Graph Folding: Extending Detail and Context Viewing into a Tool for Subgraph Comparisons

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Abstract. It is a difficult problem to display large, complex graphs in a manner which furthers comprehension. A useful approach is to expand selected sections (foci) of the graph revealing details of subgraphs. If this expansion is maintained within the context of the entire graph, information is provided about how subgraphs are embedded in the overall structure. Often it is also desirable to realign these foci in order to facilitate the visual comparison of subgraphs. We have introduced a distortion-based viewing tool, three-dimensional pliable surface (3DPS) [1], which allows for multiple arbitrarily-shaped foci on a surface that can be manipulated by the viewer to control the level of detail contained within each region. This paper extends 3DPS to include the repositioning of foci so as to bring together spatially separated regions for the purpose of comparison while retaining the effect of detail in context viewing. The significance of this approach is that it utilizes precognitive perceptual cues about the three-dimensional surface to make the distortions comprehensible, and allows the user to interactively control the location, shape, and extent of the distortion in very large graphs.

Keywords: distortion viewing, graph layout, 3D interactions, information visualization, interface design

1 Introduction

An increasing number of large and complex graphs are being generated in a great variety of fields; in computing alone they are used to express such things as visual languages, software, hypertext, natural language parsing, and databases. Part of the appeal of graphs is that they are both a mathematical and a visual formalism. While there are several available visual interpretations of a graph, creating a display that actually aids in their comprehension is far from trivial. For instance, simply spreading a complex graph across the screen usually results in dense and confusing visual clutter. However, as Tufte [19] reminds us it is not in the nature of information to be confusing, rather it is the display that needs consideration.

Ideally, one would like to take advantage of our natural visual pattern recognition abilities by being able to see the entire graph. Also, the details of subgraphs and how these subgraphs are embedded in the overall structure are of interest. However, with existing solutions such as panning and zooming, the desire to examine detail often conflicts with the ability to maintain global context. Zooming out or compressing the data to fit within the space of the screen can result in its becoming too dense to discern detail. Zooming in or magnifying to reveal sufficient detail results in the loss of context.

Multiple views allow for the simultaneous display of detail and global structure in separate images, however the integration of these distinct views must be performed consciously by the user. Evidence as to how we combine information from multiple sensory channels has arisen from a number of studies in experimental psychology [2, 10, 11]. Information perceived as a single event is integrated automatically, while that perceived as distinct events requires a more strenuous re-integration. Even though the user may be cognitively aware that views in multiple windows pertain to a single information space, perceptually they remain distinct. For example, the effort of maintaining which subgraph belongs where and of its exact embedding has to be performed consciously by the user. If the desired detail view can be provided in a manner that smoothly integrates it into the global context then it preserves the possibility of visual gestalt.

Several viewing methods have been presented that allow the user to access detail within context through the use of various distortion techniques. This is a growing body of work pioneered by Furnas's [3] paper on generalized fisheye views. These techniques are usually based on the fisheye lens metaphor, creating a magnified focus for chosen sections and displaying the rest of the graph in decreasing scale as distance from the focus increases. Some of the main themes are: finding a balance between current interest and relative importance of the information [12, 13, 17, 18], using a mathematical curve to achieve magnification (arctan [6], hyperbola [8]), and using perspective projection to create the detail in context views [9, 16]. For a more detailed survey see [14]. These approaches provide various integrated views displaying both the required details while maintaining global context.

However, one advantage of separate views in multiple windows which has previously been lost with a detail in context viewing tool is the ability to move and reposition individual views. This is often used to align images of separate subgraphs so that visual comparisons are facilitated. We extend our distortion viewing technique, 3DPS [1], to allow this freedom while maintaining integration advantages that come with the perception of the graph as a single event.

The brief overview of 3DPS in Section 2 is followed by by an explanation of how folding extends 3DPS to provide repositioning of foci (Section 3). Methods used to enable comprehension of the resulting form are presented in Section 4. Section 5 contains examples of folding. Finally, Section 6 summarizes the results.

