Distortion Viewing Techniques for 3-Dimensional Data

M. Sheelagh T. Carpendale, David J. Cowperthwaite and F. David Fracchia

School of Computing Science
Simon Fraser University
Burnaby, B.C. V5A 1S6 CANADA
carpenda@cs.sfu.ca

Abstract

As the use of 3D information presentation becomes more prevalent the need for effective viewing tools grows accordingly. Much work has been done in developing tools for 2D spaces which allow for detail in context views. We examine the extension of such 2D methods to 3D and explore the limitations encountered in accessing internal regions of the data with these methods. We then describe a novel solution to this problem of internal access with the introduction of a distortion function which creates a clear line of sight to the focus revealing sections previously obscured. The distortion is symmetric about the line of sight and is smoothly integrated back into the original 3D layout.

Keywords: Distortion viewing, screen layout, 3D interaction, information visualization, interface metaphors, interface design issues

1. Introduction

There is accumulating evidence [1, 21] supporting the idea that 3D representations of data are advantageous both intuitively and quantitatively. As this translates into frequent use of 3D information spaces the need for effective 3D viewing tools becomes increasingly important. There has been a considerable amount of work recently in developing such tools for 2D information displays. Much of this has focused on the need to display sufficient detail within its global context; for surveys see [15, 11, 18]. This has led to the notion of multi-scale diagrams [8] or distortion viewing where different sections of the information are displayed at different scales. These differing scales of magnified detail and compressed context can be integrated through various distortion functions [2, 3, 9, 10, 16, 19].

Support for the concept of integrated detail in context viewing can be found in studies by Furnas [7]. This work indicates that across many disparate fields humans store and recall information in great detail for areas of interest and gradually decreasing detail for the related context. The studies in experimental psychology [6, 12] go further to indicate that while humans integrate information that is perceived as a single event automatically, cognitive re-integration of distinct events such as multiple views requires much greater effort.

Semnet [5] discusses two 3D fisheye approaches and the implicit one provided by perspective. One, based on semantics, uses an octree to display the focal region in full detail and more remote sections in progressively larger volumes. This approach is quite efficient but suffers from sudden changes between boundaries of regions of differing scales. The other, a density approach, samples fully around the focus and less as the distance increases. This approach would actually aggravate density problems in the focal region. Mitra [14] method of threshold filtering exploded views while not actually moving occluding objects does create more space in the 3D view allowing improved if not total visual access for internal sections.

This work explores the extension of 2D distortion viewing techniques, providing framework and motivation for the development of visual access distortion techniques for 3D data. Inherent in working with data in 3D is the fact that some data will be buried within a structure, whether a solid model or a complicated 3D graph layout, and hence visually inaccessible. Previous work provides access to the internal details of such structures through the use of cutting planes, layer removal and transparency. We describe a novel solution to this problem of internal access with the introduction of a distortion function which creates a clear line of sight to a focus revealing sections that had been previously obscured. The distortion is symmetric about the line of sight and is smoothly integrated back into the original 3D layout.

This paper is organized as follows: first we will demonstrate the problems that arise with a naive translation of 2D techniques to a 3D display. Then extend Leung and Apperly's [11] observations about the mathematical distinction between displacement and magnification functions with a practical application of these aspects separately creating our viewer aligned visual access distortion [4] to provide an exploration tool for 3D information displays.

2. Identifying issues in 3D distortion viewing

This section illustrates the problems that arise when applying 2D distortion techniques to 3D displays. The intention is to demonstrate the distinctive patterns of differing types of distortion, and show that while they offer considerable advantage in a 2D display, they do little to improve access in 3D. Figure 1 shows the characteristic patterns of four 2D distortion methods. While this set of example techniques is not exhaustive, it is representative of the types of distortion available. The space-filling orthogonal approach (top left), similar to stretch tools [17] and 2D-bifocal [18], is formed by stretching all data that lies on either of the two axis centered at the focus and compressing the remaining areas uniformly. The resulting distorted image makes good use of available screen space but has entire rows and columns of distorted data.

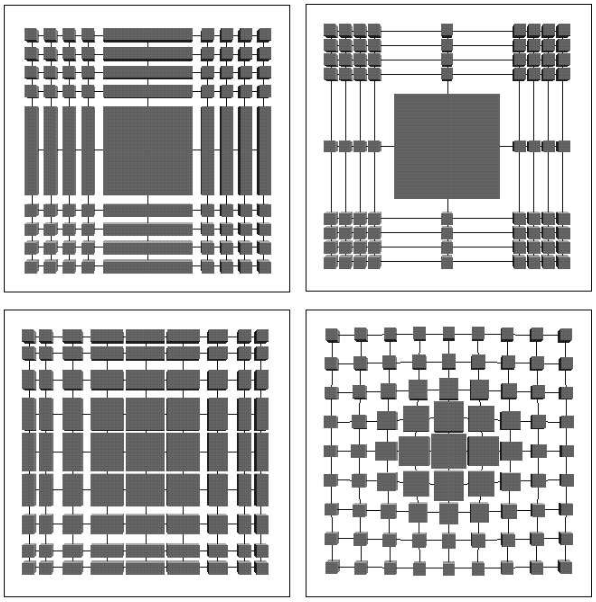

Figure 1: A group of 2D distortion methods, from top-left to bottom-right: space-filling orthogonal, simple orthogonal or step, graduated orthogonal, and radial Gaussian distortion

