A Comparison of Fisheye Lenses for Interactive Layout Tasks

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Abstract

Interactive fisheye views allow users to edit data and manipulate objects through the distortion lens. Although several varieties of fisheye lens exist, little is known about how the different types fare for different interactive tasks. In this paper, we investigate one kind of interaction – layout of graphical objects – that can be problematic in fisheyes. Layout involves judgments of distance, alignment, and angle, all of which can be adversely affected by the distortion of a fisheye. We compared performance on layout tasks with three kinds of fisheye: a full-screen pyramid lens, a constrained hemispherical lens, and a constrained flat-topped hemisphere. We found that accuracy was significantly better with the constrained lenses compared to the full-screen lens, and also that the simple hemisphere was better at higher levels of distortion than the flat-topped version. The study shows that although there is a cost to doing layout through distortion, it is feasible, particularly with constrained lenses. In addition, our findings provide initial empirical evidence of the differences between competing fisheye varieties.

Key words: Fisheye views, distortion-oriented visualization, alignment tasks, interaction techniques.

1 Introduction

Interactive fisheye views show both local detail and global context in the same view [4,13]. They provide a user-controlled focus point for indicating which part of the data is to be shown in detail, and allow both exploration and focused interaction with data objects. Fisheyes are one solution to the space problem in information display, allowing many more objects to be displayed than would be possible in a regular view.

Fisheye views have been used in a number of applications including visualizations of graphs [19], software structures [22], documents [17], and web sites [6]. Although all fisheyes are characterized by their ability to show an entire dataset in a single window, many different types of visualization are possible, and many different types of view have been proposed and implemented.

Each different types of fisheye lens has different display characteristics with varying implications for interaction: lenses may cover the entire screen or may be constrained to be a certain size, can provide different magnification effects and different transitions from focus to context, and may use widely different shapes. However, little research has been done to compare different types of fisheye lens, and decisions about which type to use for particular interactive tasks currently must be based on ad hoc analyses.

In this paper we explore one particular type of interaction that we have previously observed to be difficult in a fisheye view. This interaction is that of *spatial layout* – arranging graphical objects in 2D space to satisfy constraints on position, orientation, alignment, and relative distance. The problem is that a fisheye view's distortion effects make it difficult to determine spatial relationships between objects. For example, Figure 1 illustrates the problem of aligning three graph nodes and spacing them equally: with a fisheye lens over the work area, it is difficult to determine whether the nodes line up and whether they are equal distances apart.

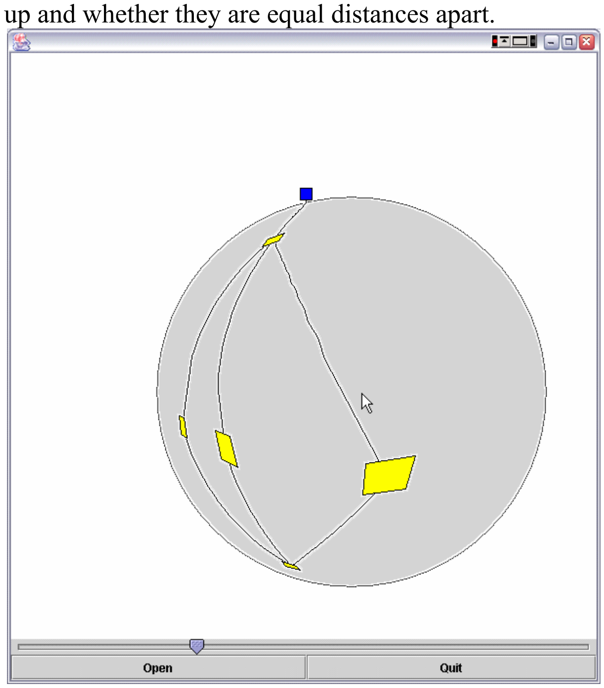

Figure 1. Example graph layout task carried out through a fisheye lens.

Although it may be possible in some circumstances to simply turn off the distortion when starting the layout task, some activities tightly couple layout with other interactions that require the fisheye view's magnification. For example, graph editing often requires layout adjustments that are closely interleaved with inspection of the nodes (e.g., to read the node's label). In these situations, it would be advantageous to have a fisheye lens that adequately supported both the inspection and layout activities simultaneously.

