Finding Things in Fisheyes: Memorability in Distorted Spaces

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Abstract

Interactive fisheye views use distortion to show both local detail and global context in the same display space. Although fisheyes allow the presentation and inspection of large data sets, the distortion effects can cause problems for users. One such problem is memorability – the ability to find and go back to objects and features in the data. In this paper we investigate the issue of how people remember object locations in distorted spaces, using a Sarkar-Brown fisheye lens that drastically affects the space. We carried out two studies. The first gathered information about what memory strategies people choose at increasing levels of distortion, without presupposing any particular strategy. The second looked more closely at how two particular strategies (maintaining a mental map, and using landmarks in the data) affected memory performance. We found that as distortion increases, people do use different memory strategies and that at higher levels of distortion, landmarks become increasingly important as memory aids.

Key words: Fisheye views, landmarks, mental maps, 2D navigation, distortion-oriented visualization.

1 Introduction

Distortion-oriented visualization techniques allow the presentation of large data sets on limited-size displays (e.g. [5]). They show both local detail and global context in the same view, and allow the user to move the focus point to inspect different areas of the data. Fisheye views are one type of distortion-based visualization (e.g. [7,9]). Fisheyes are characterized by the smooth visual transition they provide between the high magnification of the focus region and the de-magnification of the context area (see Figure 1).

Fisheyes use non-linear magnification to balance magnification and compression of the data. Depending on where the focus is located, different areas of the data will be magnified, yet all the data will still be shown. Fisheye views effectively solve the problems of presenting both focus and context; however, despite the increasing size and complexity of data sets and the increasing popularity of visualization systems, fisheyes are not widely used. One reason for the slow adoption is that the distortion used to create the fisheye view can cause problems as people interact with the data (e.g. [1]).

One problem with fisheyes is that they can hinder people's abilities to remember where things are in the data. Since the nonlinear magnification function enlarges and compresses different parts of the space depending on where the focus is located, objects move around as the focus point moves. At high levels of distortion, they can move quite far from their original locations.

We are interested in how people can remember things in distorted spaces, with the goal of designing more usable fisheye views. Two strategies that people use to remember things in undistorted spaces are mental maps and landmarks. Mental maps are 'bird-eye-view' representations of the data where the locations of individual objects or features are maintained by their absolute position in the map [11]. Landmarks, in contrast, involve local knowledge, and help people to remember object locations by forming distinct relationships based on visual, spatial, or semantic content [3]. However, both of these strategies can be affected by distortion, and it is not known what people use in fisheye views.

To investigate these issues, we carried out two studies that looked at landmarks and mental maps in a well-known fisheye technique. The first study gathered information about how people thought they would remember particular objects at several increasing levels of distortion. This study showed that people use colour as a main landmarking technique, and that they only

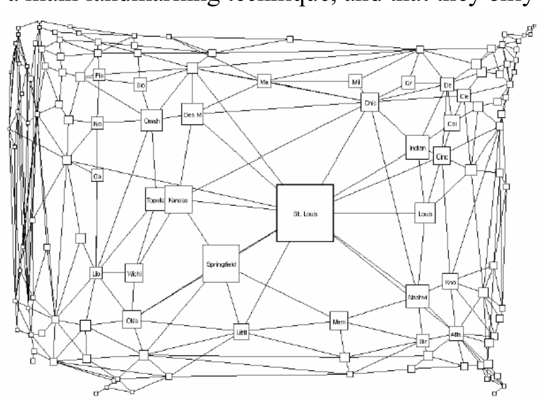


Figure 1. Fisheye view of a map of the United States with the focus point at St. Louis. Objects grow larger as the focus approaches them.

begin to use other features of the data when colour becomes difficult to use. The second study looked more closely at how two strategies – maintaining a mental map of the space, and using landmarks – affected performance in a before-and-after memory game. We found that the changing layout of the data (which should primarily affect mental maps) had much less effect on memorability than whether objects were near robust landmarks. Our results suggest that memorability in fisheye views may be improved if designers explicitly design data spaces to include landmarks that are robust to changes in distortion.

In this paper, we first present a brief review of fisheye views and spatial memory techniques, and then report on the methods, results, and implications of the two studies.

2 Interactive Fisheye Views

Fisheye views are focus+context techniques that show both local detail and global context in the same view (e.g. [4, 9]). Fisheyes, named for the photographer's wide-angle lens, are characterized by their ability to show all of the data in a single view, and by the smooth transition between the high magnification of the focus region and the de-magnification of the context area.

Fisheye views use non-linear magnification to achieve their balance between magnification and compression of the data; depending on where the user's focus point is, different areas of the visualization will be magnified (or de-magnified) by different amounts. Fisheye lenses have been applied to two [5] and three dimensions [5], use either Cartesian or polar coordinate systems [5], and may have multiple points of focus [5]. In this paper, we use the well-known Sarkar and Brown technique [6], a 2D fisheye in which distortion is controlled by a single parameter *d*, and in which the position of every object in the data space (e.g. every node in a graph) is recalculated for a new focus point. This type of fisheye was chosen for this initial study because of its drastic effects. It represents the extreme of distortion of fisheye lenses, and its influence on memorability should therefore be clear.

