the one monitor configuration, participants could not see enough detail in the overview and had to zoom in.

We also observed that on the one and four monitor configurations people were more algorithmic in their approach to finding objects. As explained, on the nine monitor configuration participants rarely zoomed in. So, for the find tasks (and other similar tasks) participants on the nine monitor configuration would use more intelligent heuristics to finding an object. For example, instead of searching the entire map for a university, as did participants on the one and four monitor configurations, the participants on the nine monitor configuration wold search logical areas, such as dense city areas or other areas that a university would logically be located. This might give indication of increased insight into the overall map [13]. By having a higher pixel count, participants were able to get a more accurate mental model of the map.

Also, in general, we concur with [3] that the larger the monitor configuration the less virtual navigation (mouse moves) and more physical navigation (eye saccades, head movement, etc.) was used.

5 Details-on-Demand Strategic Planning

The main motivation for our details-on-demand experiment was to evaluate the results of [3] on a interactive technique that is distinctly different from pan and zoom for performance increases on large, high pixel count displays.

Another motivation for this experiment was to see if the additional pixels could be used to increase the usability of the application by adding additional details to the overview.

There were two different versions of the experiment. The first version of the experiment did not display any details on the icon, just an image of soldiers (see figure 5). The second version included displaying a team icon with aggregated details about the team on the icon.

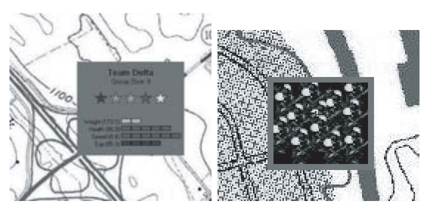

Figure 5. a) Example of an icon with details in the overview for the nine monitor configuration. b) Example of an icon without details in the overview.

As a scenario we presumed that the first version of the experiment had been created for the use of a single monitor. The first version did not have any details on the icon because it is hard to have an icon that is both small enough for the underlying map to be usable and have readable details on the icon itself. The second version was created with the intent of changing the first version to take advantage of the extra pixels that come with tiled displays.

The amount of detail on the icon displayed in the second version was dependent on the monitor configuration size. While maintaining the same area of the map, icons that had more pixels had more details on them. This is idea is shown in figure 6. Figure 6 shows how the icons in the left image take up as much area as on the right image even though the left image is a screen shot of the nine monitor configuration and the right image is a screen shot of the one monitor configuration.

Figure 6. a) Screenshot from the nine monitor configuration. b) Screenshot from the one monitor configuration. Both screenshots have been shrunk to show that the icons take up the same area in the map. The screenshots are not proportional to each other.

The reasoning behind this design decision was based on the fact that more pixels were available for each icon at larger monitor configurations. By keeping the size of the icon to the size of the map ratio the same (the same area), the larger the monitor configuration, the more room was available for aggregated details in the overview. For example, if the icon had aggregated details in the one monitor configuration then the icon space available was small and we only displayed the team's name. On the nine monitor configuration the icon took up the same amount of space of the map, but as the map was stretched out the icon itself was larger and had more room for more aggregated details in the overview.

Figure 5 shows two images of icons. The image on the left shows the icon as it appeared with aggregated details on the icon for the nine monitor configuration (the second version). The image on the right shows an icon without the aggregated details (the first version).

5.1 Experiment Setup

The experiment consisted of displaying a map with multiple army teams located across the map. The team locations were represented by a team icon, with the lower left hand corner representing the team's exact location. A left click on a team icon displayed a popup window about the team and their statistics (see figure 7). A range of team information was displayed within the window (e.g. team name and average health). Listed with each soldier's name was their respective job and personal statistics. The window was resizable and movable.

Participants were told that they were to act as a general in an army to decide which team should be used for an ensuing battle. Participants had a range of tasks which included different types of analysis. The following list shows the different types of tasks:

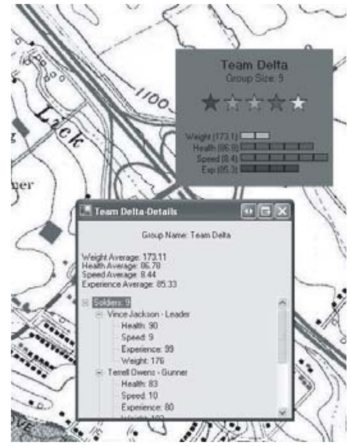

Figure 7. Example of an icon with detail in the overview with an associated popup window showing details.