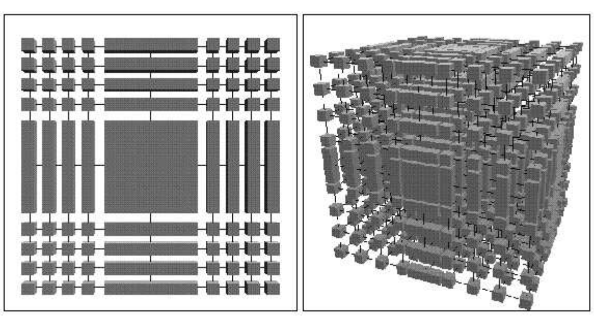

Figure 2: Space-filling orthogonal applied in 3D

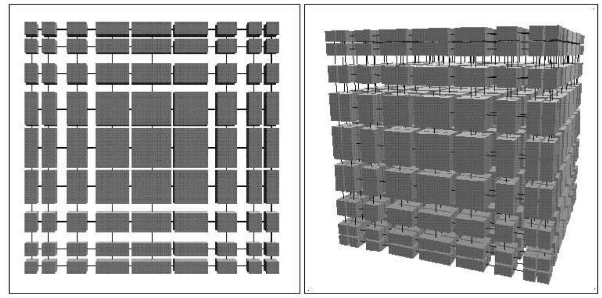

Figure 3: Graduated orthogonal stretch applied in 3D

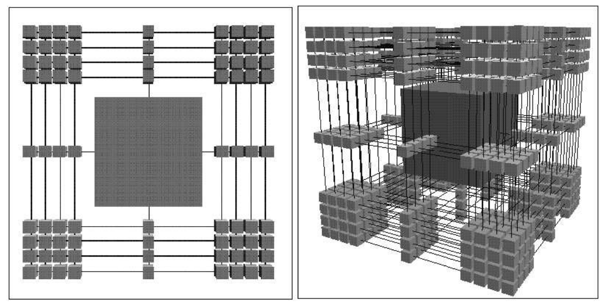

Figure 4: Simple orthogonal or step applied in 3D

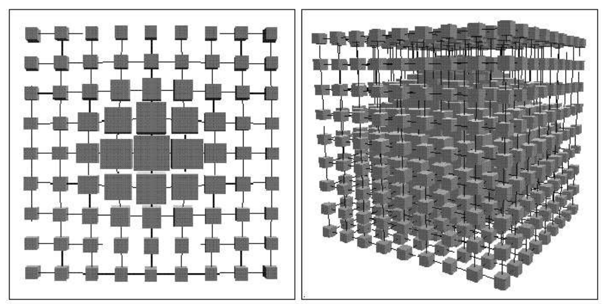

Figure 5: Gaussian radial magnification applied in 3D

The simple orthogonal approach (top right), used by [2, 20], performs the same distortion but leaves the data in the rows and columns aligned with the focus unstretched. This basic approach creates less data distortion but leaves more unused space. The graduated orthogonal approach (bottom left) magnifies data according to its orthogonal distance from the focus. A variety of mathematical curves have been used with this approach including arctan [9, 13], hemisphere [16], and hyperbola [10]. The particular pattern of this figure is based on the sine curve. The fourth example (bottom right) uses a Gaussian curve to radially distribute the distortion. Again other curves are possible, in fact many techniques include both radial and orthogonal options. The principle of non-linear radial distortion is common to [3, 10, 17].

These four distortion patterns reveal the different possibilities offered in providing a magnified focus in a 2D context. Figures 2, 3, 4 and 5 show a direct naive extrapolation of the previously discussed two-dimensional schemes to 3D data. Simply applying these approaches to a three-dimensional display does more to obscure the focal point than reveal it. In fact, the usual problem of some objects occluding others in 3D layouts has been exacerbated in 2D distortion approaches with space-filling aspects. While the orthogonal step function (Figure 4) does open up some visual access to the focal node, it still does not allow viewing from all angles. If distortion is to aid in full examination of internal aspects of 3D data, one necessary function is that the user actually have unrestricted visual access to the chosen focus.

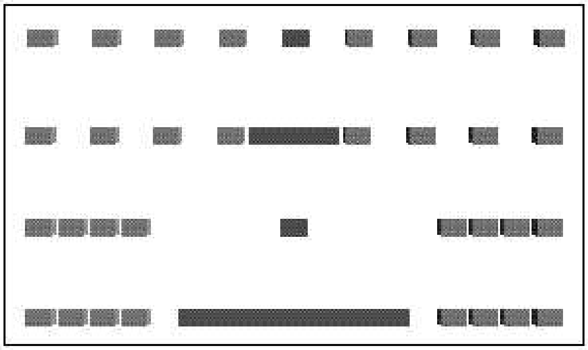

Figure 6: One-dimensional orthogonal distortion, from top to bottom: original data, magnification only, displacement only, magnification and displacement

Leung and Apperly [11] discuss distortion viewing in terms of a transformation or displacement function with a derivative magnification function. As the 2D examples reveal, displacement provides the space that allows for the magnification. The usual application creating 2D detail within context views is achieved by applying both magnification and displacement distortions simultaneously. However, this does not have to be the case; these ideas are distinct and can be applied alone or in conjunction. Figure 6 shows at the top an undistorted one-dimensional array of cubes, second from the top is the same array with a central focus magnified only (no nodes are displaced), third the distortion is applied to displace nodes to either side of the focus (no magnification), and the last example makes use of both magnification and distortion.