We carried out a study to compare the usability of three types of fisheye lens for graphical layout tasks. Participants were asked to duplicate the layout of a target figure, working through one of a full-screen pyramid lens, a constrained hemisphere lens, or a flat-topped hemisphere. Some of our findings followed expectations: for example, accuracy was significantly better with the two constrained lenses, since they allow the user to move the lens away from the work area and thus see an undistorted view of the objects. However, some results were unexpected: the flat-hemisphere, despite showing a region of fixed magnification (which we expected would assist the task) did not perform better than the hemisphere – and in fact, at higher levels of distortion, the hemisphere was the only lens to significantly outperform the pyramid. In addition, several people preferred the pyramid overall, even though it was the least accurate.

This study provides the first empirical results about layout in distortion-oriented views – a previously-unstudied aspect of fisheye usability. In addition, it provides initial data that compares different types of lens, and can act as a starting point for building a more complete understanding of the differences and design implications between different fisheye varieties.

2 Related work

Here we review the range of fisheye lenses that have been seen previously, prior work on other aspects of fisheye usability, and research into the specific elements of graphical layout.

2.1 Types of fisheye lenses

All interactive fisheye lenses allow for varying magnification and movable focus point. However, there are several ways that lenses can vary: extent, magnification mechanism, number of focal points, and lens shape [4].

- *Extent*. Lenses can either be full-screen, in which they extend all the way to the boundaries of the workspace, or constrained, where the distortion is limited to a fixed radius around the focus point.
- *Magnification mechanism*. Fisheyes provide different magnification between the focus and the context, and a mechanism is needed for effecting that transition. Three methods have been used [5]: mathematical functions (e.g. [12,19]), 3D perspective (e.g. [17]), or morphing (e.g. [18]).
- *Number of focal points*. Some schemes allow for multiple focal points, either through the presence of multiple constrained lenses [5], by modifying the magnification function of a single lens, or by using a 'rubber sheet' metaphor where any number of points may be pushed forward [18].
- *Lens shape*. Both constrained and full-screen lenses can have different shapes. The most common shapes are circular (e.g., [4,12]) and rectangular (e.g.,[17,22]), but any polygon is possible with some systems [4].

Carpendale's Elastic Presentation Space (EPS) [4] allows for the creation of a wide variety of lens types, and has provided the opportunity for an analytical comparison of several common types. For example, simply by varying the magnification function (or its parameters), lenses can be created with steep or shallow drop-offs, flat or curved focus regions, and abrupt or smooth transitions between the lens and the surrounding context.

2.2 Interactive fisheye usability

Fisheyes and distortion-oriented views have been tested in many different studies in widely-varying task contexts, from command and control [20] to web navigation [6] to menu selection [2]. Although all of these task situations involved interaction with a data set or an interface, the studies focus on overall task performance rather than on specific issues of fisheye usability.

Some studies have considered fisheye usability outside the context of a particular domain. This research attempts to decompose interaction into a set of component elements that can be examined in detail. There are a limited set of components that make up interaction in a typical mouse-and-windows environment. For example, pointing, selecting, and dragging are all variants of basic targeting [14]; similarly, cascading menu navigation, scrolling, and gesturing are all related to steering [1].

Studies of fisheye views with these two basic types of interaction show that fisheyes have both strengths and weaknesses. Their strength is that they are able to show the entire dataset in one view, so selection and steering tasks do not have to be interleaved with view navigation (e.g. panning or zooming) [7]. A fisheye's potential weakness, however, is that the distortion effect caused by the non-linear magnification makes certain interactions more difficult. In particular, movement of a magnifying lens causes the underlying data to appear to move in the opposite direction, which can cause overshooting when attempting to select targets [8]. In addition, since fisheyes magnify things in visual space but not in motor (i.e. mouse-pointer) space, users can be tricked into thinking that objects are larger (and easier to select) than they really are [15].