2 3D Pliable Surface

The intention behind distortion viewing is to magnify a chosen section or focus until the desired level of detail is revealed. To compensate for the extra screen space used by this magnification, the rest of the image is distorted and/or compressed. Ideally this compression is gradual enough to provide good visual integration between the focus and its context.

For the basic distortion function we chose the three-dimensional Gaussian curve as its bell shape curves away from the focus at its apex and inflects to curve back into the surface (Figure 1). These Gaussian curves transform the

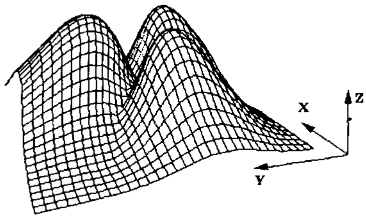

Fig. 1. 3D surface of blended Gaussian curves

two-dimensional flat surface into a three-dimensional curved surface. The three-dimensional nature of this distortion approach offers several advantages. For instance, using single-point perspective to view the surface from above provides magnification of detail to scale. Second, it provides a useful metaphor for the actions performed to create the distortions; pulling a section towards oneself to see it better, or in this case magnify it, appears to be a natural response.

Magnification of Single Focus to Scale: Magnification is provided by raising a 3D Gaussian curve perpendicular to the surface. The center of the gaussian

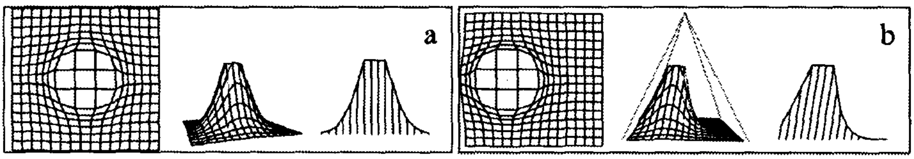

Fig. 2. (a) Single focus with flattened top, leftmost image shows the top view, center image shows the 3D view, and rightmost image shows the profile with ToEye vectors along which it is raised. (b) This single focus is to one side of center. Dotted lines denote the viewing frustum. The ToEye vectors directed at the viewpoint are shown

curve is projected up to the height h_c. To provide a flat region where only scaling occurs, the curve may be truncated; limited to a fraction f of this maximum height (Figure 2a). The points of the graph in the central magnified region are all projected up to the same height, $h_c f$. The height h_p of all other points on the curve is a simple relationship of the distance d_p to the center of the region, the height h_c, and its standard deviation s_c:

$$h_p = h_c \exp^{-\frac{s_c}{d_p}}$$

To keep foci from any point on the surface inside the field of view (Figure 2b) we use vectors directed from the plane to the view-point, *ToEye*, rather than move the view-point to align with the focus as in [16]. The ToEye vector from the center of a focus is used throughout the curve. This provides the desired magnification and ensures magnification to scale across the tops of the foci. Normalizing the z-component of these vectors instead of the length provides equivalent magnification response for any point on the surface. Within the focus region, where all points are projected to the same height, scaling is still preserved.

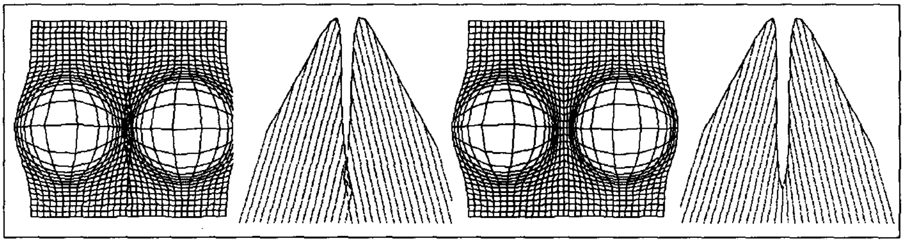

Fig. 3. Examples of two foci using ToEye vectors. When viewed from above the visual effect is as if the foci are being pulled up perpendicular to the plane On the left the inter-focal region is unblended; On the right blended

Multiple Foci: Using ToEye vectors for each focus allows for multiple foci within the field of view and magnification to scale for each focus region (Figure 3). However, a point under multiple curves will have a projection vector associated with each curve. A blending is performed using the curve's ToEye vector and a weight contributed by the curve's height at this point [1] This allows for larger foci to be positioned more closely, while still maintaining a continuous smooth (unwrinkled) surface.

