Sizing Up Visualizations: Effects of Display Size in Focus+Context, Overview+Detail, and Zooming Interfaces

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ABSTRACT
Whereas the literature is clear on the benefits of large displays and visualizations, little is known about their combination, that is, how display size affect the usability of visualizations. We describe a controlled experiment where 19 participants used focus+context, overview+detail, and zooming techniques with varying display sizes (13.8, 1.5, and 0.17 megapixels). Participants navigated geographical maps to find specific locations, compare items, and follow routes. Results show that for multi-scale navigation, classic interactive visualization techniques did not benefit from being scaled to a large display: In contrast to the literature we find similar performance on medium and large displays. Across display sizes, overview+detail works the best, in particular for comparing items. Focus+context is relatively more difficult to use at a small display size. We explain these findings and discuss the design of interactive visualization techniques for large displays.

Author Keywords
Large high-resolution displays, information visualization, multi-scale navigation, user study.

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

INTRODUCTION
Interactive visualization techniques aim to help users navigate large information spaces that do not fit within the display. However, their usability has mostly been investigated for a narrow range of display size (roughly corresponding to Figure 1, b). Meanwhile, the range of display sizes in common use is increasing, from mobile devices to large high-resolution displays. This paper investigates how classic interactive visualization techniques perform with larger and smaller displays (Figure 1, a and c).

Large high-resolution displays allow more information to be shown at a time, and have been found to improve task performance and user satisfaction [e.g., 14, 35]. Similarly, visualization techniques have been shown useful for many tasks [e.g., 11, 13]. The combination of large displays and visualizations, however, raises new questions: Can we expect the performance gains of visualization approaches for smaller displays [10] to scale to large displays? Does the finding that overview+detail visualizations improve task completion time and satisfaction [13] hold on displays with enough pixels to give an overview? Which tasks are most effectively solved with visualizations on a large display?

North and colleagues have given answers to some of these types of question [1, 3, 36, 37]. They have shown how physical navigation improves performance on large displays and that comparison of visualizations' performance gives similar results across display sizes. However, they have argued that questions about what happens when "the data/pixel count scales up" and how "different navigation strategies, such as overview+detail, and focus+context, affect high resolution visualization" remain unanswered [3].

This paper contributes empirical data on the effect of display size on the usability of visualization techniques for navigating multi-scale information spaces. We investigate three classic interactive visualization techniques (focus+context, overview+detail, and zooming), using tasks and data similar to previous studies. In contrast to most work by North and colleagues, we investigate interactive visualizations and look at their usability for navigating the same, large information space. In contrast to work on visualization for small displays [e.g., 10], we compare across all display sizes of Figure 1. The intended benefit of this line of work is to understand better how to design and adapt visualizations for small and large displays.

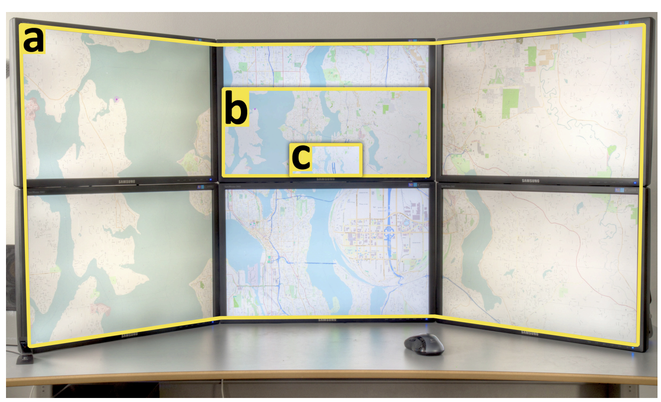

Figure 1: How do visualization techniques perform at different display sizes such as (a) 13.8, (b) 1.5, or (c) 0.17 megapixels?

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RELATED WORK

Increasing display size has been shown to improve performance across tasks as different as 3D navigation [35], office work [14], map navigation [3, 6], sensemaking [1], and collaboration [23]. Large displays have also played important roles in systems such as Prairie [34], iLand [33], Stanford Information Mural [16], and Liveboard [15]. Several mechanisms behind the improvements promised by large displays have been proposed, including that they (a) provide a wider view of data, allowing peripheral awareness of context and better spatial orientation [35], (b) ease window management and navigation [14], and (c) prompt physical navigation in front of the display, reducing the need for virtual navigation [5].

Similarly, information visualizations are well researched, and much is known about the relative performance of different visualizations [e.g., 11, 32]. For instance, overview+detail visualizations have been shown to increase subjective satisfaction and improve performance for both complex tasks, like essay writing [22], and simpler tasks [8]; Cockburn et al. recently reviewed these benefits [13]. Different terms are used for these interface approaches that transform the view of a visual structure [11]: We use the term visualization technique, as used in previous research [e.g., 7, 17, 22].

Few papers, however, have studied the relation between information visualization and display size. Next we review empirical studies of information visualization where display size played a central role; Figure 2 shows the size of display used in these studies. Unless otherwise noted, we focus on the displays' pixel counts (rather than their physical size or dots-per-inch).

Baudisch et al. [7] presented focus+context screens. They surrounded a 17.3-inch monitor with a cardboard frame onto which a projected image gave low-resolution context to the information on the monitor. Focus+context screens were found superior to zooming and overview+detail

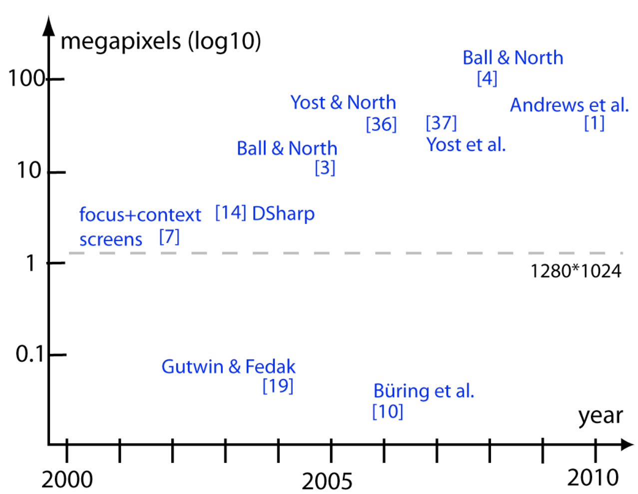


Figure 2: Studies of visualizations using large and small displays. Numbers in brackets may be found in the reference list, and the axes indicate the year of publication and pixel count of displays.