Graphical layout is an activity that certainly involves components like targeting and steering; however, there is an additional element to consider, that of interactively judging alignment, relative position, and angle during the adjustment operations. These types of interactions have not been studied with fisheye views.

2.3 Layout of graphical objects

Spatial layout tasks involves a three part cycle: perception of the spatial qualities of a set of graphical objects, evaluation of those qualities with respect to some criteria, and manipulation of the objects to reduce the difference between the current state and the goal [10].

Human visual and spatial perception is well-discussed elsewhere (e.g. [3,9,11,23]). Previous research suggests that humans are in general good at perceiving certain types of alignment [23], but not as skilled in determining absolute angles or positions [21]. Perception of small differences (e.g. the lengths and angles of two lines) is also difficult unless the lines are positioned close together and allow alignment-based comparison. Perception of spatial qualities through a non-linear magnifying lens has not been extensively studied, although it is reasonable to expect that difficulty will increase with distortion.

Similarly, humans performance in manipulating objects precisely in order to bring them into a particular spatial orientation has limitations. In mouse-and-windows systems, these limitations have often been designed for with aids such as snapping [16] and grids and guides (available in most drawing programs).

3 Study Methodology

We carried out a user study to further explore how distortion affects people's spatial abilities in layout tasks, and to compare the usability of the three fisheye views.

3.1 Participants and apparatus

Fifteen people (10 male, 5 female) were recruited from the computer science department of a local university, and were given course credit for participating in the study. All participants were frequent users of mouse-and-windows based systems (at least 20 hours per week). None were experienced with interactive fisheye views, but all had heard of optical fisheyes.

The experiment was conducted on a P4 Windows XP PC running a custom-built Java application. The display was a 21" monitor set to 1600x1200 resolution.

3.2 Tasks

The system was set up with the capabilities of a basic graph editor. Participants were asked to reproduce the layout of simple figures made up of nodes and edges (see Figure 2). The target figures were shown with no distortion in a separate window (500x500 pixels) beside the study system.

For each task, participants had to lay out a new graph in the study system window (900x900 pixels), to match the target figure as closely as possible. Participants were asked to position the nodes such that the location of their graph, the angles formed by the edges, and the overall scale was as close as possible to the target figure. One vertex was fixed (and coloured blue in both figures) to provide a common reference point between the target and the test figures.

The layout-reproduction tasks were carried out under a number of different conditions in which the type of fisheye lens and the level of distortion was varied. Participants were given 60 seconds to complete each task, and were instructed to continue working on the layout until they felt that the match was as close as they could achieve in that minute.

3.3 Fisheye lenses

The study considered three types of fisheye lens: a pyramid full-screen lens, a constrained hemispherical lens, and a constrained flat hemisphere (Figures 3-5 show each lens at a distortion level of 5, with grid lines added). In all cases, the focus of the fisheye view was controlled by the location of the mouse.

- *Full-screen pyramid lens*. The pyramid fisheye is based on Sarkar and Brown's 2D fisheye algorithm [19] using the polar transformation. In a rectangular window this results in a pyramid-shaped lens; lines were added to define the edges of the pyramid and help the subjects understand how the representation was distorting the space. The point of maximum magnification is the apex of the pyramid. This lens covers the entire screen; all objects in the display are always distorted to some degree.
- *Constrained hemispherical lens*. Constraining the Sarkar and Brown polar algorithm to a fixed radius produces a lens that approximates a hemisphere (although no 3D projection is used). This lens was 500 pixels in diameter, and so covered approximately one-quarter of the window (see Figure 4). The area of the lens was shown in a darker gray to help the subjects understand how the representation was distorting the space. The point of maximum magnification is the apex of the hemisphere.
- *Constrained flat-hemisphere lens*. A flat-topped lens was created by inserting a circular region of constant magnification into the centre of the hemispherical lens. This results in fixed magnification in the area immediately around the focus, and decreasing distortion in the remaining part of the hemispherical base. The lens was also 500 pixels in diameter, with a flat region 333 pixels in diameter.