1. Details only: Find the weakest soldier. This task entailed looking at the details of every soldier. The aggregated details did not help in this task.

2. Overall statistics of teams: Find the team with the strongest overall statistics.

3. Map only: Find the team with the best geographic location in reference to the attack point.

4. Map and overall statistics of teams: Find which team is the *best* to attack with based on the best geographic location and statistics.

5. Map and overall statistics of teams: Find which team is the *worst* to attack with based on the worst geographic location and statistics.

In this experiment we used three different monitor configurations as the first experiment (one, four, and nine tiled monitors). However, we used a within-subject design so that every participant used every monitor configuration. However, participants only used one version of the experiment (with or without aggregated details) for a between-subject design. We used two Latin Square designs (one for each of the two versions) for counter balancing. To get an equal distribution of gender, we used six females and twelve males for both versions of the experiment.

We also used three different scenarios each with a different map. We did this so that participants would not become overly familiar with a single map. All scenarios were performed in the same order.

In summary, our independent variables were:

- Monitor configurations (one, four, or nine monitors)
- With or without aggregated details in the overview
- Map (three different maps from Rhode Island)

Our dependent variables were: amount of virtual navigation (clicks, moves, and resizes), performance time, and accuracy.

A ten minute tutorial was given to the participant about how to use the application in order to baseline the participants.

5.2 Software Used

The details-on-demand strategic planning experiment was developed using C# in a Visual Studio.NET environment with Microsoft Access as a backend. All participant moves, resizes, and clicks were tracked and recorded by the application.

In order to change scenarios and enable or disable monitors quickly UltraMon [1] was used. UltraMon is an application that works with Windows that allows for custom scripts to change the desktop and monitor configurations.

5.3 Virtual Navigation Quantitative Results

By recording mouse events of each participant, we were able to track how much virtual navigation took place. As mentioned above, we used JMP to perform standard ANOVA analyses of our data.

We found that the monitor configuration size statistically correlated to the number of mouse clicks ($p < 0.001$). We also found that our independent variable of with or without aggregated details also correlated to mouse clicks ($p = 0.003$). We tested for an interaction effect and for multicollinearity and did not find either.

Looking at figure 8 one can see that participants on the nine monitor configuration clicked on average 70% less than on the one monitor configuration. Also, participants that had aggregated details in the overview clicked 15% less than participants that did not have the extra details.

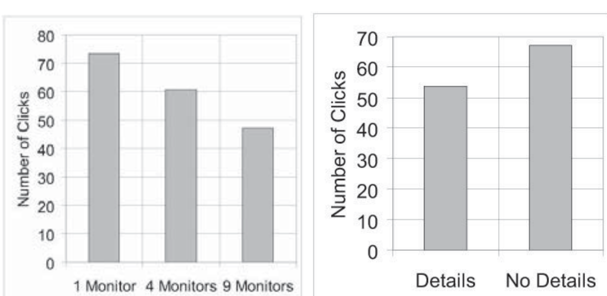

Figure 8. a) Chart showing the trend of number of clicks decreasing as monitor configuration increases. b) Chart showing how the number of clicks was less with icons that had aggregated details.

We found similar results with window moves (i.e. window management). Participants often moved the popup window (see figure 7) for a number of reasons: move windows closer to compare different team statistics, move a window to see the underlying map, etc. We found that the monitor configuration size statistically correlated to the number of mouse moves ($p = 0.0509$) as did the aggregated details variable ($p = 0.0572$). Again we tested for an interaction effect and for multicollinearity and did not find either.

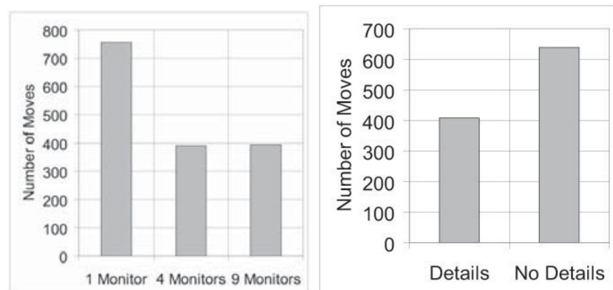

Figure 9. a) Chart showing the trend of number of window moves corresponding to the monitor configurations. b) Chart showing how the number of window moves was less with icons that had aggregated details.

Figure 9 shows that the number of window moves was approximately equal for the four and nine monitor configurations. However, the four and nine monitor configurations moved windows approximately 90% less than the one monitor configuration. We also found that participants that used the aggregated details in the overview moved windows 60% less than than participants that did not used the aggregated details in the overview.