Interactive fisheyes provide a user-controlled focus point for indicating which part of the data is to be shown in detail. As the focal point moves around the graph, nodes are magnified and demagnified, and moved to make room for the focus region. As the focal point moves in a Sarkar and Brown fisheye, every part of the graph will also move to some extent.

3 Methods of Preserving Spatial Memory

There are several methods that can be used to remember the position of an object in a space. People may use the object's absolute position ("in the top left corner of the screen"), what is near the object ("next to the purple star") or some semantic property of the object or its surroundings ("the node labelled 'Armadillos' in the section about exotic pets"). With any method, however, navigating a data space relies on the user's memory of it. When the space changes, the user can become confused if steps are not taken to minimize how the change affects the particular strategy in use.

In terms of the absolute positioning of objects in a graph, Misue et. al [11] called the user's memory of the space the *mental map*, and identified three properties that should be preserved in order to maintain it: orthogonal ordering, clusters, and topology. Other research [12, 13] has concentrated on preserving these properties as much as possible when the space is changed.

The concept of the mental map is based on the idea that the user's memory of the space is like a bird's-eye view, using absolute positions such as "the top right corner" to describe the location of items. The more an item changes in terms of its absolute position, the more damaged the user's mental map becomes.

The idea of the mental map has a parallel in the development of spatial memory of real world spaces. The highest level of spatial knowledge is called *survey knowledge* [3], which is the ability to take a bird's eye point of view of one's environment. This is effectively having a mental map of the real world space.

In research on spatial navigation [7, 8], however, landmark knowledge as well as survey knowledge has been investigated. Landmark knowledge has been shown to be a factor in successful spatial memory, both in real and virtual spaces [2, 9]. Landmark knowledge is the memory of distinctive features of a space, and the relation of all elements of the space to those features. Objects become landmarks because of their distinctiveness, either because of a visual property or because of some significance to the navigator. As long as the landmarks are identifiable, spatial memory is preserved, even if time has passed or the landmarks are seen from a different perspective [10]. Describing an object as being "near the purple star" is using a distinctive feature of the space as a landmark.

The semantic content of an object can either be used as a landmark ("the only node labelled 'Armadillo'") or as a basis for organizing the space in clusters to improve navigation and memorability. Like landmarks, the semantic content is an aid to spatial memory as long as the content is visible.

4 Overview of Studies

A fisheye transformation applied to a graph, either by changing focus or distorting the space, can be considered redrawing the graph; therefore, it is reasonable to consider how well the mental map, landmarks and the visibility of semantic content are preserved. In a Sarkar-Brown fisheye, some properties of a graph are exactly the same before and after changing the focus or distortion level: orthogonal ordering, topology, and edge shape. Other metrics will show differences between two focuses of the same fisheye graph, such as the angles and distance between nodes. Depending on the degree of distortion, the individual nodes in the non-focus area may be too small to see any detail. The effect that these changes have on the user's spatial memory is investigated in the following two experiments.

The first study was designed to identify the memorization strategies that people choose at increasing levels of distortion in a fisheye view of a graph. The second study examined the effect of distortion, magnitude of focus-point change, and distance from landmarks on user performance in simple memory tasks.

Both studies used the same two-dimensional graph for the data space (see Figure 2). The graph was always displayed using a Sarkar-Brown fisheye visualisation at one of four different distortion levels (d = 0 (no distortion), d = 1, d = 3 and d = 5). The graph had several features that could be used as landmarks, but no special effort was taken to create intentional landmarks. The nodes were repeated thumbnail representations of Web pages, with several colour schemes and different semantic content. There were varying numbers of edges between nodes, and several unique node-edge shapes, referred to below as "constellations."