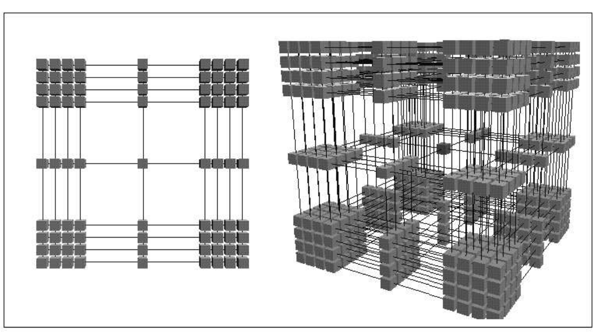

Figure 7: Both types of orthogonal displacement provide the same distortion patterns without magnification

The effects of applying only displacement distortion with the four 2D approaches we have been examining can be seen in Figures 7, 8 and 9. Notice that without the magnification

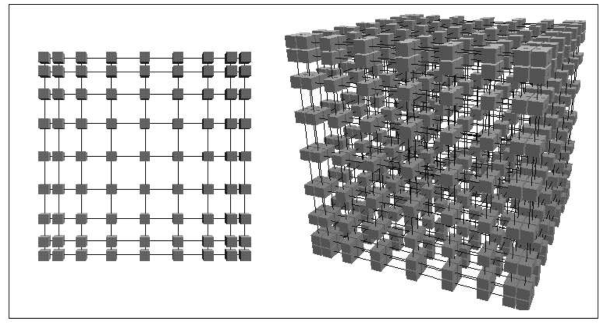

Figure 8: Graduated orthogonal displacement without magnification

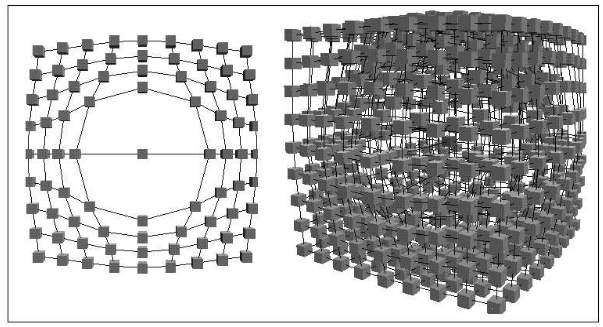

Figure 9: Gaussian radial displacement without magnification

both orthogonal techniques have the same appearance (Figure 7). This offers little improvement with the graduated and radial techniques (Figures 8 and 9). However, while the orthogonal approaches seem an inefficient use of space in two dimensions, in three dimensions the separation provides partial visual access. However, this partial solution is not very satisfying and creates artificial groupings which can still occlude the focus during rotation.

3. Visual Access Distortion

We believe that for effective three-dimensional detail in context viewing it is important to:

- Magnify a chosen focus to display detail.
- View the focus as a 3D object with the usual advantage of rotation, allowing examination from all angles.
- Clear a visual path to the focus.

We have extended the traditional magnification and displacement distortion viewing to include a visual access distortion [4]. This is applied radially along the line of sight to displace data items in gradually decreasing amounts as the distance from the line of sight increases. This creates an opening directly in front of the view point, giving visual access to the focus while minimally affecting the rest of the data. Figures 10, 11 and 12 show an undistorted lattice and two views using a particularly effective combination, simple orthogonal magnification combined with our visual access distortion.