Foci with Arbitrary Shapes: The single-point foci can be extended to other arbitrary shapes as well, for example lines or polygons (Figure 4). The exact shape and location of a focus can be drawn on the screen by the user. Now the

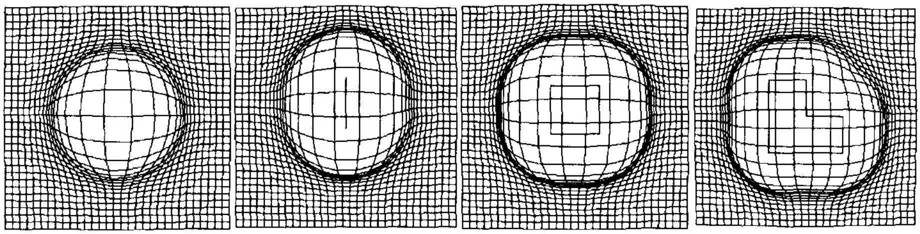

Fig. 4. Various foci types: from left to right: point, line, convex and concave polygons

height h_p of a point outside of a focus but within a region is determined not by its distance from the center of the region but by its distance to the edge of the defined focus. If the point is either on the line or within the polygonal focus it is projected to the full height h_c of the curve. The center of the arbitrary region is still used to determine the vector to the eye.

Distortion Control: In any distortion viewing tool compromises are made between the magnification in each foci and compression in the rest of the image. Our model offers the user considerable control not only over how much compression there is but where minimum and maximum compression occurs. The pattern of compression is a direct result of the slope of the curve. Therefore giving user control of the parameters (height h_c and standard deviation s_c) that affect the slope and providing an auxiliary function (half sine wave) that can be subtracted to actually adjust curvature allows to user to set preferences such as increased magnification in the region immediately adjacent to the focus or a more gradual integration into the context.

3 Surface Folding

In many cases it is desirable to provide the ability to bring detail views of spatially separated regions of an image together in order to facilitate visual comparisons. Traditionally this has meant the use of magnified views in sub-windows which are moved independently of the original image and hence have no direct visual connection to the rest of the image. Folding allows for this freedom to reposition magnified sections without detaching them from the rest of the image.

Folding: Extending 3DPS to include the repositioning of multiple foci while retaining the effect of a detail in context viewing tool, is possible in part because of the three-dimensional nature of the distortions. A focus, or magnified section, is the top of a 'hill'. The steepness of the sides of this 'hill focus' can be adjusted to minimize interference with other foci. The top, or focus can then be moved without changing the location of the base of the hill. The stable base maintains the same section of the graph within focus, and keeping the focus at the same height retains the degree of magnification. It is the sides of the hill that are stretched and bent. The context is maintained over the sides of the hills and across the valleys. This allows foci from different sections of the graph to be repositioned adjacently, without losing the sense of context.

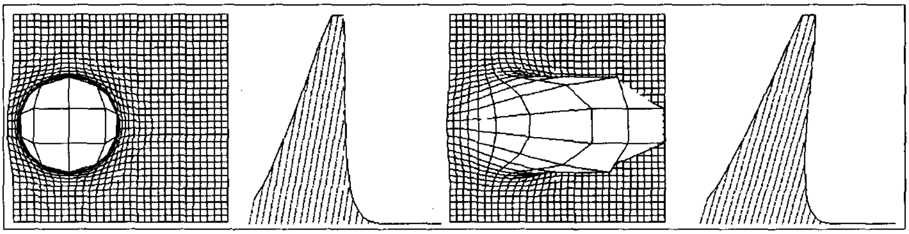

Fig. 5. Single off-center focus. On the left, pulled towards viewpoint; on the right, folded across the image

As the surface appears to be a solid object, we as humans, will assume it to be complete. This is an asset, because if the surface is perceived as complete then it can be stretched, folded, and warped without sections of it perceptually disappearing. Unfolding or viewing it from a different angle will expose temporarily obscured sections. The result is a tool that can be used analogously to folding a printed map to expose the areas of interest. This allows for the repositioning of foci without loss of the perception of the image as a single event.