This data objectively supports many of the subjective finding in [2] that shows that people perform less window management with higher pixel counts. Also, the implications of this decrease in navigation means that people can use tiled displays to help them perform less navigation and focus more on the tasks they want to accomplish.

5.4 Performance and Accuracy Quantitative Results

As explained earlier there were five different tasks that each participant performed. As expected, the first task that was based solely on details and the third task that was based solely on geospatial location with respect to the map did not have statistical significance.

However, the second task which asked about overall statistics had an interactive effect between monitor configuration size and the details variable ($p = 0.04$). This is logical as the larger the display the more aggregated details were provided. The fourth task, finding the team with the best overall statistics and geospatial location had similar results as the second task with an interactive effect ($p = 0.002$).

Figure 10 shows the average time to complete the second task did not vary much for the non-details ver-

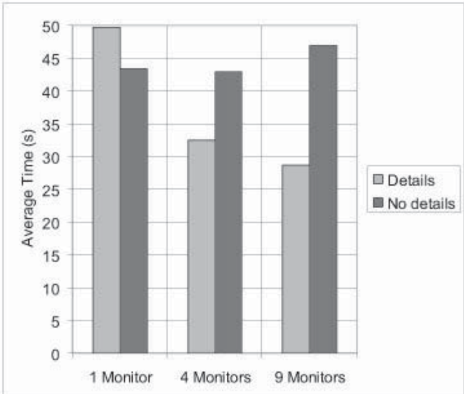

Figure 10. Chart showing general trends for finding the team with the best statistics.

sion of the experiment as the monitor configuration size increased. However, for the details version, as more details were added as each monitor configuration size afforded more pixels, the task performance was improved. For the aggregated details version of the experiment, participants performed 57% faster on the nine monitor configuration compared to the one monitor configuration.

The last task, finding the worst team with overall statistics and geospatial location had more variance. We did not find an interactive effect, nor statistical significance for monitor configuration size. The aggregated details variable was not statistically significant using the standard alpha of 0.05, but had a p of 0.069.

Accuracy was found to be statistically correlated to the aggregated details variable ($p = 0.0115$), but not to the monitor configuration size. Participants who used the details version of the experiment totaled 47 incorrect answers, while participants who used the non-details version, totaled 74 incorrect answers.

Our hypothesis for the difference in accuracy is attributed to the aggregation of the details. Participants were able to get a better overview of a team by looking at the aggregated details than by aggregating the details themselves.

The implications of this trend of greater performance and accuracy where more details could be shown on larger monitor configurations indicate improved insight and understanding of the task at hand.

5.5 Qualitative Results

Window management was a major issue between the different monitor configurations that participants were confronted with. When participants were given more monitors to work with, they did not necessarily use it to their advantage. Many participants during the study would move their windows to different locations. One common technique participants used on larger monitor configurations is putting all team windows together on the same monitor. This helped participants read through the information in one area. This method of clustering windows together was consistently seen as participants were given more monitors.

Another important window management technique that was observed was the idea of closing windows. As the number of monitors decreased, participants would spend more time closing windows, in order to see the underlying map. On the one monitor configuration, participants would generally close all windows before starting a new task. On the other hand, on the nine monitor configuration, participants would leave windows open.

Figure 6 shows much of the screen the popup windows used on the different monitor configurations. The left image shows the amount of room that the windows take up on the nine monitor configuration while the image on the right shows the amount or room that the windows take up on the one monitor configuration. One can see that with the nine monitor configuration the majority of the underlying map can be seen while most of the map is hidden by windows in the one monitor configuration.

A map reading error that participants often made was focusing on a specific area of the map and not observing other areas. This was especially prevalent on the nine-monitor configuration where participants would focus their attention on where most teams were and not analyze teams that were farther away. For example, if four teams were situated near each other, participants might only focus on those four teams and not on the other teams on the opposite side of the display.

Participant's responses indicate that participant preference for monitor configuration size was split. We found that 15 of the 36 participants preferred the four monitor configuration. The four-monitor configuration provides somewhat of a threshold where participants can perform better than the one-monitor configuration without the overwhelming setup of nine monitors. Sixteen participants preferred the nine-monitor configuration. Participants cited the novelty of the nine-monitor configuration as the reason for their preference. Three participants preferred the one-monitor configuration. Their reasoning was that the larger-configurations were overwhelming. The remaining two participants had no preference.