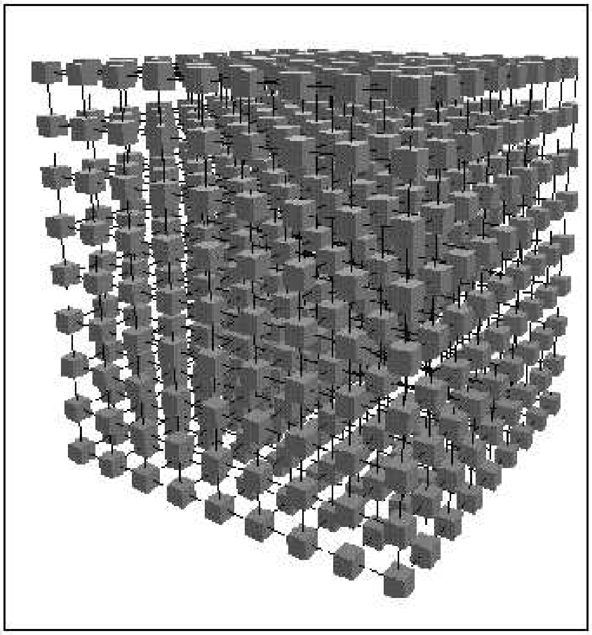

Figure 10: Ordinal lattice with no distortions

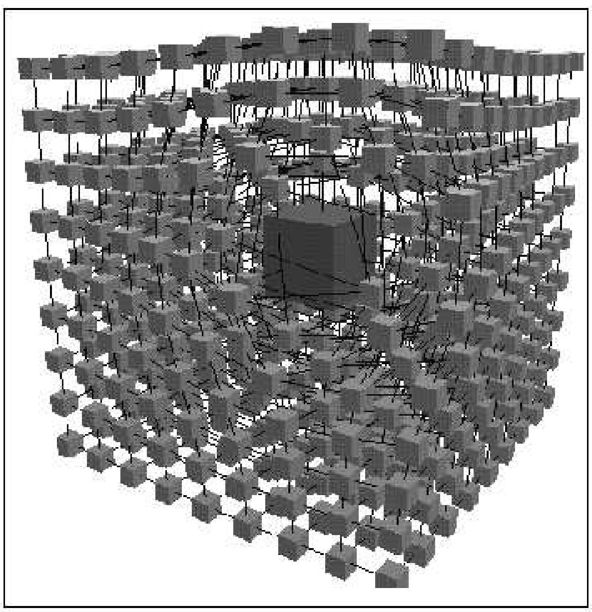

Figure 11: Lattice with central focus made visible through radial Gaussian expansion along line of sight. Focus magnification is applied through the simple orthogonal pattern

Our method uses the ideas and techniques, particularly those concerned with occlusion and blending of interfocal regions, developed in 3DPS [3], extended to 3D information spaces. Visual access distortion proceeds as follows. Let L be a line segment extending from the focus to the viewpoint (the line of sight), and a vector $\vec{v}$ be the shortest vector from an object O in the display and a point P on the line L (used to establish the direction of the displacement). A Gaussian

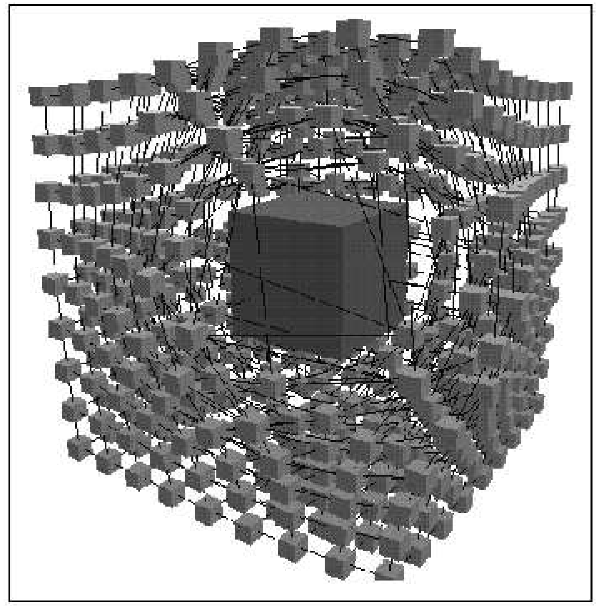

Figure 12: The same lattice with increased displacement of interfering nodes and magnification of focus

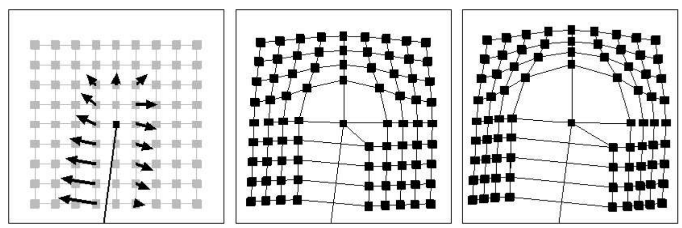

Figure 13: 2D cross-section of view aligned Gaussian access distortion. Nodes are displaced away from the line of sight along a vector perpendicular to the line segment from the focus to the viewpoint. The line to the lower left indicates the direction to the viewpoint, degree of distortion increases left to right

function is used to calculate the magnitude of the displacement. The image on the left of Figure 13 indicates in cross-section the focal node, the line of sight, and the direction of radial displacement. The remaining series in Figure 13 shows progressive applications of the visual access distortion.

The shortest distance from a object O to the line of sight is the measure that will be used to determine the distortion at O. A vector $\vec{v}$ from the nearest point P on the line of sight to O will define the direction of the distortion at O and the length of this vector $|\vec{v}|$ will be used to determine the magnitude of the distortion. To achieve our goal of smooth integration back into the original data topology we use a Gaussian distribution to determine the magnitude of the displacement. For a given value of $d = |\vec{v}|$, we can determine the height (h) of the Gaussian. The shape of the Gaussian function, and hence the distribution of the distortion can be controlled simply by adjusting the height and standard deviation of the curve. Since our viewing direction is along the line of sight the distortions will appear to the viewer as radially symmetrical about the focus.