Surface folding is achieved by shearing the projection (ToEye) vectors. To create a focus that is simply magnified a section is pulled up towards the viewpoint. When viewed from the top it appears that the focus is rising straight up from its base. However, when viewed from the side one can see that off-center foci are slightly tipped so that they point towards the viewpoint (Figure 5). This is accomplished by pointing their ToEye vectors at the viewpoint (Figure 2). In

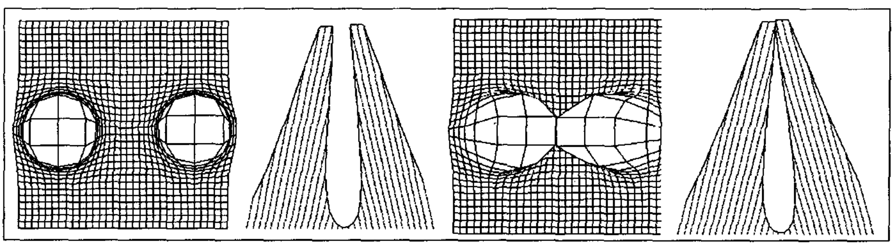

Fig. 6. A pair of foci, repositioned to be adjacent

this manner the whole projection of the focus can be readily shifted by pointing the ToEye vector elsewhere. If the ToEye vector is directed at any point on the plane parallel to the original surface which also contains the viewpoint, all the properties of height, magnification and scaling for the foci remain constant while its position in x and y change. Figure 5 shows side and profile views of the same single focus, on the left it is pulled towards to viewpoint which appears to be straight up, on the right it is folded or pulled across the viewing frustrum. Notice how a small change in profile view translates to a considerable visual difference when viewed from above. Figure 6 shows the same views of the two foci. This time the folding is used to bring two separated foci together.

Foci Motion: There is an important distinction between moving a focal point and folding a focus. Moving a focus through the graph allows for a sequential roving search, the image in the focus changing as the focus moves over different areas of the graph. Folding the focal point maintains the same view within the focus; this view is repositioned over other sections of the graph or aligned with other focal points. This allows spatially separate areas to be positioned adjacently while maintaining a continuous surface between them. At any moment the graph on this surface can be viewed by rotating and adjusting the three-dimensional image or by unfolding the graph.

Elision: While the principle intention in introducing surface folding was to allow for subgraph comparisons, it is possible to think of this as a method for hiding sections of the graph that are not of immediate concern. The result is a tool that can be used analogously to folding a printed map to hide and/or expose the areas of interest. Since folding is directly reversible, sections that have temporarily been hidden are readily retrievable. In fact, one can unfold to allow closer examination of the connections between the expanded detail in the focus and the rest of the graph.

4 Comprehension Factors

A primary goal in the creation of 3DPS is that the distortions remain comprehensible, allowing the user to understand the relative magnification or compression of the various sections of the resulting image. Other distortion methods can be quite readable when applied to regularly spaced information, particularly grids or text; unfortunately not all information is laid out so regularly. We make a distinction between the graph as a 2D image encoding the information and the surface on which the graph is displayed. As visual cues are provided about the surface, distortions will still be readable even when there are gaps in the image. The separation of the image and distortions of the surface means that the original topology of the image is maintained across the surface. Once the surface is manipulated the image is placed upon it. Displaying a surface in such a manner