techniques. Other studies have used focus+context effects on large displays (e.g., Spotlight [25]), but have not attempted to generalize findings across display sizes or to other focus+context designs. We are unaware, for instance, of papers studying fisheye lenses on large displays. Several studies of small displays, however, have focused on focus+context techniques. Büring et al. [10] compared zooming and fisheye interfaces on small screens. Based on preferences for the fisheye interface, they suggested that users might value the navigational context in a fisheye interface higher when using a small screen. Gutwin and Fedak [19] compared interface techniques on displays about the size of mobile devices and typical desktop monitors. For small displays, they found that two-level zoom (an overview and a detail view) and a fisheye lens performed well with most tasks, even though users of the fisheye interface experienced overshooting. DateLens, a fisheye calendar interface, was found superior to an existing calendar application on PDA-sized devices [9].

North and colleagues have provided the most extensive empirical data on how visualizations work on large displays. Ball and North [3] compared simple navigation tasks using a zoom+pan interface with one, four and nine tiled monitors. Data images fit the largest display. Thirty-six participants performed tasks faster and felt less frustration with nine monitors than with one monitor. Also, participants engaged in more physical navigation and less virtual navigation with nine monitors than with one monitor. Later studies provided further evidence for the importance of physical movement for solving map tasks on a 100 megapixel display [4]. Yost and North [36, 37] investigated how visualizations that provide more pixels than visual acuity improved performance and showed that data density could be increased significantly with larger displays with only a modest increase in task completion times. The visualizations tested were small multiples of bar charts and graphs. In these studies by North and colleagues, the information space is significantly larger for the large displays, although not in [5]. For instance, [37] compared three interfaces that increased pixel counts by a factor of four (2, 8, and 31.5 megapixel displays); the number of data points was similarly increased (5488, 23548 and 94192 data points). The increases in task completion time on large displays were less than a factor of four, supporting the conclusion that "performance on most tasks was more efficient and sometimes more accurate because of the additional data that could be displayed" [37, p. 101].

In sum, most studies on visualization have been made on standard-sized displays. Data on the general performance of visualizations on other sizes of display are thus lacking. Specifically, the literature on the relation between display size and visualization technique mainly concern static visualizations. For some interactive visualization techniques (e.g., overview+detail) few results exist; for others (e.g., focus+context) results are positive for small displays, but it is unclear if the technique is useful on large displays. Finally, studies that investigate the effect of display size typically keep the size of the data set constant [e.g., 3, 5] or varied relative to display size [e.g., 4, 36, 37]. The scale factor between an overview of the entire data set and the lowest zoom level varies if data size is kept constant, which can impact the performance of different visualization techniques. The scale ratio can be kept constant if the data set size is varied, but because data and tasks differ across display sizes, performance cannot be compared in absolute measures. Instead, conclusions are based on whether increases in completion time are lower than increases in data set size. In the experiment presented next, we use the same size information space for different sizes of display and different interactive visualizations.

EXPERIMENT

We conducted an experiment with three interfaces for navigating maps using three different sizes of display. Our aim is to understand better the relation between usability of interactive visualization techniques and display size.

The guiding principle behind the design of the experiment is to build on existing work on visualization. Thus, the interfaces implemented three widely used visualization techniques: focus+context, overview+detail, and zooming. The implementations resemble those typically used in the literature so as to extend earlier results, in particular from comparisons of visualization techniques. For this reason we did not use improvements such as speed-coupled flattening or high-precision magnification lenses [2, 28]. Further, participants solved tasks similar to previous research on visualizations or large displays. This choice means that our aim is not, initially, to adapt visualizations for a particular display size, but rather to bring about the empirical data that would inform such adaptations.

Method

A within-subjects design was used in which three factors were varied: display size (Small, Medium, Large), interface (Focus+Context, Overview+Detail, Zooming), and task type (Navigate, Compare, Trace). Participants performed all types of task in each of nine blocks. Each block used a unique combination of display size and interface. We systematically varied the order of the combinations across participants using a Greco-Latin square so as to reduce the influence of learning effects. Also, the order of task types was varied randomly across blocks. In total, 21 repetitions of tasks were made in each block (10 Navigate, 9 Compare, 2 Trace), giving 189 data points for each participant (3×3×21).

Participants

Nineteen volunteers (five female), 19-38 years old, participated in the experiment. Participants were recruited by word of mouth and were provided no compensation.

Apparatus

Participants used a 13.8 megapixel (5760x2400) display (shown in Figure 3). The display consisted of six 24" LCD monitors, each with a maximum resolution of 1920x1200, arranged in a 3x2 grid. The monitors were positioned at a 135° horizontal angle relative to each other, so that they are curved around the user, as suggested by [31]. The monitors were operated by a Radeon HD 5870 Eyefinity card.

Figure 3: The six-monitor setup used in the experiment.

Three display sizes were used in the experiment containing 1/81th, 1/9th, and all of the display's pixel area (see Figure 1). Thus, the aspect ratio could be kept constant at 2.4:1 across display sizes. The Small condition used 640x267 pixels of the upper-center panel; the Medium condition used 1920x800 pixels. The Large condition used the full 5760x2400 of the display. The display contained 94 pixels per inch in all conditions.

For input, participants used a Logitech LX8 wireless laser mouse with a scroll-wheel. The default mouse settings in Windows 7 were used. Touch input is becoming common for small-screen devices. However, we chose a mouse as input across conditions for experimental control. Also, mouse is the input device most frequently used for the visualization techniques we study.

Interfaces

Three interfaces allowed users to navigate the maps. The interfaces were implemented in Java using a modified version of the ZVTM library [27]. We optimized the interfaces so that the screen updated at a minimum of 15 frames per second, which was found acceptable in informal evaluations with users.