5 Study 1 – Memorisation Strategy Identification

5.1 Participants

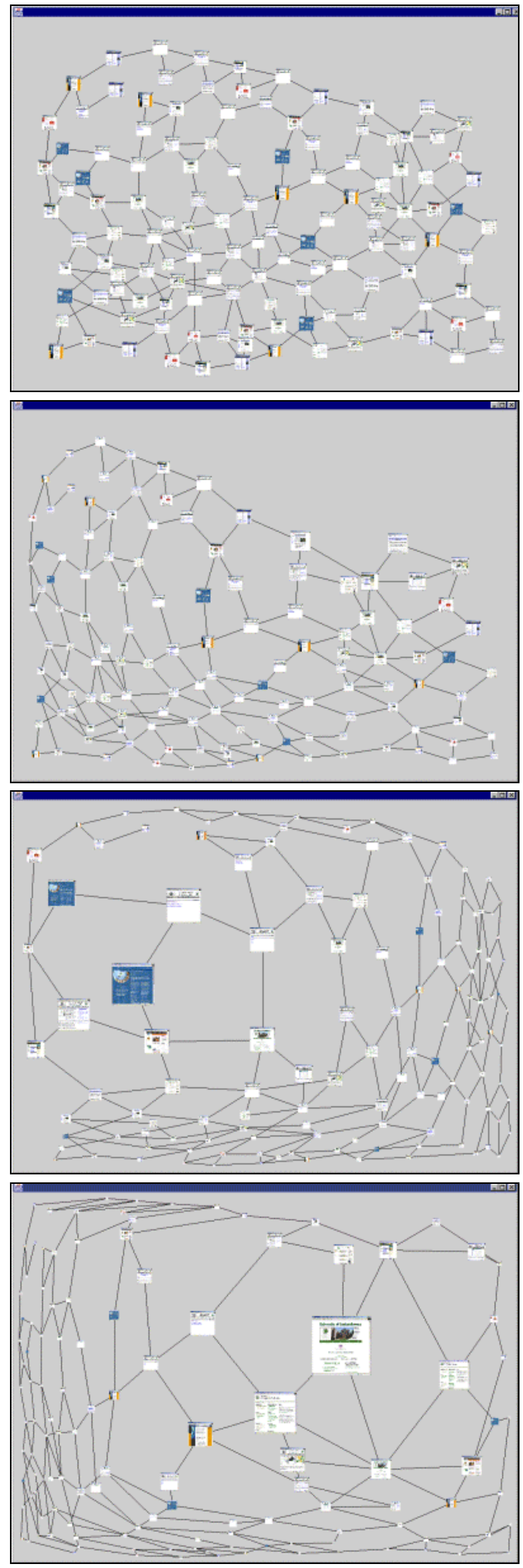
The subject group for the first study was seventeen fourth-year Computer Science students at the University of Saskatchewan. Their participation was rewarded by a bonus mark in a class that they were all taking. All participants were frequent computer users (at least twelve hours a week) and only one had ever used a software application with a fisheye view before.

5.2 Apparatus

The experiment was run on a PII Windows NT PC. The graph was shown on the PC with a custom built Java application to provide the fisheye distortion. The focal point of the fisheye lens was linked to the mouse cursor, and participants were able to freely move the focal point to investigate the effects of the distortion on the graph.

5.3 Procedure

Participants were introduced to the system and to the fisheye representation. They were allowed to interact



d = 0

d = 1

d = 3

d = 5

Figure 2. Graph used in the study, showing distortion levels 0,1,3,and 5. Note that the focus point is different in each picture.

with the system and move the focus point for several minutes, in order to familiarize them with the way that the distortion effect worked. Participants were then asked to state how they would remember particular nodes in the graph, for each of several distortion levels and focus positions. With each screen, participants were given time to understand the current distortion effect by freely moving the mouse for one minute.

If participants did not mention any specific memory scheme, they were asked if there were any features that stood out with the current distortion level, and also if there were any areas of the graph that would be particularly difficult to remember.

5.4 Results

The study was designed to investigate what techniques people used to maintain their spatial awareness of the distorted space, and to determine any common factors in choice of technique. The experimental graph was not designed to deliberately encourage any one method. The techniques that participants identified were grouped into five categories: 1) absolute screen position, 2) landmarking by node colour, 3) landmarking by edges and corners of the graph structure, 4) landmarking by constellations (shapes formed by nodes and edges) and 5) semantic content of the nodes.

We expected participants to mainly use screen position and constellation landmarks at low levels of distortion, since those are properties defined as important in the mental map and at low levels of distortion, the users' mental map would be unchallenged. At high levels of distortion we expected greater use of colour and semantic content, since these properties do not vary with distortion. However, contrary to expectations, participants chose landmarking by colour as the most popular strategy at all levels of distortion except d=5 (Figure 3). At this level of distortion, the majority opinion was that out-of-focus nodes were too small to see their colour. Landmarking by constellation was the second most popular strategy, and actually became the first choice at the maximum distortion level despite the distortion's effect on the constellations' shapes. Absolute screen position remained secondary to the landmarking strategies, but at higher levels of distortion it became a popular way to specify a neighbourhood so that the focus magnification would show enough detail to use other properties as landmarks.

With landmarking being such a common choice, we further investigated the properties that were chosen by the majority as being effective landmarks. Figure 4 shows the most commonly chosen landmarks circled for each distortion level. The weight of the circle is roughly proportional to the number of participants who identified that landmark.

At zero distortion, all participants chose landmarking by colour as the main strategy. All seventeen participants mentioned colour as the first property that made an area distinctive. Pairs of distinctively coloured nodes were identified as being especially useful by five subjects. When constellations on the edge of the graph and the graph edges and corners themselves were mentioned, they were always secondarily to colour.