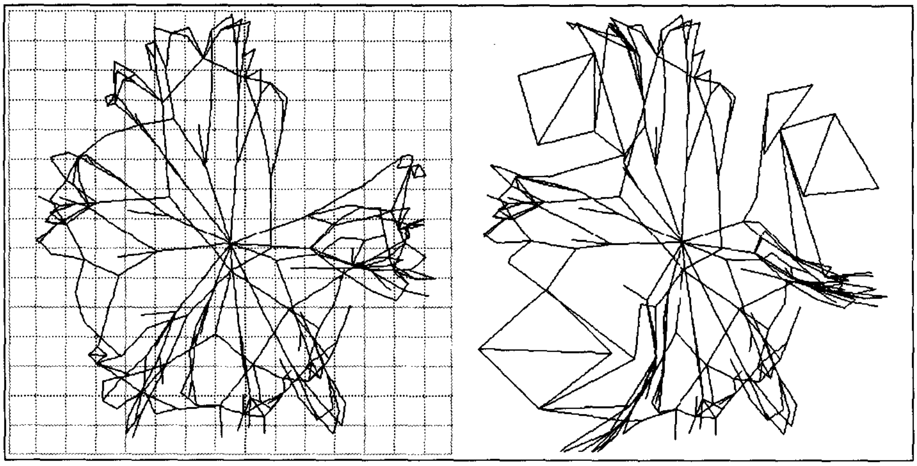

Fig. 7. This series uses the same graph and same distortion throughout. On the left is the undistorted graph; on the right is the graph with 3 foci and no visual cues

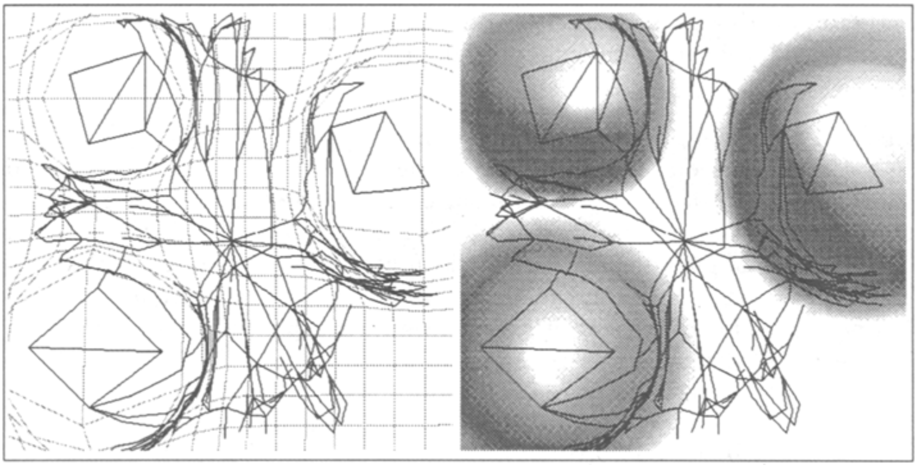

Fig. 8. On the left same 3 foci with shading. On the right, the same graph with 3 foci and both grid and shading

as to reveal its three-dimensional form provides the perceptual information that describes the distortion.

Using Nodes and Edges: Nodes are currently displayed either as single points or as squares. Edges are segmented small enough so that they will lie snuggly against the surface. This provides additional information about the surface. Information spaces that contain long lines now aid in the description of the surface.

Using a Grid: Perspective can be used to provide distortion information. However, understanding three-dimensions from perspective appears to be a learned skill and culturally tied [4]. Perspective has been indicated with the outlines of a three-dimensional shape [9] or by the visual pattern of the data [16]. The choice of smooth curves for distortion and allowing for data with irregular layouts means neither outlines nor patterns in the data will reveal the nature of the distortions. However, a regular grid can be displayed over the entire surface, providing both curve and perspective information. Grid lines indicate relative magnification as well as serving as a texture gradient.

Using Shading: Another choice for revealing form is to employ shading. It has been well established that humans can discern three-dimensional shape from shading alone [15, 18], and there is considerable evidence to support the fact that this is a low-level precognitive skill [7]. Such a low-level visual routine will interfere less with conscious processing and may even provide an aspect of the interface that requires no learning [20].

The series in Figures 7 and 8 shows the progressive addition of each visual cue. The first image is of the undistorted graph laid out with the spring embedder algorithm from GraphEd [5]. The second image shows the graph with three foci and no additional visual cues, third the grid is added and the fourth shows the use of shading. All of these visual cues are optional and are displayed in shades of grey so that while they are readily visible apart or in unison they do not dominate the image.