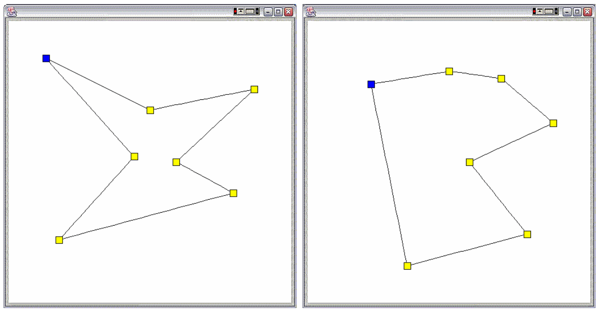

Figure 2. The two target figures used in the study.

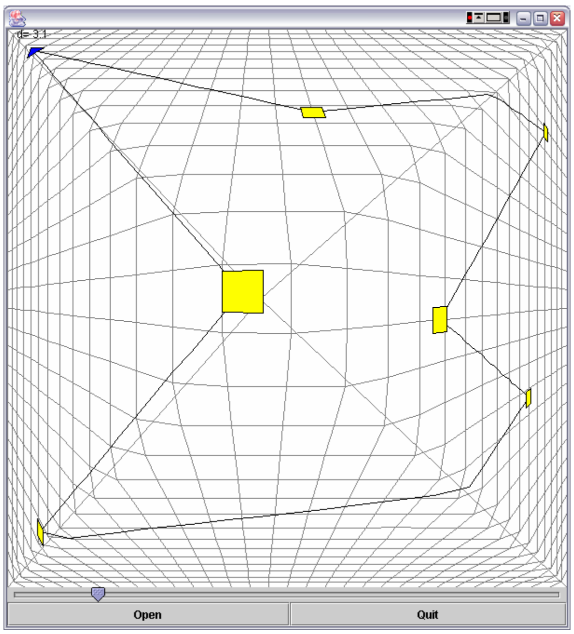

Figure 3. Full-screen pyramid lens showing the initial configuration of the test figure. Note that grid lines are added to Figures 3-5 to help show the shapes of the lenses; gridlines were not present in the study system.

3.4 Distortion levels

We tested layout performance at four levels of distortion, defined by the variable *d* in the Sarkar-Brown algorithm [19]. The levels were *d*=1 (minimal distortion), *d*=3 (moderate distortion), and *d*=5 (high distortion). These levels are shown in Figure 6.

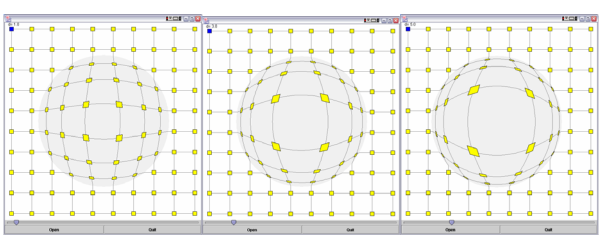

Figure 6. Distortion levels used in the study (showing hemispherical lens): d=1, d=3, d=5.

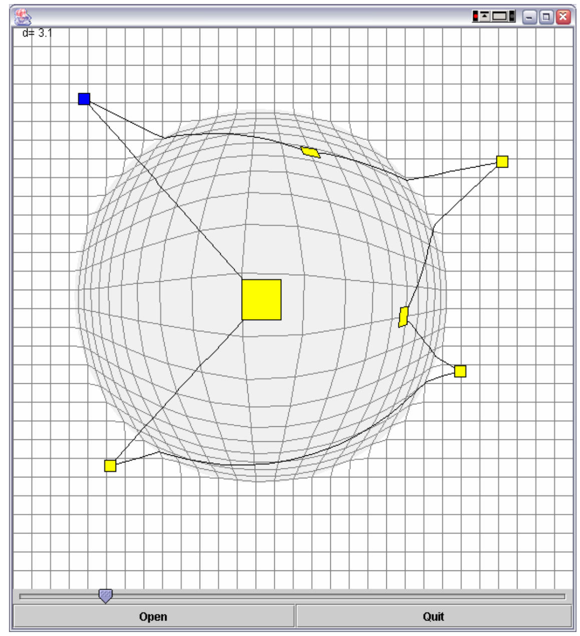

Figure 4. Constrained hemispherical lens.