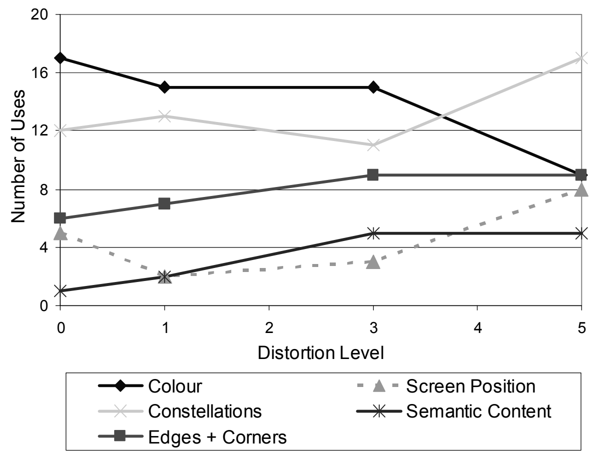
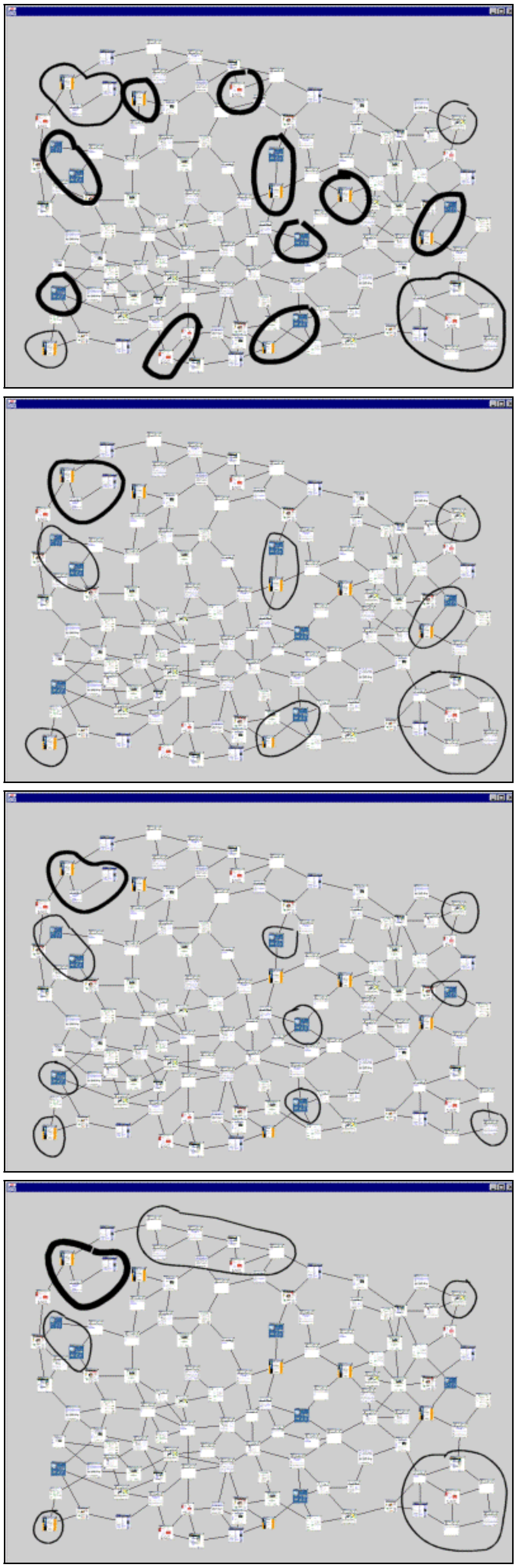


Figure 3. Memorisation strategy choices (number of times mentioned over all tests) for each distortion level.

When some distortion was added to the graph (d = 1), colour was still the most commonly mentioned feature. However, nine participants said that now the pairs of coloured nodes were more useful than the single nodes. Also, as shown in Figure 4, fewer participants used absolute screen position and more relied on the edges and corners of the graph itself. Six participants, however, said that this level of distortion did not affect their memory strategies at all.

As distortion increased (d = 3), the effect of the fisheye lens became noticeable to all the participants. Seven said that only dark blue was an effective landmark now, since the nodes became too small when not magnified to see any of the other colours. However, eight people also said that the constellations became too distorted to be effective landmarks. The overall effect was described as "very uncomfortable" by one subject, and several said that nothing was useful as a landmark unless the focus was already in the neighbourhood. Absolute position was mentioned only in the context of getting "into the neighbourhood" and then using other landmarks. The use of edges and corners, in default of any other feature, was more frequently mentioned. The semantic content of the nodes was also mentioned for the first time by several participants, since the magnification of the focus was finally large enough for the details of the node to become visible.