5 Examples

This section contains some examples of graph folding in action. The first set of examples is of a random graph; in Figure 9 on the left is a simplistic layout, placing each vertex on a grid,

resulting in an image that is a confusion of lines. On the right the same graph has been laid out using the spring embedder algorithm in GraphEd [5]. This reveals several small fans of pendant vertices. Figure 10 magnifies three sections of the denser center part to reveal similar subgraph structure.

The second set of examples(Figures 12 and 10) is of an iterated K12 graph. The outer subgraphs are so densely packed that one can not tell for sure what they are. Two of these have been magnified and compared to verify that they are indeed K12's.

6 Conclusions

While detail in context distortion viewing tools hold much promise as a method for interacting with representation of large graph, the approaches of other systems had made the repositioning of focal regions difficult if not impossible. This

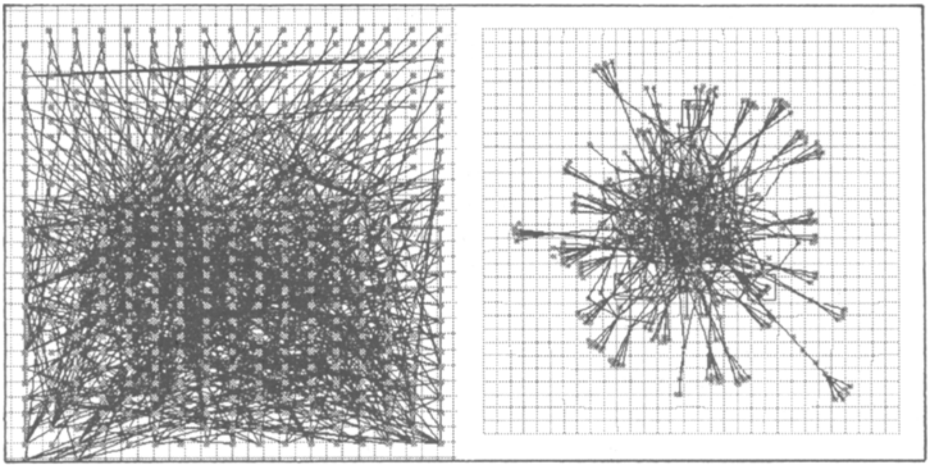

Fig. 9. On the left, a random graph with vertices placed in the grid. On the right, the same graph laid out with spring algorithm

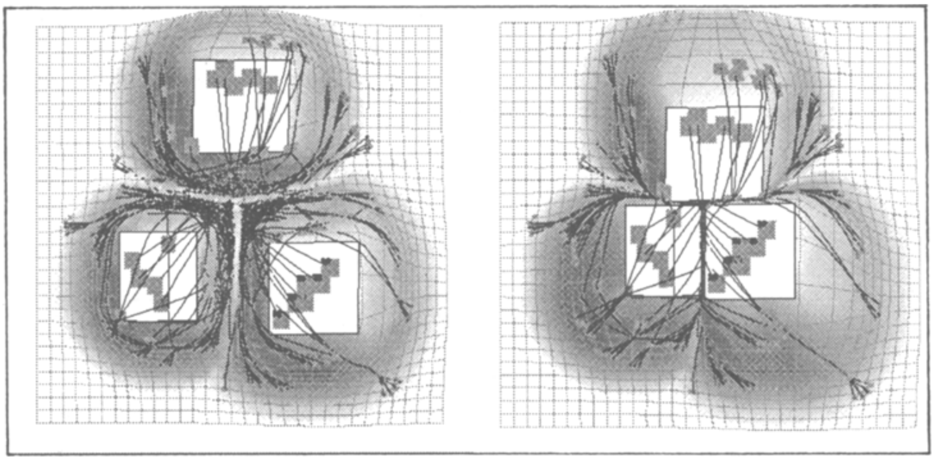

Fig. 10. A random graph with spring layout and three foci folded

paper has introducing folding, a novel concept which combines the advantages of detail in context viewing with the freedom of movement provided by magnified views in separate windows.

The distortion viewing tool 3DPS that we have extended to include folding in itself has several advantages over existing tools; briefly these include:

1. Arbitrarily-shaped focal regions. Sarkar et. al. [18] approximate this advantage with convex polygons. We allow for interactive user specification of a chosen outline for a focal region.