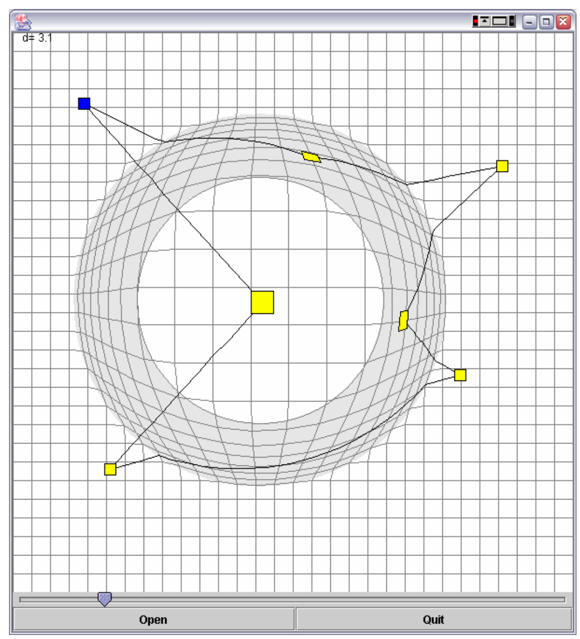

Figure 5. Constrained flat-hemisphere lens.

3.5 Study design

The study used a 3 x 3 within-participants factorial design. The factors were:

- Lens type: pyramid, hemisphere, or flat-hemisphere.
- Distortion level: 1, 3, 5.

Lens order was balanced using a Latin square design; distortion level was always presented in increasing order. We also gathered baseline data with no lens (which is the same as d=0). Within each condition, participants carried out two tasks, one with each target figure. In total, each participant completed 19 layouts (2 in each of 9 conditions, plus one baseline with no distortion). The study system recorded the following data:

- total positional error for each figure (by summing the individual differences between corresponding vertices in the target and test figures);
- total angular error for each figure (the sum of the differences between the angles of each corresponding edge in the target and test figures);
- completion time (although a maximum of 60 seconds was allowed for each task); and
- total lens movement for each task.

In addition, answers to summary questions about preferences were recorded on a questionnaire.

3.6 Procedure

Participants were assigned to one of three order groups, were introduced to the experiment and to the study system, and were asked to complete a practice trial with each lens at low distortion (*d*=1). Participants were thus familiar with the lenses and the target figures before testing began, but they had not seen the higher levels of distortion. Participants then completed the layout tasks in the baseline condition of no distortion, and then in each of the nine study conditions. Participants were instructed to be as accurate as possible in reproducing the target layout within the one-minute limit. Rests were allowed between conditions. After all conditions for a session were complete, participants were asked which of the three fisheye lenses they felt was most accurate, and which they preferred overall.

4 Results

Below we report on analyses of our main experimental factors (lens type and distortion level) for each of the measures (positional error, angular error, completion time, lens movement, and preference). Note that with no distortion there is no difference between the lenses, so the baseline condition was not included in the analyses; however, this case is included in charts (as either 'no distortion' or '*d*=0') for comparison purposes.

4.1 Positional error

Positional error is calculated by summing the individual Euclidean differences between each corresponding point in the source graph and the participant's graph. Using Analysis of Variance (ANOVA), we found significant main effects of both lens type and distortion level: for lens type, $F_{2,30}=9.95$, $p<0.001$; for distortion level, $F_{2,30}=28.84$, $p<0.001$. Means are shown in Figures 7 and 8. The lenses were consistently ordered at all distortion levels: the pyramid lens had the highest positional error amount, the hemisphere lens had the lowest, with the flat-hemisphere lens between. Note that the values in Figure 8 are likely generous towards the higher distortion levels, since participants had the most practice by the time they saw those conditions.

Given that there were six moveable nodes in the figure, these results mean that with no distortion, each node was 'off' by about 40 pixels from its true position; for the best-performing lens (the hemisphere), each node was off by about 70 pixels.