At the maximum level of distortion (d = 5), most participants found that even the dark blue nodes became



d=0

d=1

d=3

d=5

Figure 4. Landmarks chosen at different distortion levels (note that images are not distorted).

too small to distinguish when they were out of the focus. Almost all participants that still used colour as a landmark did so only after using absolute screen position to put the focus in the neighbourhood first. At this distortion level, however, the greater apparent motion of the nodes as the fisheye focus moved seemed to help several participants see the constellations. One subject explicitly commented "I just now noticed that sawtooth shape!" and several said that the cube shape in the lower left corner was actually easier to see as a unit as it was being moved around by the changing focus. Semantic content was mentioned, like colour, as being useful when the focus was in the neighbourhood.

Participants were also asked to identify areas of the graph they thought would be especially difficult to remember. All participants identified the lower left of the graph as being difficult, since it is a dense and homogenous area with few distinctive features.

6 Study 2 –Effects on Memory Tasks

Based on the results of the first study, we decided to look more closely at the interaction of the landmarking and the mental map memorisation strategies. We thought that the participants would use a combination of the two strategies when attempting memory tasks in a distorted space, rather than one exclusively.

6.1 Participants and Apparatus

The subject group for the second part of the experiment was seven participants recruited from the first study. The second study used the same experimental setup and application as the first, and the same two-dimensional graph was used.

6.2 Procedure

The second study tested the participants' memory of the experimental space through a set of memory tasks. For each distortion level, five memory tasks were given. For each of these, the graph was shown with the focus fixed in a certain location, and a node in the graph (not necessarily at the focus) was outlined in red. Participants were asked to memorise the location of the red target node. A second static image of the graph was then shown but with the focus at a different point and without the red outline on the target. Again, the mouse cursor did not affect the focal point. The participants were then asked to click on the target node.

The study used a 4x1within-participants factorial design. The factor was distortion level (d=0,1,3,5). With seven participants and five trials, there were 140 tasks recorded in total. The study system recorded the participant's selections and the time required to find each target in the second view.

6.3 Results

In each task, two factors determined how much the graph changed between the first and second view: the distortion level, and the distance that the focal point changed moved (*focal point delta*). These factors affected the absolute position of each node of the graph to some extent. If participants were only using a mental map memorisation strategy, then these factors should have been the only ones that affected their performance in the memory tasks. However, we found that their performance was also dependent on the proximity of the target node to a distinctive landmark. In the following sections we report on how distortion, focal point delta, and proximity to landmarks affected performance.

Effect of Distortion Level on Performance

In general, we expected participants' accuracy in the memory tasks to decrease as the distortion level increased, and the average time to find the target to increase with the distortion level. In general, this does occur (see Figures 5 and 6); however, there is considerable variation within each distortion level. Some tasks took longer to complete at a lower distortion level than ones at a higher level, and some tasks at low distortion had lower accuracy than tasks at a higher distortion.

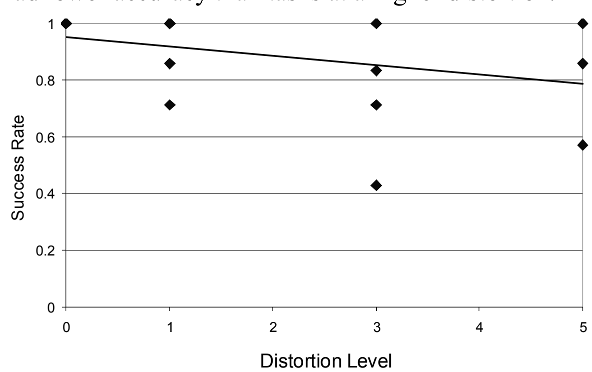


Figure 5. Accuracy in each memory task (mean of all participants) as a function of distortion level.

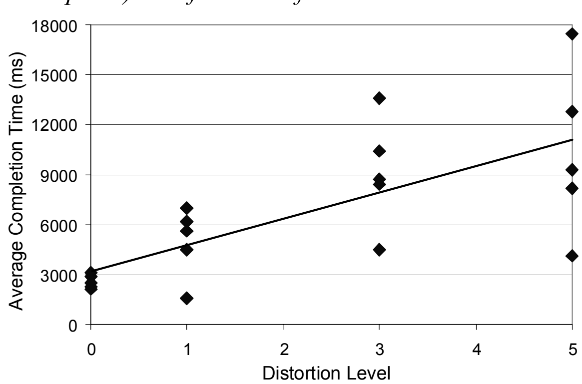


Figure 6. Completion time in each memory task (mean of all participants) as a function of distortion level

We tested the correlation between accuracy and completion time, and distortion level. There is only a weak relationship with accuracy ($r^2 = 0.037$ $p < 0.005$), and a slightly stronger one with completion time ($r^2 = 0.18$, $p < 0.001$).