Focus+Context

The focus+context interface (see Figure 4) shows the entire map at the lowest possible scale (i.e., map pixels per display pixels, see Table 1). A Gaussian lens using an L(2) radial metric [12] magnifies the focus region at the mouse cursor. The lens has a diameter of 50% of the display height

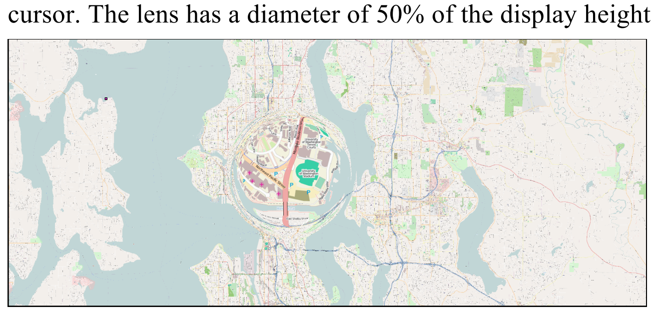


Figure 4: The focus+context interface at Medium display size.

Figure 5: The overview+detail interface at Medium display size containing an overview window in the upper-right corner.

and thus covers 12% of the total display area. The lens has a flat top that shows the focus area at constant magnification, with a diameter of 30% of the display height. The magnification in the focus area varies between 3x in Large, 9x in Medium, 27x in Small so that the lens shows the map at the lowest scale (1 map pixel per display pixel, see Table 1).

Our aim was for the focus+context interface to resemble the implementations used in previous research. We reviewed 14 papers reporting empirical studies of fisheye interfaces published between 2000 and 2009 [e.g., 10, 17, 18, 20]. A flat-top lens was most frequently used and most often with a diameter around 30%.

Overview+Detail

The overview+detail interface (see Figure 5) includes a detail view that can be panned to show different parts of the map at lowest scale. To pan the view, the user clicks and drags the mouse opposite the panning direction (i.e., the map follows the mouse). The interface also includes an overview window, located in the upper right corner of the detail view, which shows the entire map at a higher scale (see Table 1). The user can click and hold the left mouse button to drag a field-of-view box in the overview in order to pan the detail view. Also, the user can click on a point in the overview outside the field-of-view box to center the detail view on that point. We used 10% of the display area for the overview widget. This size was found by reviewing 13 studies mentioned in [13] and choosing the median size overview; the field-of-view and the interaction facilities working on it were also typical among the reviewed studies.

Zooming

The zooming interface (see Figure 6) includes a view that can be panned in the same way as the detail view in

		Small	Medium	Large
F+C	Focus / Context	1 / 27	1 / 9	1 / 3
O+D	Detail / Overview	1 / 85	1 / 28	1 / 9
Z+P	Highest / Lowest	1 / 27	1 / 9	1 / 3

Table 1: Scale (map pixels per display pixels) in the focus and surrounding context of focus+context (F+C), detail and overview windows of overview+detail (O+D) and at highest and lowest zoom level in zooming (Z+P). For instance, maps are 7200 pixels high, the overview window at Small 84 pixels, requiring 85 map pixels per display pixel.

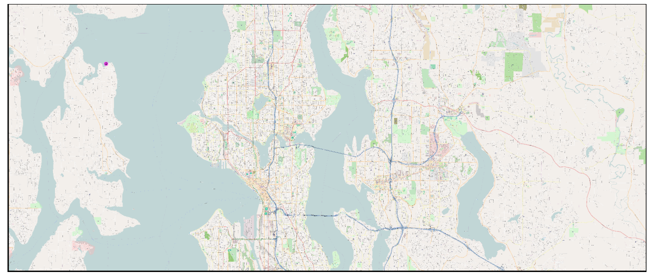


Figure 6: The zooming interface at Medium display size.

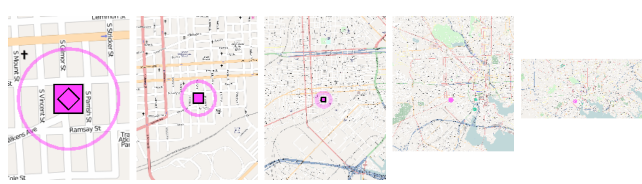
overview+detail. Additionally, the user can zoom the view to show the map at different scales. Zooming is constrained between the lowest scale of 1 map pixel per display pixels and the scale at which the entire map fits in the display (see Table 1). The user scrolls the mouse wheel up to zoom the map to a lower scale, and scrolls down to zoom to a higher scale; transitions between scales are animated. The zoom rate was adjusted so that zooming from the highest to the lowest scale (or vice versa) could be done in 300ms. The mouse cursor is used as the center of zooming, which is familiar to users of widespread map interfaces (e.g., Google Maps, maps.google.com).

Information Spaces and Tasks

Participants performed geospatial tasks using maps of large cities. Nine maps were used, all generated from OpenStreetMap (www.openstreetmap.org) at zoom level 16 for which most street names are visible. Each map was 17280 x 7200 pixels, which is the same aspect ratio as the display. Participants completed a block of 21 tasks with each interface × display size combination. Each block was completed with a different map.

All tasks involved targets superimposed on the maps. Targets are smaller at higher levels of scale (see Table 2). To make targets perceptible at high levels of scale on the small display (especially in the overview) and with the wide field-of-view of the large display, an animated halo was shown (increasing radius in one-second repeating loop) around each target. Three tasks were used:

For *Navigate* tasks, a single target was shown on the map that participants had to select by clicking it using the mouse. The target could only be selected at the lowest level of scale, at which the target representation would change so as to indicate that it could be selected. Clicking on the target completed the task. Targets were 40x40 map pixels and were placed at distances of 3500 or 7000 map pixels



1 3 9 27 85

Table 2: Map containing a Navigate target, shown at different scales. The lowest scale (left) is 1 map pixel per display pixel and, the highest scale (right) is 85 map pixels per display pixel (only used in the overview window at Small display size).

(about 50% and 100% of the map height) from the center of the map; their angle to the center was varied at random.

For *Compare* tasks, three targets representing fictional houses were shown on the map, placed equidistant to each other. Participants were asked to compare the dollar amount of the targets and select the target with the highest amount. The amounts were only visible at the lowest level of scale and also, similar to Navigate tasks, targets could only be selected at the lowest level of scale. Clicking on a target finished the task. A similar type of task was used by Ball and North [4]. Targets were 40x40 map pixels. The distance between targets varied between 1440, 3600, and 5760 map pixels (20%, 50%, or 80% of the map height).

For *Trace* route tasks, the start and end point of a route were indicated as a green triangle and a red circle on the map. The routes used in the tasks were sections of roads about 3000 map pixels in length. We selected major roads (e.g., interstate highways) that were distinguishable at all levels of scale for all display sizes. Participants had to follow the route, clicking on all overpasses along the route with the mouse. This task resembles that used by Shupp et al. [31]. Mouse clicks were logged for later analysis. Participants finished the task by clicking on the red circle that indicated the end point of the route.