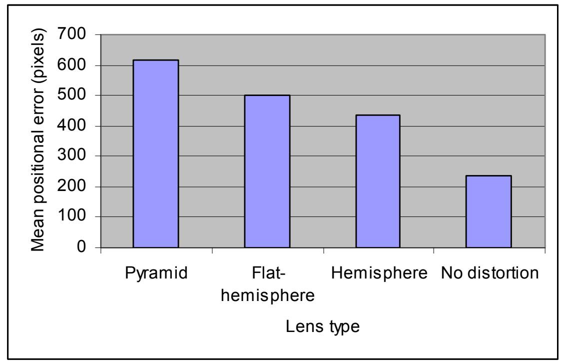

Figure 7. Mean positional error per figure for all lens types at all distortion levels. The no-distortion baseline is shown for comparison but was not included in the analysis.

A Tukey HSD test was carried out to look for differences between the individual lens types. There were significant differences between the pyramid lens and both of the others (between flat-hemisphere and pyramid, $p<0.05$; between hemisphere and pyramid, $p<0.001$). There was no significant difference between the two hemispherical lenses ($p=0.25$) when considering all distortion levels.

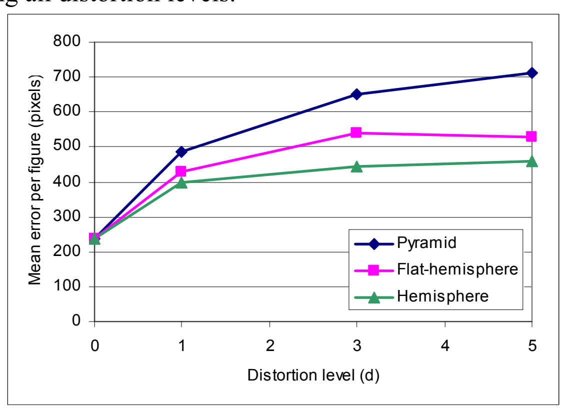

Figure 8. Mean error, by lens type and distortion level.

A significant interaction was also found between lens type and distortion level ($F_{4,60}=6.99$, $p<0.001$). Inspection of the means shows that as the distortion level increases, the differences between the full-screen pyramid lens and the other lenses increases. Follow-up Tukey tests to examine differences at each distortion level showed that the hemisphere lens was significantly better than the pyramid lens at distortion levels 3 and 5 (at d=3, $p<0.05$; at d=5, $p<0.01$). No other significant differences were found; the flat-hemisphere lens was not significantly different from either of the others.

4.2 Angular error

Angular error is calculated by summing the differences between the angles of each edge in the target figure and the corresponding edge in the participant's test graph. This measure differs from positional error in that it is not sensitive to scale: if participants were able to reproduce the shape of the figures but at a larger or smaller size, the angular error would be low. However, there was no difference between the lens types: ANOVA showed a main effect of distortion level ($F_{2,30}=28.35$, $p<0.001$), but not of lens ($F_{2,30}=2.64$, $p=0.088$). Means are shown in Figure 9.

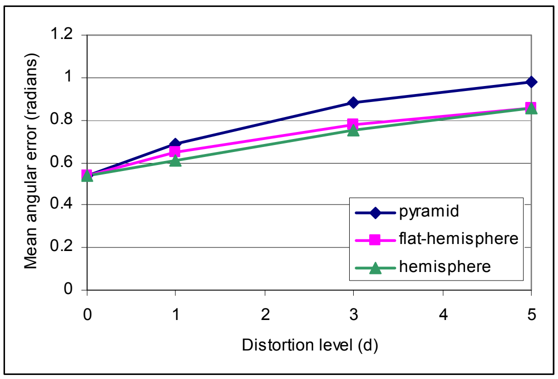

Figure 9. Mean angular error per figure, by lens type and distortion level.

4.3 Completion time

Although the time allowed for the task was limited to 60 seconds, participants were free to stop as soon as they felt that they had done the best job that they could. Completion time is therefore a measure of how long participants believed that they could continue to improve their layout with the given lens.