Effect of Focal Point Delta on Performance

Similar to the effect of the distortion level, we expected participants' accuracy in the memory tasks to decrease if the focal point delta increased, and the average time to find the target to increase if the focal delta increased. Again, this occurs in general, but with large variations (see Figures 7 and 8). Completion time and accuracy are not well predicted by focal point delta: for accuracy: $r^2 = 0.0072$, $p = 0.32$; and for completion time, $r^2 = 0.0001$, $p = 0.93$.

Effect of Landmark Proximity on Performance

Given people's dependence on landmarks in Study 1, we expected the proximity of the target to a landmark to affect performance. These effects are shown in Figures 9 and 10. The distance to the landmark is expressed in steps - the graph path length between the target and the nearest landmark. Counting steps in the graph was the used by all participants when landmarking in Study 1.

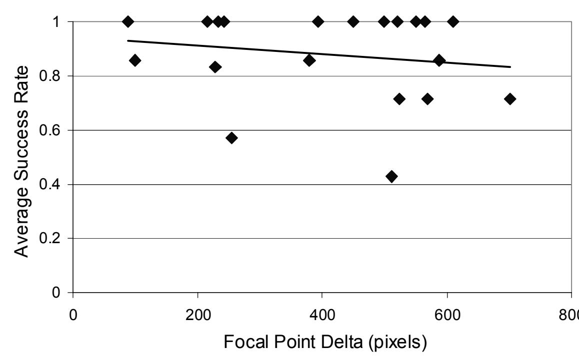


Figure 7. Accuracy in each memory task (mean of all participants) as a function of focal point delta.

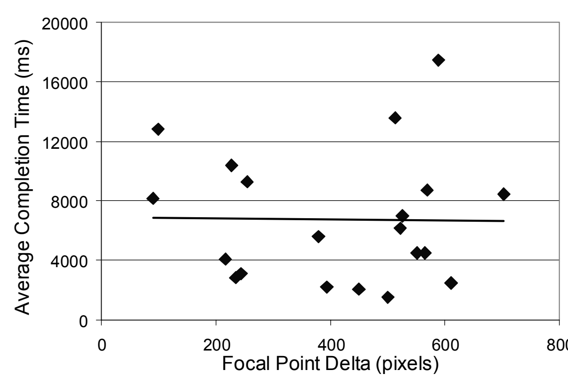


Figure 8. Completion time in each memory task (mean of all participants) as a function of focal point delta.

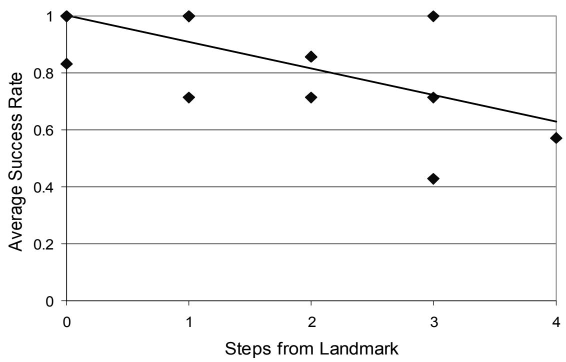


Figure 9. Accuracy in each memory task (mean of all participants) as a function of steps from a landmark.

Completion time and accuracy are as strongly predicted by landmark proximity as they are by distortion and focal delta (for accuracy, $r^2 = 0.12$, $p < 0.001$; for completion time, $r^2 = 0.089$, $p < 0.001$). When all three factors are combined, the prediction is stronger, but still explains only a small fraction of the overall variance: for accuracy, $r^2 = 0.14$, $p < 0.001$; for completion time, $r^2 = 0.22$, $p < 0.001$).

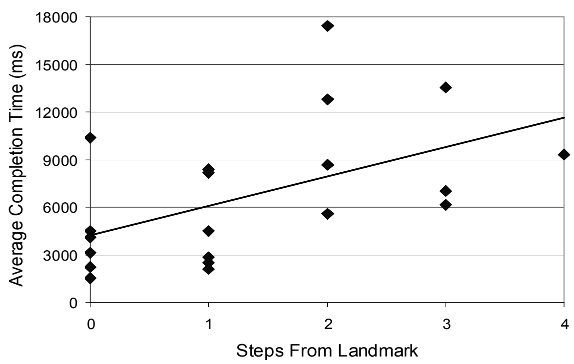


Figure 10. Completion time in each memory task (mean of all participants) as a function of steps to landmark.

Case Studies

There are several of the tasks that provide interesting case studies of how landmarks and mental maps interact with performance measures. In these cases, tasks at the same distortion level and with comparable (within 15%) focal point deltas had very different results for accuracy and completion time. We consider three in particular, one at d=1, one at d=3, and one at d=5.

Tasks 8 and 9, both occurring at d=1, are compared below in Table 1 (actual target locations are shown in Figure 11). In Task 8, the target is on an edge, and connected to a coloured corner node (one step away from a commonly identified landmark). The target in Task 9, in contrast, is in the middle of the homogenous are that was identified as difficult by all participants. It is three steps away from the closest landmark, (a blue pair on the left edge).