Dependent variables

Dependent variables were time to complete tasks, measures of accuracy, and subjective measures of mental effort. We automatically recorded task completion times, accuracy, and data describing participants' interaction with the interfaces. Following the advice of Sauro and Dumas [30], we used the Subjective Mental Effort Questionnaire (SMEQ, see [38]). SMEQ consist of a graphical rating scale, annotated with descriptions of effort. It is easy for participants to use, and could thus be administered after each task type. Thereby we get a more fine-grained, and thus more valid, assessment of participants' mental effort, based on SMEQ measures for each of the 27 display size × interface × task type combinations.

Procedure

Participants sat in a chair with their face at a distance of about 67cm from each of the monitors. The field-of-view angle varied between 16° for Small and 135° for Large.

Participants were first given an introduction to each of the interfaces, using the medium display size. The three types of task used in the experiment were then explained. Next, participants performed training tasks of each type using each of the nine display size × interface conditions. After the introduction, participants completed nine blocks of 21 tasks using a different display size × interface condition to complete the tasks in each block. Tasks were presented in a window that cued participants to continue when they were ready. Immediately after participants clicked 'start', targets were added to the map and the mouse cursor was automatically placed in the center in the display. An electronic version of SMEQ was administered to participants after completing all trials of a particular type of task. After completing all tasks, participants were asked to comment on their use of the interfaces at different display sizes. The experiment lasted on average one hour and 15 minutes for each participant.

Expectations

Although we consider the experiment exploratory, we did form some hypotheses before running the experiment. Overall, we expected users to perform tasks fastest using the Large display condition, because less virtual navigation is required. This is suggested by results from earlier research [3, 5, 36, 37].

For focus+context, we expected relatively faster performance with a larger display. Increasing the display size results in lower control-display ratio in the lens and thus problems of acquiring targets are less severe. Also, the size of the lens is larger, resulting in (1) less compression in transition between focus and context, and (2) more information shown in detail. It was not clear a priori whether the positive findings from earlier research on small-display focus+context techniques would transfer to our setup, because earlier research would make extensive adaption of techniques to suit the small displays.

For overview+detail, we were unsure whether to expect faster overall performance with larger display because a larger area can be viewed in detail. Nevertheless, we expected comparison tasks to benefit from the difference in ratio between scales in overview and detail views, because of decreased motor effort.

For zooming, we expected comparable performance across display sizes, although the zooming functionality and the accuracy with which you can zoom towards a point is likely to hurt performance in the Small display condition.

RESULTS

We performed a 3 (display size) × 3 (interface) × 3 (task type) repeated measures analysis of variance on the task completion times and the SMEQ ratings. To correct the skew and to reduce the influence of outliers, the completion times were logarithmically transformed. We examine significant effects using Bonferroni-corrected pairwise comparisons. Unless otherwise noted, differences are significant at the $p < .001$ level.

Accuracy was uniformly high ($M = 99\%$, $SD = 10\%$) and is not analyzed further.

Task completion times

Average task completion times with the different display sizes and interfaces are shown in Figure 7. We found a main effect for interface, $F(4, 36) = 118.05$, $p < .0001$. Overall, pairwise comparisons showed that overview+detail ($M = 7.9$s) was faster than zooming ($M = 9.6$s), $p < .05$, which in turn was faster than focus+context ($M = 14.9$s). However, an interaction between interface and task type was found, $F(2.65, 47.69) = 13.666$, $p < .0001$. Figure 8 summarizes task completion times for the different task

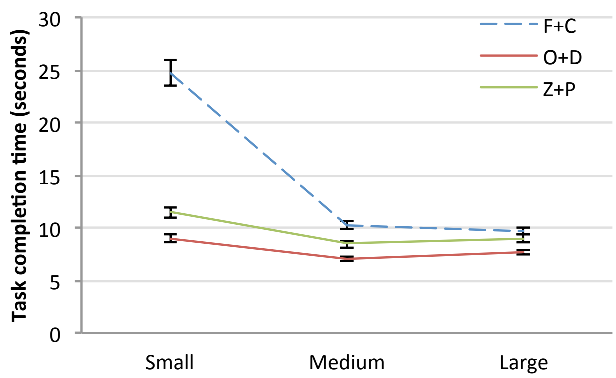


Figure 7: Average task completion times with focus+context (F+C), overview+detail (O+D), and zooming (Z+P) at different display sizes. Error bars show standard error of the mean.

types. As the figure suggests, overview+detail (*M* = 9.1s) was faster than zooming (*M* = 12.9s) for Compare tasks, but was not faster for Navigate or Trace route tasks. It is likely that overview+detail only performed better in Compare tasks because participants could bring the three targets into view with low physical effort, once they had moved the mouse to the overview; in zooming, participants had to either pan or zoom to navigate to each target.

We also found a main effect for display size, $F(4, 36) = 167.59$, $p < .0001$. Participants performed tasks faster with Large (*M* = 8.8s) and Medium (*M* = 8.6s) compared with Small (*M* = 15.1s). Contrary to our expectations, Large was not faster than Medium, but slightly slower, $p < .05$; however, the difference is small (2.5%). As suggested by Figure 7, this finding is related to differences between interfaces, which we analyze below. Despite the qualifications below, this finding is a key result because the expectation raised by the literature would be a strong effect in the opposite direction.

A significant interaction between display size and interface was found, $F(4, 72) = 38.904$, $p < .0001$. Post-hoc comparisons showed a significant increase in time for all interfaces when moving from Medium to Small display size, $p < .0001$ (see Figure 7). The largest differences between interfaces are found for the Small display; in particular, participants spent 173% more time with focus+context (*M* = 24.7s) compared with overview+detail (*M* = 9.1s). Possible explanations for the exceptionally poor performance of focus+context at the Small display size are that (1) the very small lens top together with the increased compression in the transition between focus and context make focus targeting more difficult and (2) the high control-display ratio makes it hard to acquire targets.