6 Conclusion

During the course of our study we performed two different tasks: navigating large map with pan and zoom and strategic planning with detail-on-demand. We found a number of benefits for the nine monitor configuration compared to the one monitor configurations which include:

- Finding objects twice as fast
- Performing route tracing twice as fast
- 70% less mouse clicks
- 90% less windows management

With our details-on-demand strategic planning experiment we found that having more pixels allowed us to put aggregated details in the overview even with keeping the same ratio of icon size to map size (i.e. the icon used the same ratio of space on each monitor configuration). By putting aggregated details into the overview participants not only performed faster but 73% more accurately.

Overall, improved performance on geospatial interpretive tasks indicates that the large, high pixel count displays can improve insight and understanding into the data.

7 Future Work

We plan on expanding our study by looking at the following factors: Expert map users such as cartographers; increasing pixel count to very large tiled displays; increasing pixel density (such as IBM's T221-DG5 - 9.2 million pixels in a 22 inch monitor; other navigation techniques such as overview and detail or focus plus context.

8 Acknowledgements

This research is partially supported by the National Science Foundation grant #CNS-04-23611. This study was also supported and monitored by the Advanced Research and Development Activity (ARDA) and the National Geospatial-Intelligence Agency (NGA) under Contract Number HM1582-05-1-2001. The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official US Department of Defense position, policy, or decision, unless so designated by other official documentation.

References

[1] Ultramon. http://www.realtimesoft.com/ultramon/.

[2] Robert Ball and Chris North. An analysis of user behavior on high-resolution tiled displays. In *Interact '05*, 2005.

[3] Robert Ball and Chris North. Effects of tiled high-resolution display on basic visualization and navigation tasks. In *Extended abstracts of CHI '05*, pages 1196–1199, 2005.

[4] Robert Ball and Chris North. Tracking user navigation and performance on high-resolution displays using a dynamic real-time strategy game. In *Submitted to Infovis '05*, 2005.

[5] Patrick Baudisch, N. Good, V. Bellotti, and P. Schraedley. Keeping things in context: a comparative evaluation of focus plus context screens, overviews, and zooming. In *Proceedings of CHI '02*, pages 259–266. ACM, 2002.

[6] Hrvoje Benko and Steven Feiner. Mutli-monitor mouse. In *Extended abstracts of CHI '05*, pages 1208–1211, 2005.

[7] Mary Czerwinski, G. Smith, T. Regan, B. Meyers, George Robertson, and G. Starkweather. Toward characterizing the productivity benefits of very large displays. In *Proceedings of Interact 2003*, 2003.

[8] Mary Czerwinski, M. Tan, and George Robertson. Women take a wider view. In *Proceedings of CHI '02*, pages 195–201, 2003.

[9] F. Guimbretire, M. Stone, and T. Winograd. Fluid interaction with high-resolution wall-size displays. In *Proceedings of UIST 2001*, pages 21–30. ACM, 2001.

[10] J. Lin, H. Duh, D. Parker, H. Abi-Rached, and T. Furness. Effects of view on presence enjoyment, memory, and simulator sickness in a virtual environment. In *Proceedings of IEEE Virtual Reality*, 2002.

[11] Kenji Oka Mark Ashdown and Yoichi Sato. Mouse ether: Accelerating the acquisition of targets across multi-monitor displays. In *Extended abstracts of CHI '05*, pages 1180–1191, 2005.

[12] K. Hinckley Patrick Baudisch, E. Cutrell and R. Gruen. Combining head tracking and mouse input for a gui on multiple monitors. In *extended abstracts of CHI '04*, pages 1379–1382, 2004.

[13] Purvi Saraiya, Chris North, and Karen Duca. An insight based methodology for evaluating bionformatics visualization. *IEEE Transactions on Visualizations and Computer Graphics*, 11(4), July/August 2005.

[14] Desney Tan, Mary Czerwinski, and George Robertson. Women go with the (optical) flow. In *Proceedings of CHI '03*, pages 209–215, 2003.

[15] Desney Tan, D. Gergle, and P. Scupelli. With similar visual angles, larger display improve spatial performance. In *Proc. of CHI '03*, pages 217–224, 2003.

[16] Desney Tan, D. Gergle, and P. Scupelli. Physically large displays improve path integration in 3d virtual navigation tasks. In *Proceedings of CHI '04*, pages 439–446, 2004.

[17] Desney Tan, J. Stefanucci, D. Proffitt, R. D. Pausch, Gergle, and P. Scupelli. The infocockpit: providing location and place to aid human memory. In *Proceedings of PUI '01*, pages 1–4, 2001.