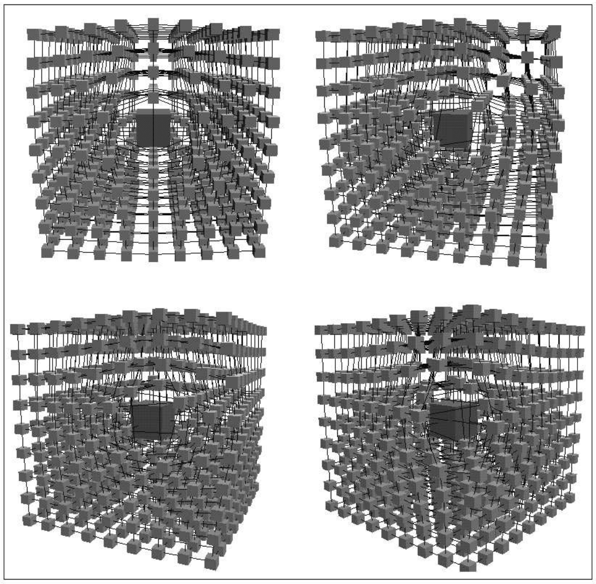

Figure 14: The distortion remains aligned to the viewer as the data set is rotated, nodes are moved smoothly away from the line of sight

The result is a distortion of the original data that provides a clear visual path from the viewer to the focal node. The visibility of the focus will be maintained under rotation of the data or motion of the viewpoint, smoothly deflecting nodes away from the line of sight as they approach it and returning them smoothly to their original positions as they move away (Figure 14).

The creation of a clear visual path can now be combined with one of the magnification distortions described earlier to permit an unobstructed view of the focus. Currently, one has choice between the four discussed functions (orthogonal, step, sine and Gaussian) for each of the the three types of distortion (access, displacement and magnification).

4. Combining visual access, magnification and displacement

Our visual access distortion [4] can be applied by itself or in combination with either or both magnification and displacement distortions. By itself it allows in context browsing of a 3D display. With magnification it provides detail in context viewing. With the inclusion of displacement greater degrees of magnification can be achieved.

Applying a visual access distortion to any of the four examined 2D approaches (see Figure 6) successfully exposes the focus in context. Figures 15, 16, 17 and 18, show 2D magnification applied to 3D on the left, and the result of applying the visual access distortion on the right.

In Figure 15 the space filling approach (left) has completely occluded the central focus node. In applying the visual access distortion we see that it clears a line of sight to the focus.

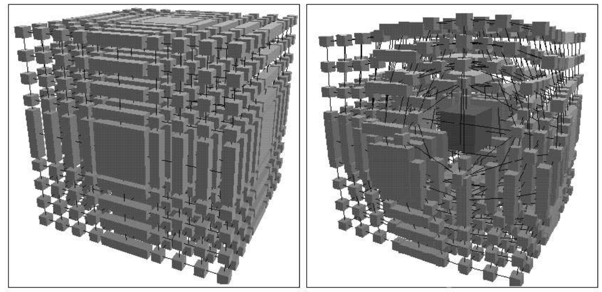

Figure 15: The space-filling orthogonal distortion around the central focus in 3D on the left, and with the visual access distortion on the right

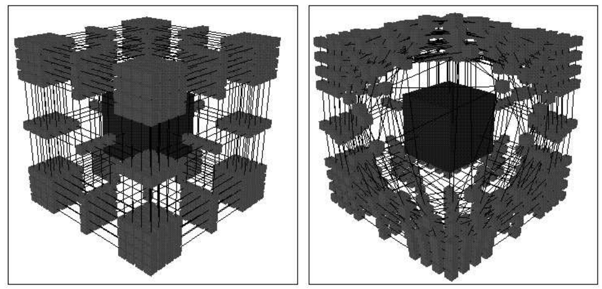

Figure 16: The simple orthogonal distortion around the central focus in 3D on the left, and with the visual access distortion on the right

In Figure 16 the simple orthogonal approach (left) magnification of the central node leaves it highly obscured by its neighbors. The application of the visual access distortion (right) can be even more extreme as the inter-node spacing of the surrounding nodes is greater. It is possible to displace them further before they intersect. This combination of the simple orthogonal stretch or step function which magnifies focus only and the visual access distortion is particularly effective.

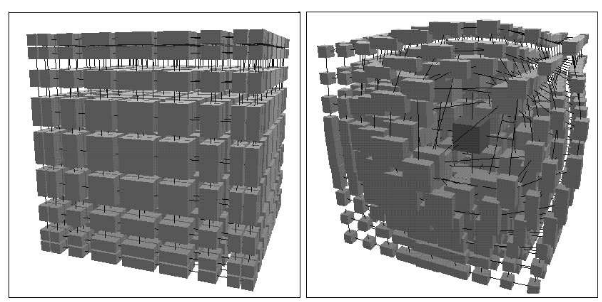

Figure 17: The graduated orthogonal distortion around the central focus in 3D on the left, and with the Gaussian access distortion on the right

In Figures 17 and 18 the central focal node is obscured by its neighbors as they are magnified as well (left), though to a lesser degree. Once again the viewing access distortion (right) restores the visibility of the central focus.

Visual access distortion scales well to multiple focal points. Because each line of sight utilizes its own access dis-

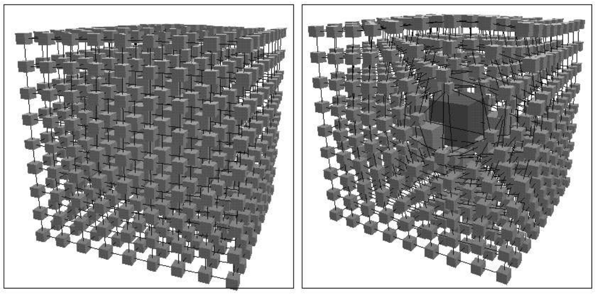

Figure 18: The radial Gaussian distortion around the central focus in 3D on the left, and with the visual access distortion on the right