One explanation behind the observation that Medium slightly outperforms Large could be that participants with the large display initially had to spend more time searching for targets, offsetting other performance benefits of that display. We thus analyzed the initial search time, that is, task completion times minus the time spent before participants moved the mouse more than a threshold distance. The average initial search time was 0.8s (*SD* = 1.1s). Adjusting the times for initial search did not change the overall result, but reveals an interface-specific finding: the poorer performance with focus+context and zooming in the Large display seems due to slower initial search for targets. First, in Table 3, which shows initial search times as percentage of total task time for each interface, we see an increase in time spent searching with focus+context and zooming, but not with overview+detail. By comparing Figure 8 with Figure 9 (in which initial search times are excluded) we see that this increase in initial search time accounts for the decreased performance with focus+context and zooming for Navigate tasks; the performance decrease with overview+detail, in contrast, seems unrelated to search time. The reason participants spent more time searching with focus+context and zooming is probably because of the wider field-of-view that needs to be searched; with overview+detail, participants could likely find targets faster in the overview. The increase in search time on large displays has less impact on the relatively longer task times for Compare and Trace route tasks (see Table 4).

Subjective ratings of effort

Participants rated each interface × display size × task type using SMEQ; higher values of SMEQ indicates higher effort. Figure 10 shows average ratings for the different display sizes and interfaces. There was a main effect for

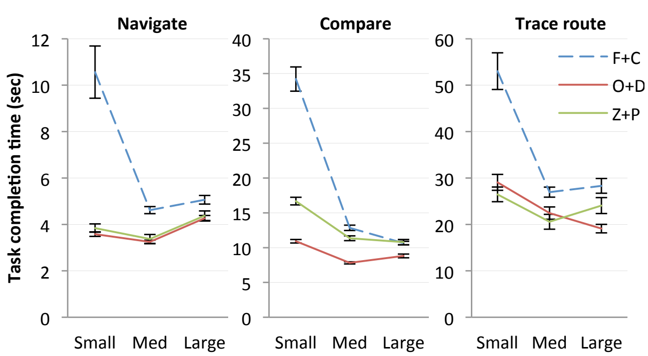


Figure 8: Average completion times for the three task types with focus+context (F+C), overview+detail (O+D), and zooming (Z+P) at different display sizes. Error bars show standard error of the mean.

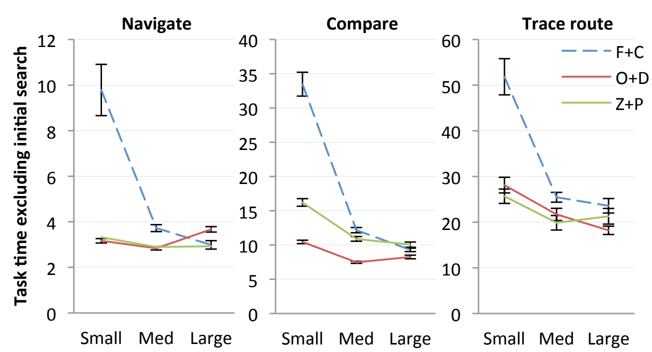


Figure 9: Average completion times without initial search time for the three task types with focus+context (F+C), overview+detail (O+D), and zooming (Z+P) at different display sizes. Error bars show standard error of the mean.

	Small	Medium	Large
Focus+context	4%	10%	23%
Overview+detail	6%	7%	8%
Zooming	6%	7%	17%

Table 3: Percentage of task time initially spent searching for targets with different interfaces and display sizes. A noticeable increase between Medium and Large is found for focus+context and zooming, but not for overview+detail.

	Small	Medium	Large
Navigate	9%	16%	30%
Compare	3%	5%	9%
Trace route	3%	4%	12%

Table 4: Percentage of time initially spent searching for targets for different types of task and different display sizes.

display size, $F(2, 32) = 91.178$, $p < .0001$. Participants found tasks "fairly hard" to "rather hard" to do ($M = 48.9$) with Small, a significantly worse rating than both Medium ($M = 22.5$) and Large ($M = 19.9$). There was no overall difference in ratings between Medium and Large, $p = .396$.

We also found a main effect for interface, $F(2, 32) = 71.438$, $p < .001$. Participants found both overview+detail ($M = 18.4$) and zooming ($M = 21.2$) easier to use than focus+context ($M = 51.7$) but ratings did not differ between overview+detail and zooming, $p = .569$.

A significant interaction of display size × interface was found, $F(4, 64) = 57.629$, $p < .0001$. Participants found overview+detail more difficult to use on Large ($M = 18.3$) than Medium ($M = 12.0$), $p < .05$, whereas focus+context was found less difficult on Large ($M = 25.0$) than Medium ($M = 37.9$), $p < .01$. No difference was found for zooming.

Participants' comments

Participants commented on their use of the interfaces after the experiment. Supported by informal observations we made during the experiment, these comments help explain the results.

Overall, most participants expressed preference for overview+detail; the overview helped finding targets and moving them into the detail view. Focus+context was the least preferred, especially with the Small display; common reasons given were that targets were difficult or impossible to see in the transition area and that the pointing precision in the lens was poor. We saw participants employ different strategies for overcoming these problems (e.g., steering in a straight line toward the target or by geographical features or landmarks).

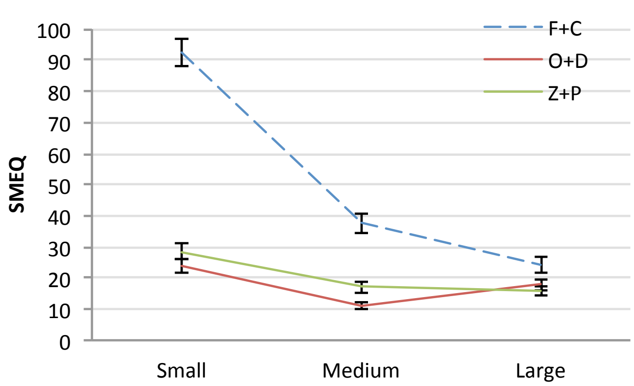


Figure 10: Average Subjective Mental Effort Questionnaire (SMEQ) ratings with focus+context (F+C), overview+detail (O+D), and zooming (Z+P) at different display sizes. Higher values indicate higher effort. Error bars show standard error of the mean.

Overall, Medium was the display size that most participants preferred. At least two participants said they liked that the Medium display fit into their field of view. In contrast, participants said that the Large display required more visual search and too much movement (head or mouse). Specifically about overview+detail with the Large display, a few participants gave comments suggesting that it was difficult to coordinate the overview and the detail view because the detail view was so large. This might explain why participants found tasks more difficult to complete with overview+detail in Large compared with Medium.