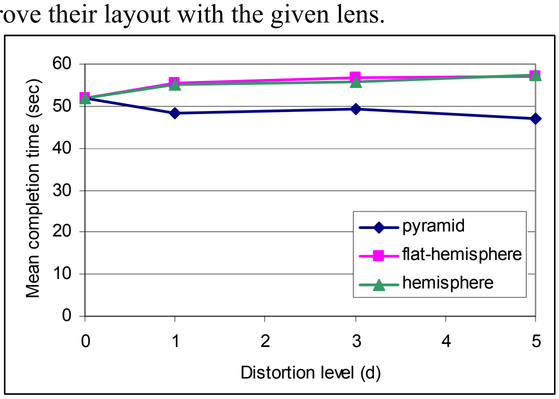

Figure 10. Mean completion time per task, by lens type and distortion level.

ANOVA showed only one significant effect, a main effect of lens type ($F_{2,30}=22.0$, $p<0.001$). As can be seen from Figure 10, people finished the task with the pyramid lens about eight seconds earlier than with the constrained lenses. It was clear from our observations that most participants using the pyramid lens did not feel that their figure was accurate when they stopped working – rather, they gave up because they felt that it would be difficult to do better given the distortion.

4.4 Amount of lens movement

The lens was under user control (the focus point of the lens followed the mouse cursor), and we recorded the number of pixels movement for each figure. There were main effects of both lens type ($F_{2,30}=21.37$, $p<0.001$) and distortion level ($F_{2,30}=3.88$, $p<0.05$). Figure 11 shows the clear difference between the pyramid and the constrained lenses; people moved the pyramid lens's focus only about 70 percent as much as the other two. Note that the lower time spent with the pyramid (see above) will have affected this data to a certain degree.

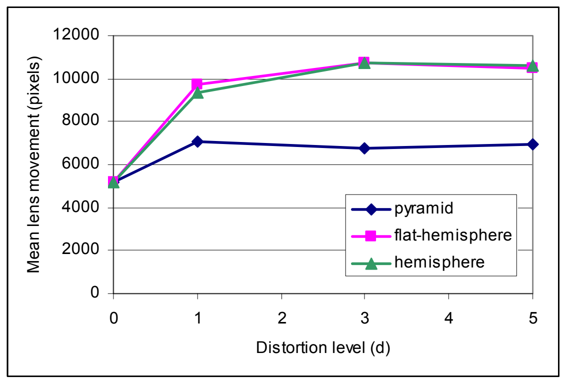

Figure 11. Mean lens movement per figure, by lens type and distortion level.

4.5 Preferences

Participants were asked at the end of the session to rank the three lenses (as well as the condition with no distortion) in terms of accuracy and overall preference. These results are shown in Figures 12-13. The figures show that all participants felt that no distortion at all was most accurate, but then were evenly divided between the pyramid lens and the flat hemisphere (7 participants each). Each of the three lenses received about the same number of votes for being the least accurate (6 for hemisphere, 5 each for pyramid and flat-hemisphere).

Overall preference responses, however, showed that a few of the participants actually preferred one of the fisheyes over no lens at all (see Figure 13). Three participants preferred the pyramid lens, and one the hemisphere; and again, these two lenses were the strongest second choices.

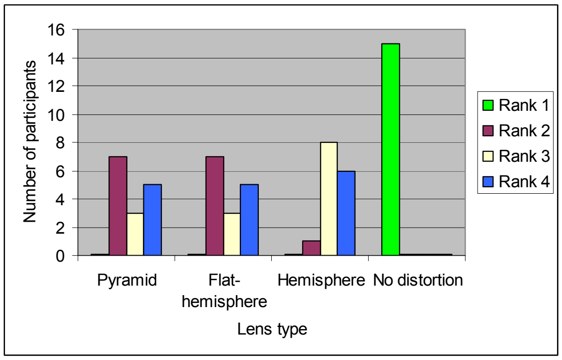

Figure 12. Participant opinions on which lens was most accurate. The cluster of bars for each lens indicates the number of participants ranking the lens as first, second, third, or fourth.