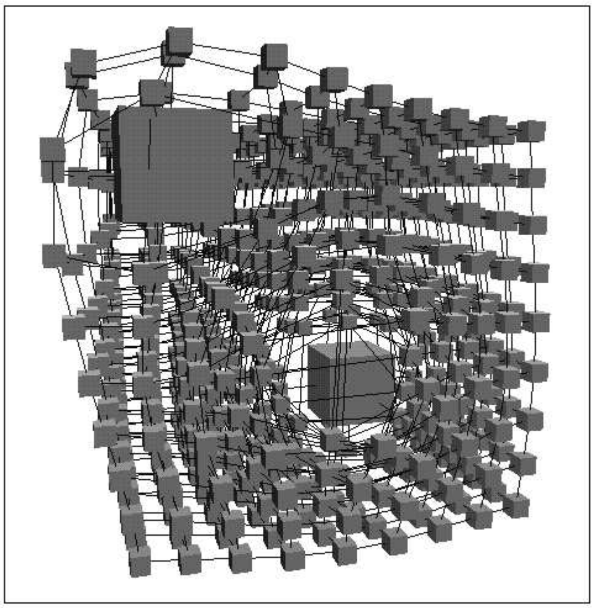

Figure 19: The visual access function may be applied simultaneously to more than one focus

tortion function, it is possible to combine more than one focus in one view. For each point in the volume the distortion is now a function of each line of sight. The contributions from each focus are combined [3]. The displacement of any point P relative to a set of n line segments L_i, where each segment L_i begins at an object of interest O_i and terminates at the viewpoint V, may be summarized as follows:

$$D = \frac{\sum_{i=0}^{n}(P - N_i) \times g(|P - N_i|)}{n}$$

where N_i is the point on the i^{th} line segment nearest the point P and $g()$ is the function that returns the height of a Gaussian given the distance from the point P to the line L_i. The resulting displacement is the average of several independent distortions, each in a radial direction away from the line segment L_i. Thus it is possible to clear lines of sight to several objects simultaneously. In Figure 19 a simple average of the two at each point produces clear lines of sight to the two foci. The upper left is one layer deep into the 9x9x9 cube. The lower right is 8 layers deep, but still visible.

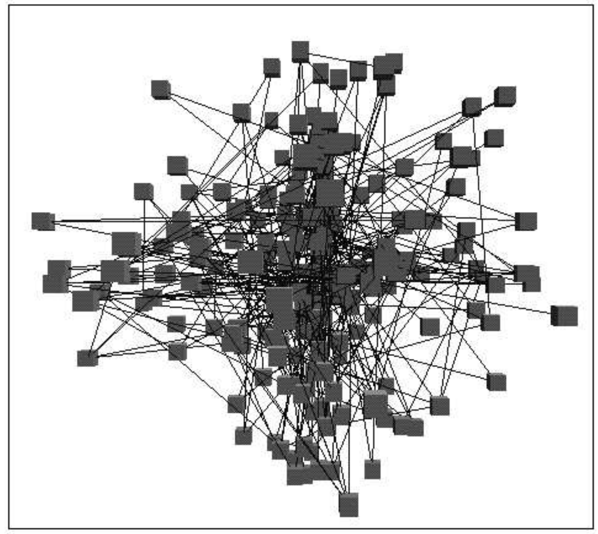

Figure 20: Undistorted random polar graph layout

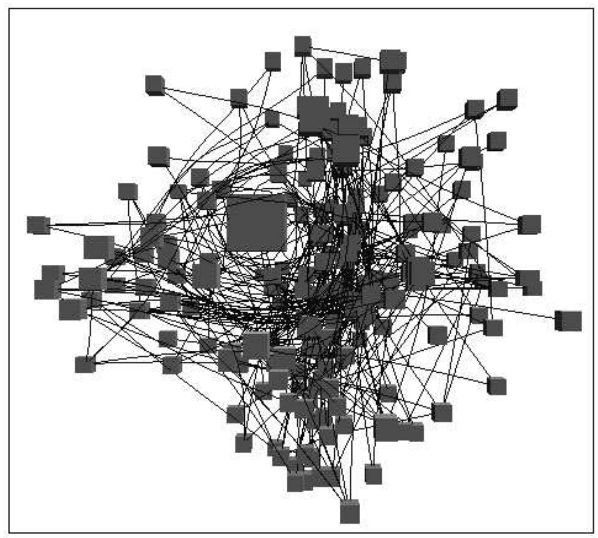

Figure 21: Random graph revealing focal node (from back of graph) with visual access distortion

A focal point can be either data objects or locations in space. When the focal point is an object, the visual access distortion is applied from the viewpoint to the object's center. Browsing involves sequential selection of objects or nodes. Alternatively using a location in space sets the end point of the line of sight that is cleared. The user can interactively control this line-segment-of-sight creating a dynamic probe, fluidly movable through the space. In browsing a 3D display the user can select focal type, position as well as which distortion method to use for displacement, magnification and access. During visual exploration each item is shifted out of the line of sight and then back into their original position. This motion provides very effective visual feedback about the context and relative positions of the individual data items.