Participants commented that the bezels could be disruptive when, occasionally, targets ended up between two display panels. From informal observations, the bezels seemed particularly problematic for the fisheye lens in route tracing tasks; the map moves inside lens across bezels, which might be confusing – we saw participants move the lens back and forth across bezels in trace route tasks.

Interaction

We analyzed the data collected during the experiment so as to understand differences in how participants used the interfaces at different display sizes. We discuss two activities in participants' interaction with the interfaces: (1) mouse movement and (2) virtual navigation (zooming, panning, and use of the overview) in the overview+detail and zooming interfaces.

First, we examined the effect of display size on physical mouse movement. To do so, we calculated the Euclidian distance between coordinates of the mouse pointer at each mouse event. We found a main effect of display size on the mouse travel distance, $F(1.25, 22.46) = 281.51$, $p < .0001$. Overall, the average mouse travel distance in pixels increased 73.4% from Small ($M = 1755$) to Medium ($M = 3043$) and 93% from Medium to Large ($M = 5874$). Figure 11 shows how the average mouse travel distance varied between display sizes and across interfaces and tasks. We note three differences between interfaces. First, the focus+context interface required the least mouse movements across tasks. Second, overview+detail required relatively more mouse movements for Navigate and Trace route tasks than the other interfaces, but less movements than the zooming interface in Compare tasks. Third, the mouse movements required by the zooming interface seems to scale proportionally with display size.

We also analyzed how much time participants spent on virtually navigating in the maps using the interfaces: Figure 12 shows how much of the time participants spent on zooming and panning with the zooming interface; Figure 13 how much of the time participants spent on using the overview and on panning with overview+detail. Time spent on zooming was the time from participants started scrolling the mouse wheel to the animated transition ended. Time spent on panning included periods where participants dragged the mouse with the button pressed. We found a main effect of display size on the amount of time participants spent navigating using Overview+Detail, $F(1.24, 22.39) = 27.366$, $p < .0001$, and Zooming, $F(2, 36) = 121.62$, $p < .0001$. Overall, participants spent less of the time zooming and panning with Large ($M = 22.9\%$) compared with Medium ($M = 32.8\%$) and Small ($M = 35.3\%$). Time spent using the overview included periods where the mouse cursor was inside the overview window. Also, relatively less time was spent on using the overview and on panning with Large ($M = 52.1\%$) than with Medium ($M = 62.7\%$) and Small ($M = 63.2\%$).

In sum, although virtual navigation was reduced on larger displays, as indicated by the reduction in panning, zooming, or interaction with the overview, there was an increase in physical mouse movements.

DISCUSSION

Our study has shown that users perform surprisingly similar with multi-scale navigation techniques used for simple visualizations on medium and large size displays. The larger display increases mouse movement and affects visual search time, possibly offsetting other performance benefits such as lowered virtual navigation. The difference between a small display and a medium display was significant, both in terms of task completion time and subjectively perceived effort. Overview+detail performed the best, was preferred by participants, and provided useful support for navigation through its overview widget. The focus+context technique worked very poorly at small displays, but required the least movement for large displays. We found strong effects of task, both on the interaction between display size and visualization technique and on how participants interacted with the interfaces.

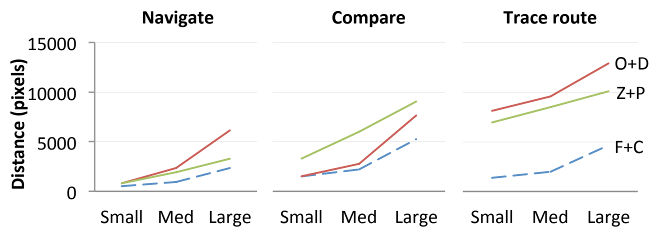


Figure 11: Average distance participants moved the mouse to complete tasks using focus+context (F+C), overview+detail (O+D), and zooming (Z+P) at different display sizes.

The main point for discussion is why the benefits that we would expect from large-display research [e.g., 14, 35] do not materialize in the present study. Whereas the wider-view-argument for large displays presented in the section on related work has extensive empirical support, a wider view negatively interferes with our techniques. First, if targets are visible at all levels of scale, then much more visual search has to be done on a large display compared to the smaller displays. Second, for interactive visualization techniques like zooming and overview+detail, most of the contents of the display changes when the user zooms or pans. The experienced optical flow is thus much higher and may potentially add to the perceived mental effort (as measured by SMEQ). This is the case, for instance, for overview+detail where SMEQ increases from Medium to Large display sizes.

Our results are particularly disappointing given the work of North and colleagues [1, 3, 5, 6, 36, 37]. Ball et al. [6] found that "find" and "trace route" tasks were performed faster when display size increased from 1 through 4 to 9 monitors. In their study, however, no interaction with targets was required. Our results show reduced virtual navigation, but potential benefits are offset by the need for more mouse movement. Other work by North and colleagues emphasize the role of physical navigation [5]. One difference in our approaches—that may explain why North et al. found performance improvements with large displays while we did not—is that target search time was excluded from their navigation tasks (find a particular house and related information), whereas search was included in our tasks. Also, physical navigation was

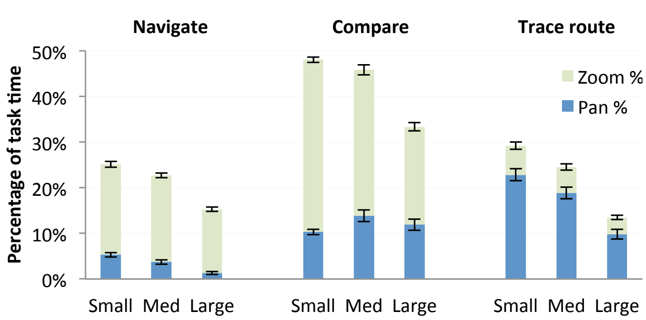


Figure 12: Time spent on zooming or panning with the zooming interface at different sizes. Error bars indicate standard error of the mean. Overall, time spent on zooming and panning actions tend to fall as display size increases.