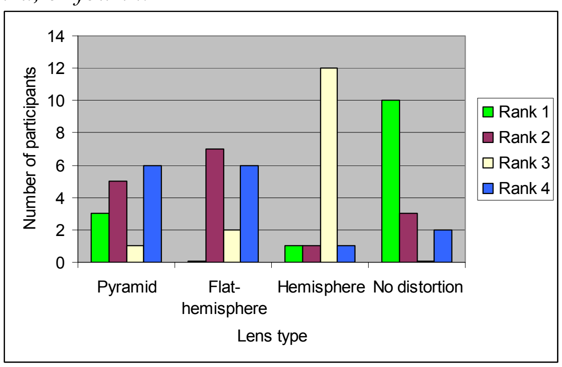

Figure 13. Participants' overall preferences.

5 Discussion

In the following paragraphs we review our main findings and consider underlying reasons for the results.

- *Finding 1. Layout tasks are considerably more difficult in fisheye views than in undistorted spaces, even when the lens can be moved.*

The distortion introduced by a fisheye view clearly affected the accuracy with which people were able to duplicate the target figures. Positional error with the fisheye views was on average twice what it was with no distortion. This is somewhat surprising for the two constrained lenses, since users can easily move them out of the way to compare their layout with the target. It seems likely, however, that although moving the lens allows comparison, it is still difficult to make accurate adjustments (since the lens must be over the data in order to interact with it). It is possible therefore that the constrained lenses put participants into a situation where they could see what changes they wanted to make, but were unable to make them accurately.

- *Finding 2. Constrained lenses allow for more accurate layout than full screen lenses.*

This result is what was expected at the outset. It was clear from the study that people had difficulty with the full-screen lens, particularly in terms of being able to compare their figure with the target. In several cases participants gave up before the allotted time was up, because they could not make further progress. Our observations suggest that the constrained lenses were better primarily because they could be moved off of the work area, which better allowed people to compare their current work with the target. This conclusion is reinforced by the differences in the amount of lens movement recorded during the task (see Figure 11).

- *Finding 3. People's overall preferences do not always match the performance data.*

Despite the pyramid lens's poor accuracy, nearly half of the participants (eight of 15) ranked it as either their first or second choice (even with the undistorted interface as an option). One possibility, based on comments from three participants, is that the full-screen lens provides a much more gradual transition from focus to context. Participants were more likely to 'lose' a node at the transition point of one of the constrained lenses, which may have figured in the pyramid's favour. Although this transition can be made as smooth as necessary with a different drop-off function [4], these lenses will always require considerably more space.

- *Finding 4. There is evidence to suggest that the flat hemisphere was worse than the simple hemisphere.*

Although there were no significant differences when comparing the two constrained lenses alone, the simple hemisphere was the only one of the two to show a significant advantage over the full-screen lens at the two higher distortion levels. Although this is weak evidence, it is interesting because it goes against our expectations: we expected the constant magnification of the flat region to provide a much better view of alignments, angles, and relative distances. It was clear that the flat-hemisphere lens was no faster, was no more efficient in terms of lens movement, and may have been less accurate. One reason why the constant-magnification region may not have been an advantage in our task is that nodes were not often close enough together to both be visible inside the flat region. This, however, is also likely true in other layout situations.

There are three main design guidelines that practitioners can take from this study. First, if layout accuracy is vital to the task, then the user should be able to turn off any distorting lenses – accuracy suffers even when lenses can be moved off the work area. Second, constrained lenses are still considerably better than full-screen lenses, particularly at higher levels of distortion; in addition, it does not appear to be useful for performance to provide a flat region in a hemispherical lens. Finally, it may be difficult to determine which lens types users will like best for a given application, regardless of which lens performs best.

6 Conclusion

Although interactive fisheye views are a solution to the screen space problem, we still have little empirical evidence about their usability, and little design information to use in choosing between different types. In this study, we compared people's performance on spatial layout tasks when using three types of fisheye view. The study shows the costs of distorting the representation of spatial information, but also shows that some fisheyes are better than others for these tasks.

Our overall goal in this line of research is to more fully understand the ways that people interact with data through distortion-oriented views, and the design implications of different representations. We plan to extend the results given here with additional comparisons of more types of fisheye lenses – both improvements on the fisheyes used here, and other types that have not been studied. In addition, we are considering ways to reduce the problems caused by distortion. For example, we plan to look at whether a superimposed grid will help people to understand relative positioning of objects in distorted space.

Acknowledgements

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