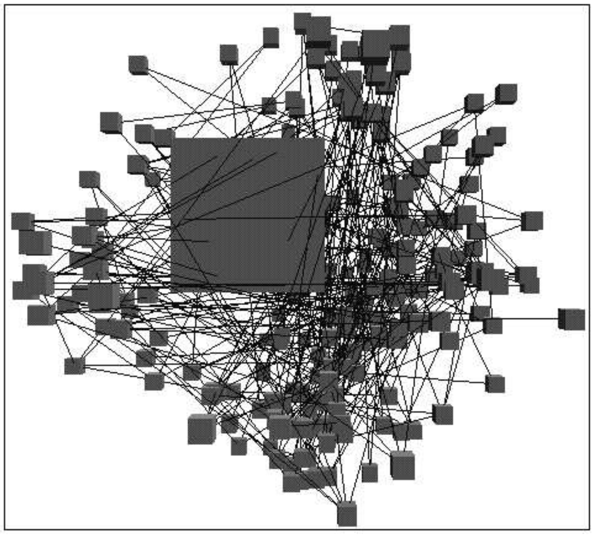

Figure 22: Increased magnification brings crossing edges into conflict

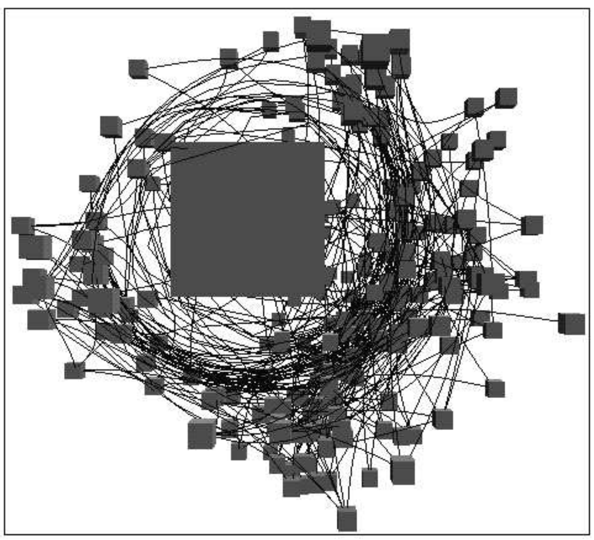

Figure 23: Visual access distortion also applied to edges

5. Arbitrary graphs

While simple grid graphs have been chosen to clearly reveal the distinctions between distortion techniques, the effectiveness of this approach is not limited to this type of display. The next series shows a polar graph layout that randomizes the radius and angles. Figure 20 is the undistorted graph. Figure 21 shows one focal point, slightly magnified. Figure 22 shows increased magnification of the focal point but with the visual access distortion applied to nodes only. This leaves edges cutting across the focal node. In Figure 23 the visual access distortion has also been applied along the length of the edges, curving them away from the line of sight.

Figure 24 shows a graph layout that randomizes position in x, y and z. Even though this graph's degree is limited to four, the random layout has a large number of edges that criss-cross the screen, creating their own type of visual density. Figure 25 shows one focal point revealed. The magnification and displacement distortions use the simple orthogonal or step function and Gaussian access distortion.

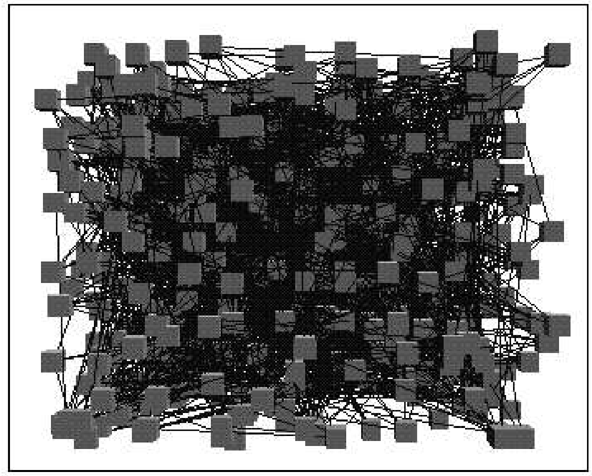

Figure 24: Random graph with dense edge structure

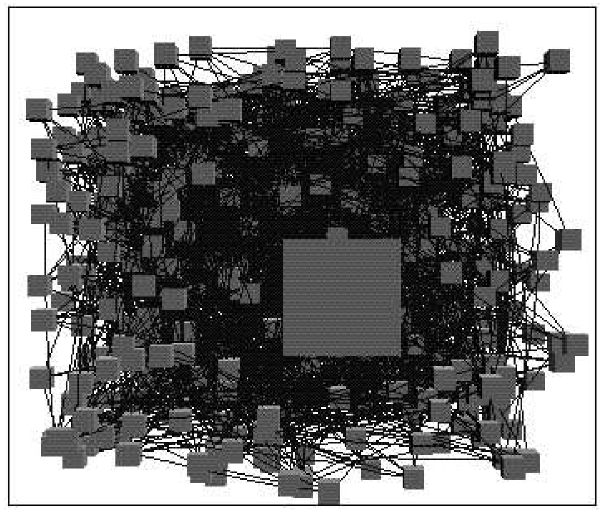

Figure 25: Random graph with one focal point

6. Conclusions

This paper has examined the issues that arise in applying established methods for improving visual access of 2D data to 3D. Simple 2D distortion algorithms for detail and context views have been shown to be readily extensible to manipulate 3D data. These approaches in themselves are insufficient to derive much benefit in 3D as the recurring problem of interior, or hidden, data becoming inaccessible nullifies any advantages of this straightforward approach.