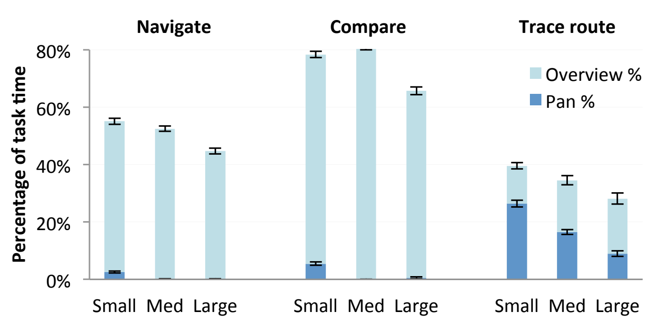


Figure 13: Time spent using the overview or panning with the overview+detail interface at different sizes. Error bars indicate standard error of the mean. Overall, time spent on navigation actions tend to fall as display size increases.

beneficial in [5], but our setup restricted physical navigation to head movements. Nevertheless, the difference in time to find a particular known object on the smallest display varies a lot between their study (about 17 seconds) and ours (about 4 seconds with overview+detail or zooming). It seems that more work is needed to define and explain these differences in methodology and results.

The inferiority of a small display to a medium display is clear, both in terms of task completion time, subjective assessments of effort, and comments after the evaluation. In particular, the relation between changes in motor space and the corresponding changes in display space poses many difficulties to participants. Earlier work [10, 19] suggested that focus+context is a particularly viable technique for small displays; in our case, focus+context performs considerably poorer than the alternatives. Key differences are (a) the size of the information space relative to the display, (b) the specialized nature of the focus+context implementations in earlier work.

Our results may also be discussed as a comparison of three visualization techniques, about which much is already known. We find overview+detail relatively robust across display sizes, in agreement with reviews [13] and empirical studies on medium-sized displays [8, 22]. Pietriga et al. [29] similarly found a preference for overview+detail, but also found that focus+context outperformed zooming; this is not the case in our experiment. One important difference is that Pietriga used an adjustable magnification factor between 2 and 12, whereas ours were fixed. Also, the zoom factor in our experiment was high. Gutwin and Skopik [20] found a focus+context interface to perform better than both overview+detail and zoom+pan interfaces in steering tasks. In the large display condition, our focus+context interface used a similar magnification factor (they used 2 and 4), but performance in trace route tasks that are similar to the steering tasks of [20] was relatively worse.

Another important point of discussion is the view that visualization techniques could not be expected to scale to larger (or smaller) displays directly; adaptations of such techniques would be needed to make them work well. In this view, the expectation that three classic interactive visualization techniques would work on large (and small) displays is overly optimistic. Several design choices in the present experiment have influenced performance. First, we restricted the allowed zoom levels, so that participants could not zoom in or out too much (as done also by for instance [21, 29]). This is often seen as a benefit, helping users avoid "desert fog" [24], but it means that participants are restricted from using approaches they might use with other zooming interfaces. Second, the field-of-view in the overview+detail was a fixed size, and the detail view thus at a constant zoom level (as done by [8, 26], though not in for instance [21]). This forces users to relatively much virtual navigation (see Figure 13). Third, other focus+context techniques could perform better than our implementation, particularly for the Small display size: speed-coupled blending lenses [22] make focus targeting easier; high-precision magnification lenses [2] help acquire targets at magnification factors as high as 27x. Fourth, the optical flow on large displays with for instance overview+detail could be reduced in future adaptations of visualization techniques (e.g., by using coordinated windows).

The experiment that we presented has some obvious limitations that should be addressed in future work. First, we used fixed-sized information spaces: As already argued, this approach differs to that of many papers by North and colleagues. Our approach may have favored larger displays in that the information space was kept constant across display sizes; it also results in higher magnification factors on small displays (which might especially impact focus targeting and target selection in focus+context). Future work should compare fixed information spaces (as we have used) to information spaces whose size scale with the size of the display. Second, the tasks we used are limited. Tasks focused on navigation in geographical maps where targets are visible at all levels of scale. None of the tasks required extensive use of information at multiple levels of scale. Third, our purpose in this paper has not been to model the differences in navigation across displays and visualization techniques. A more focused experiment using Fitts's style task and modeling (as in [29]) might help further characterize navigation on large and small displays.

CONCLUSION

Much research has documented the benefits of large displays and those of visualizations, but we know little about their combination. We have investigated the usability of classic interactive visualization techniques (viz., focus+context, overview+detail, and zooming) across three sizes of display, used by 19 participants to navigate maps.

The results show that interactive visualization techniques work comparably for multi-scale navigation across large and medium sized displays in terms of task completion time and subjective satisfaction; visualizations on small displays performed the worst. We find strong interactions of display size and visualization technique. Also, task type significantly influences the display conditions under which a particular technique performs the best.

Our findings stand in contrast to most other studies of visualizations on large displays. Key differences concern whether visualizations are interactive or not, whether physical navigation is possible or not, and the size and contents of the data sets tested. Nevertheless, we argue that adaptation of interactive visualization techniques for large display is needed, and that further work needs to investigate both the possibilities and the limitations of large displays for interactive visualizations.