	Task 8	Task 9
Avg. Accuracy	100%	72%
Avg. Completion Time (ms)	1556	7005
Focal Delta (pixels)	500	524
Landmark Distance	0	3

Table 1. Comparing Tasks 8 and 9

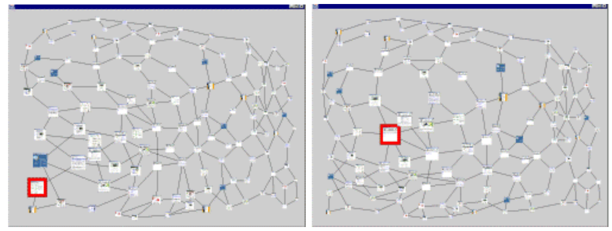


Figure 11. Target locations forTasks 8 (left) and 9.

Tasks 12 and 15, both occurring at d=3, show a similar difference in Table 2 (target locations shown in Figure 12). The task 12 target is again located in the homogenous area, three steps away from the nearest commonly identified landmark (the blue node on the lower left edge), while the Task 15 target is only one step away the dark blue node on the upper right edge.

	Task 12	Task 15
Avg Accuracy	42%	100%
Avg Completion Time (ms)	13,553	4514
Focal Delta (pixels)	512	564
Landmark Distance	3	1

Table 2. Comparing Tasks 12 and 15

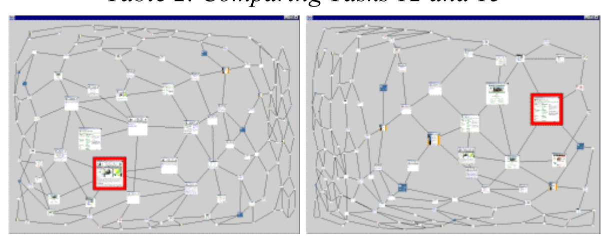


Figure 12. Target locations for Tasks 12 (left) and 15

Finally, we compare Tasks 18 and 19 (at d=5) in Table 3 (target locations shown in Figure 13). Again, the target of Task 18 was located in the homogenous area, while that of Task 19 was on the graph edge and next to a very popular landmark (the “hook” shape).

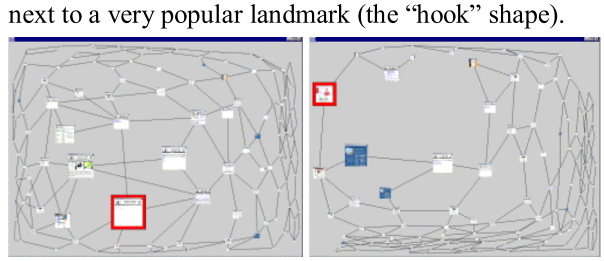


Figure 13. Target locations for Tasks 18 (left) and 19

Task 18 target was near one potential landmark; the notch in the edge, but only one subject identified that as a landmark. Most instead counted from the left edge, and one subject said they had no strategy at all for that task.

	Task 18	Task 19
Avg Accuracy	57%	100%
Avg Completion Time (ms)	9299	4090
Focal Delta (pixels)	254	216
Landmark Distance	4	0

Table 3. Comparing Tasks 18 and 19

In both of these cases, the accuracy in the memory tasks could be predicted only by considering the focal delta and the distortion level in light of target location in relation to the identified landmarks.

7 Discussion

A mental map, which stores the absolute positions of objects, is an important method by which people remember a space. Obviously, changing the absolute positioning of the space can damage this mental map. Distortion-based presentations, such as fisheye lenses, affect the mental map and encourage users to find additional methods to remember the location of objects. Remembering landmarks is one of these methods.

The first study showed that the subjects used a combination of landmarking and absolute positioning to describe the location of objects in a distorted space. Although the specific features described as landmarks varied, the participants used the technique at all levels of distortion.

The second study confirmed that a combination of techniques was affecting the participants' performance in memory tasks. In a fisheye visualization, the space changes its appearance because of two factors; the distortion level and the focal point delta. A high distortion level and a large focal point delta will create two quite different looking views of the same data. However, in the memory tests that we conducted, distortion level and focal point delta alone did not predict the participants' accuracy in memory tasks – this stands in contrast to the strong focus that has previously been placed on the idea of maintaining the mental map (e.g. [11,12,13]). It is clear from our studies that success in remembering a target may depend considerably on how near the target is to a landmark. The experimental data space contained many features that could be used as landmarks, and some features were identified by all the subjects as distinctive. Targets that were near these identified landmarks were easier to remember.

8 Lessons for Designers

Preserving the mental map as much as possible is still an important goal when changing a data space. But if affecting the map is unavoidable, such as when using a distortion-based presentation, there may be other ways to preserve memorability.