Visual access distortion provides a clear line of sight to the internal structures of 3D data sets meeting the stated goals of smooth integration, using view rather than data alignment, and providing control over the degree and extent of the distortion. This method of displacing the data preserves context and presents an appealing, understandable result. The viewer aligned access distortion may be applied in conjunction with another space allocation algorithm to further improve the visibility of the focus.

Future plans for this concept include the application of the ideas presented here to both general 3D graph structures and to solid 3D data. An examination of the potential use of perceptual cues (3D grids, color and shading, stereo display) to reveal the nature of the distortions when applied to more general data sets, is another area of investigation we intend to pursue.

Acknowledgments

This research was supported by graduate scholarships and research and equipment grants from the Natural Sciences and Engineering Research Council of Canada. Thanks also to the Algorithms Lab, Graphics and Multimedia Research Lab and the School of Computing Science, Simon Fraser University.

References

1. K. W. Arthur, K. S. Booth, and C. Ware. Evaluating 3d task performance for fish tank virtual worlds. *ACM Transactions on Information Systems*, 11(3):239–265, 1993.
2. L. Bartram, R. Ovans, J. Dill, M. Dyck, A. Ho, and W. S. Havens. Contextual assistance in user interfaces to complex, time critical systems: The intelligent zoom. In *Graphics Interface'94*, pages 216–224, 1994.
3. M. S. T. Carpendale, D. J. Cowperthwaite, and F. D. Fracchia. 3-dimensional pliable surfaces: For effective presentation of visual information. In *UIST: Proceedings of the ACM Symposium on User Interface Software and Technology*, pages 217–226, 1995.
4. D. J. Cowperthwaite, M. S. T. Carpendale, and F. D. Fracchia. Visual access distortion. In *CHI'96: Proceedings of the ACM Conference on Human Computer Interaction*. ACM Press, 1996.
5. K. M. Fairchild, S. E. Poltrock, and G. W. Furnas. Semnet: Three-dimensional graphic representations of large knowledge bases. In *Cognitive Science and its Applications for Human-Computer Interaction*, pages 201–234. Lawerence Erlbaum Associates, 1988.
6. B. D. Fisher and Z. W. Pylyshyn. The cognitive architecture of bimodal event perception: A commentary and addendum to Radeau. *Cahiers de Psychologie Cognitive/Current Psychology of Cognition*, 13(1):92–96, Feb. 1994.
7. G. W. Furnas. Generalized fisheye views. In *Human Factors in Computing Systems: CHI'86 Conference Proceedings*, pages 16–23, 1986.
8. G. W. Furnas and B. B. Bederson. Space-scale diagrams: Understanding multiscale interfaces. In *CHI '95: Proceedings of the ACM Conference on Human Computer Interaction*, pages 127–140, 1995.
9. K. Kaugers, J. Reinfelds, and A. Brazma. A simple algorithm for drawing large graphs on small screens. In *Lecture Notes in Computer Science: Graph Drawing*, pages 278–282, 1994.
10. J. Lamping and R. Rao. Laying out and visualizing large trees using a hyperbolic space. In *UIST: Proceedings of the ACM Symposium on User Interface Software and Technology*, pages 13–14, 1994.
11. Y. K. Leung and M. D. Apperly. A review and taxonomy of distortion-oriented presentation techniques. *ACM ToCHI*, 1(2):126–160, 1994.
12. D. W. Massaro. Attention and perception: An information integration perspective. *Special Issue: Action, attention and automaticity. / (In Acta Psychologica)*, 60(2-3):211–243, Dec. 1985.
13. K. Misue and K. Sugiyama. Multi-viewpoint perspective display methods: Formulation and application to compound digraphs. In *Human Aspects in Computing: design and Use of Interactive Systems and Information Management*, pages 834–838. Elsevier Science Publishers, 1991.
14. D. A. Mitra. Fisheye presentation of information: Imis user interface. Air Force Office of Scientific Research, contract no. F49620-88-C-0053, 1989.
15. E. G. Noik. A space of presentation emphasis techniques for visualizing graphs. In *Graphics Interface'94*, pages 225–233, 1994.
16. M. Sarkar and M. H. Brown. Graphical fisheye views. *Communications of the ACM*, 37(12):73–84, 1994.
17. M. Sarkar, S. Snibbe, O. J. Tversky, and S. P. Reiss. Stretching the rubber sheet: A metaphor for viewing large layouts on small screens. In *UIST: Proceedings of the ACM Symposium on User Interface Software and Technology*, pages 81–91, 1993.
18. R. Spence. A taxonomy of graphical presentation. Information Engineering Section report 93/3, Imperial College of Science, Technology and Medicine, 1993.
19. R. Spence and M. Apperly. Data base navigation: an office enviroment for the professional. *Behaviour and Information Technology*, 1(1):43–54, 1982.
20. M. A. Storey and H. A. Muller. Graph layout adjustment strategies. In *Graphing Drawing '95*, 1995.
21. C. Ware, D. Hui, and G. Franck. Visualizing object oriented software in three dimensions. In *CASCON'93 proceedings*, 1993.