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REFERENCES

1. Andrews, C., Endert, A. and North, C. Space to think: Large, high-resolution displays for sense making. In *Proc. CHI 2010*. ACM Press (2010), 55-64.
2. Appert, C., Chapuis, O. and Pietriga, E. High-precision magnification lenses. In *Proc. CHI 2010* (2010), 273-282.
3. Ball, R. and North, C. Effects of tiled high-resolution display on basic visualization and navigation tasks. In *Proc. Extended Abstracts, CHI 2005*. ACM (2005), 1196-1199.
4. Ball, R. and North, C. The Effects of Peripheral Vision and Physical Navigation on Large Scale Visualization. In *Proc. GI 2008* (2008), 9-16.
5. Ball, R., North, C. and Bowman, D. A. Move to improve: promoting physical navigation to increase user performance with large displays. . In *Proc. CHI 2007* (2007), 191-200.
6. Ball, R., Varghese, M., Carstensen, B., Cox, E. D., Fierer, C., Peterson, M. and North, C. Evaluating the Benefits of Tiled Displays for Navigating Maps. In *Proc. IASTED International Conference on Human-Computer Interaction* (2005), 66-71.
7. Baudisch, P., Good, N., Belotti, V. and Schradley, P. Keeping things in context: a comparative evaluation of focus plus context screens, overviews, and zooming. In *Proc. CHI 2002*. ACM Press (2002), 259-266.
8. Beard, D. B. and Walker, J. Q. Navigational Techniques to Improve the Display of Large Two-Dimensional Spaces. *Behaviour and Information Technology*, 9, 6 (1990), 451-466.
9. Bederson, B. B., Clamage, A., Czerwinski, M. P. and Robertson, G. G. DateLens: A fisheye calendar interface for PDAs. *ACM Transactions on Computer-Human Interaction*, 11, 1 (2004), 90-119.
10. Büring, T., Gerken, J. and Reiterer, H. User Interaction with Scatterplots on Small Screens - A Comparative Evaluation of Geometric-Semantic Zoom and Fisheye Distortion. *IEEE transactions on visualization and computer graphics* 12, 5 (2006), 829-836.
11. Card, S. K., Mackinlay, J. D. and Shneiderman, B. *Readings in Information Visualization*. Morgan Kaufmann, San Francisco, CA, 1999.
12. Carpendale, M. S. T. and Montagnese, C. A framework for unifying presentation space. In *Proc. UIST2001*. ACM Press (2001), 61-70.
13. Cockburn, A., Karlson, A. K. and Bederson, B. B. A review of overview+detail, zooming, and focus+context interfaces. *ACM Computing Surveys*, 41, 1 (2008).
14. Czerwinski, M., Smith, G., Meyers, B., Robertson, G. and Starkweather, G. Towards characterizing the productivity benefits of very large displays. In *Proc. Interact'2003*. IOS Press (2003), 9-16.
15. Elrod, S., Bruce, R., Gold, R., Goldberg, D., Halasz, F., Janssen, W., Lee, D., McCall, K., Pedersen, E., Pier, K., Tang, J. and Welch, B. Liveboard: a large interactive display supporting group meetings, presentations, and remote collaboration. In *Proc. CHI'92* (1992),
16. Guimbretière, F., Stone, M. and Winograd, T. Fluid interaction with high-resolution wall-size displays. In *Proc. UIST 2001* (2001), 21-30.
17. Gutwin, C. Improving focus targeting in interactive fisheye views. In *Proc. CHI 2002*. ACM Press (2002), 267-274.
18. Gutwin, C. and Fedak, C. A comparison of fisheye lenses for interactive layout tasks. In *Proc. GI 2004*. Canadian Human-Computer Communications Society (2004), 213-220.
19. Gutwin, C. and Fedak, C. Interacting with big interfaces on small screens: a comparison of fisheye, zoom, and panning techniques. In *Proc. GI 2004*. Canadian Human-Computer Communications Society (2004), 145-152.
20. Gutwin, C. and Skopik, A. Fisheye views are good for large steering tasks. In *Proc. CHI 2003*. ACM (2003), 201-208.
21. Hornbæk, K., Bederson, B. and Plaisant, C. Overview+Detail and Zoomable User Interfaces: An Evaluation of Navigation Patterns and Usability. *ACM Transactions on Computer-Human Interaction*, 9, 4 (2002), 362-389.
22. Hornbæk, K. and Frøkjær, E. Reading patterns and usability in visualizations of electronic documents. *ACM Transactions on Computer-Human Interaction*, 10, 2 (2003), 119-149.
23. Jeremy P. Birnholtz, Tovi Grossman, Clarissa Mak and Balakrishnan, R. An exploratory study of input configuration and group process in a negotiation task using a large display. In *Proc. CHI 2007* (2007), 91-100.
24. Jul, S. and Furnas, G. W. Critical zones in desert fog: aids to multiscale navigation. In *Proc. UIST'98*. ACM (1998), 97-106.
25. Khan, A., Matejka, J., Fitzmaurice, G. and Kurtenbach, G. Spotlight: directing users' attention on large displays. In *Proc. CHI 2005* (2005), 791-798.
26. Nekrasovski, D., Bodnar, A., McGrenere, J., Guimbretiére, F. and Munzner, T. An evaluation of pan & zoom and rubber sheet navigation with and without an overview. In *Proc. CHI 2006*. ACM Press (2006), 11-20.
27. Pietriga, E. A Toolkit for Addressing HCI Issues in Visual Language Environments. In *Proc. VL/HCC'05* (2005), 145-152.
28. Pietriga, E. and Appert, C. Sigma lenses: focus-context transitions combining space, time and translucence. In *Proc. CHI 2008* (2008), 1343-1352.
29. Pietriga, E., Appert, C. and Beaudouin-Lafon, M. Pointing and beyond: an operationalization and preliminary evaluation of multi-scale searching. In *Proc. CHI 2007* (2007), 1215-1224.
30. Sauro, J. and Dumas, J. Comparison of three one-question, post-task usability questionnaire. In *Proc. CHI 2009* (2009), 1599-1608.
31. Shupp, L., Andrews, C., Dickey-Kurdziolek, M., Yost, B. and North, C. Shaping the Display of the Future: The Effects of Display Size and Curvature on User Performance and Insights. *Human-Computer Interaction*, 24, 1&2 (2009), 230-272.
32. Spence, R. *Information Visualization: Design for Interaction. Second Edition*. Prentice Hall, Harlow, UK, 2007.
33. Streitz, N. A., Geißler, J., Holmer, T., Konomi, S., Müller-Tomfelde, C., Reischl, W., Rexroth, P., Seitz, P. and Steinmetz, R. i-LAND: an interactive landscape for creativity and innovation. In *Proc. CHI'99*. ACM Press (1999), 120-127.
34. Swaminathan, K. and Sato, S. Interaction design for large displays. *interactions*, 4, 1 (1997), 15-24.
35. Tan, D. S., Gergle, D., Scupelli, P. and Pausch, R. With similar visual angles, larger displays improve spatial performance. In *Proc. CHI 2003*. ACM (2003), 217-224.
36. Yost, B. and North, C. The perceptual scalability of visualization. *IEEE Transactions on Visualization and Computer Graphics*, 12, 5 (2006), 837-844.
37. Yost, B., Haciahmetoglu, Y. and North, C. Beyond visual acuity: the perceptual scalability of information visualizations for large displays. In *Proc. CHI 2007* (2007), 101-110.
38. Zijlstra, F. *Efficiency in work behavior. A design approach for modern tools*. Delft University Press, Delft, The Netherlands, 1993.