Though this has yet to be confirmed by further experiments, colour seems to be by far the most distinctive property that a screen object can have. Contrasting colours were used as landmarks in preference to any other memory strategy by all participants, for as long as colour was visible. This may have been because the graph was fairly dense and structurally uniform, but it shows that colours should to be carefully chosen. Deliberately giving certain features contrasting colours may be a promising way of introducing landmarks to aid memorability.

The constellations (the patterns formed by the graph connections) were the next most popular landmark despite their aspect becoming distorted. These, though, are dictated by the graph data and cannot be chosen or changed as a design decision as easily as colour can. If three nodes are connected linearly (A to B to C) then distortion will not cause A to be connected to C. Similarly, the borders and corners of the graph were commonly described as referents and these too depend on the graph structure. A node on the border will stay on the border no matter what the distortion. Indeed, this constancy is what makes them good landmarks. However, it may be possible to alter the graph layout to create distinctive structural features (creating a "fjord" halfway along each edge, for example).

Since landmarks can affect the user's ability to remember a target, a data space should be designed with the 'landmarkability' of its components in mind. Depending on the data space, that could mean preserving certain spatial relationships, or choosing colour to match either the semantic content of nodes or the structure of the data itself. The important thing to remember is that landmarks need to be distinctive with respect to their surroundings. When users can identify and trust landmarks in the data space, distortion has a less detrimental effect on their spatial memory.

9 Conclusion and Future Work

In this paper we investigated the problem of memorability in fisheye views. This study was a preliminary comparison of memory techniques, with only one data set and one distortion method, to set a direction for further, detailed research.

We carried out two studies: the first shows that people make use of landmarks (particularly colour) but also use a range of memory strategies; the second study showed that changes to the data space itself can not be used to reliably predict accuracy or completion time in memory tasks. We showed that landmarks play a role in many cases, but that there is still considerable variance that may be explained by other factors.

In future work, we hope to look for these factors (such as gender) and continue the exploration of how people remember things in distorted spaces. In addition to increasing the number of subjects, we also plan to do further experiments to look more closely at the relationships between focal point delta, distortion, and landmark distance. We are particularly interested to see whether the idea of 'landmarkability' can be added to any current graph layout algorithms to improve graphs used in fisheye views. Finally, this experiment used the Sarkar-Brown fisheye, which affects every part of the view when the focus is changed. We plan to test other types of distortion views, such as a limited-extent fisheye or a bifocal lens [5], which have less of a global effect on the view. Constrained lenses reduce overall changes to layout, which may reduce damage to the mental map, and may make structural landmarks more usable at higher levels of distortion.

References

[1] Gutwin, C. (2002) Improving Focus Targeting in Fisheye Views. In Proc. ACM CHI 2002, 267-274

[2] Satalich, G. (1995). Navigation And Wayfinding In Virtual Reality: Finding The Proper Tools And Cues To Enhance Navigational Awareness. Master's Thesis, University of Washington, Seattle. http://www.hitl.washington.edu/publications/satalich

[3] Lynch, K., (1960). The Image of the City. Cambridge, MA: MIT Press.

[4] Furnas, G.W. (1981) "The FISHEYE View: a new look at structured files" Bell Laboratories Technical Memorandum #81-11221-9

[5] Leung, Y. and Apperley, M. (1994) "A review and taxonomy of distortion-oriented presentation techniques", ACM Transactions on Computer-Human Interaction, Vol. 1 No. 2, June 1994, pp. 126-160.

[6] Sarkar, M. and Brown, M. (1992) Graphical Fisheye Views of Graphs. In Proc. ACM CHI'92, 83-91

[7] Siegel, A.W., and White, S.H., (1975). The Development of Spatial Representation of Large-Scale Environments. In H.W. Reese (Ed.), Advances in Child Development and Behavior. New York: Academic Press.

[8] Golledge, R.G. (1999) "Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes", Johns Hopkins University Press

[9] Sadalla, E. K., Burroughs, W. J., and Staplin, L. J. (1980) Reference points in spatial cognition. Journal of Experimental Psychology: Human Learning and Memory, Vol. 6 No. 5, 516-528.

[10] Spencer, J. and Schöner, G. (2000). A Dynamic Field Model of Location Memory. In Proc. CogSci2000 http://www.cis.upenn.edu/~ircs/cogsci2000/PRCDNGS/SPRCDNGS/posters/spe_sch.pdf

[11] Misue, K., Eades, P. Lai, W. and Sugiyama, K. (1995) Layout Adjustment and the Mental Map. Journal of Visual Languages and Computing, Vol. 6 No. 2, 183-210.

[12] Storey, M., Fracchia, F., and Müller, H. (1999). Customizing a Fisheye View Algorithm to Preserve the Mental Map. Journal of Visual Languages and Computing, Vol. 10 No. 3, 245-267.

[13] Bridgeman, S. and Tamassia, R. (2000). Difference Metrics for Interactive Orthogonal Graph Drawing Algorithms. Journal of Graph Algorithms and Applications, Vol. 4 No. 3, 47-74.