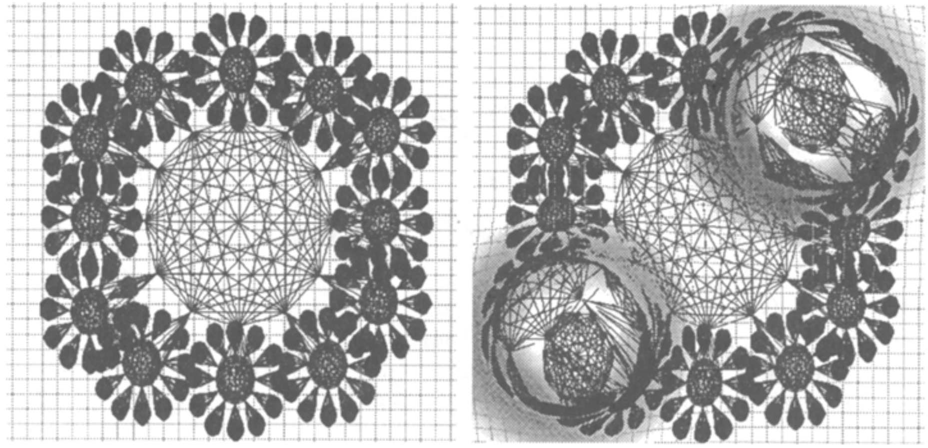

Fig. 11. On the left; iterated K12. On the right; two foci magnified to reveal subgraphs of K12

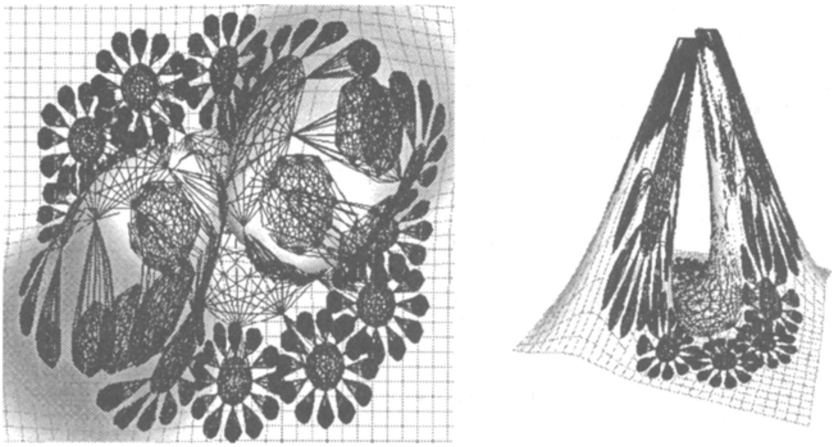

Fig. 12. On the left; iterated K12 folded. On the right; iterated K12 folded side view

2. Distortion control. By adjusting the slope parameters the user can determine the distribution of compression. For instance, distortion can be contained within a relatively small section of the surrounding graph leaving most of the context undistorted. In other techniques the pattern of distortion is controlled by the system, user choices being limited to such things as a global choice between Cartesian or polar transformation [6, 17].
3. Multiple foci. Sarkar et. al [18] introduced multiple foci with two different techniques. However, both approaches have limitations For instance, their orthogonal approach cause strips of uni-direction magnification that create extra unrequested foci at their intersections. Their polygonal approach which

is more similar to ours in appearance, required limitation on focal size and positioning as two large foci that were too close together would cause position reversals in the inter-focal regions. Also this polygonal technique can require iteration of the algorithm to produce an acceptable final image. Our approach requires no iteration and our blending function allows large foci to interact and in fact move through each other. Furthermore, this is the first provision of multiple foci in a three-dimensional distortion approach. This is significant in that it is partly the three-dimensional nature of the distortion that makes folding possible.

4. Precognitive perceptual cues. These are used to reveal the nature of the distortions. Being able to understand the distortion provides knowledge about the degree of compression, information about the original undistorted topology of the graph, and the cumulative result of the history of the user's actions.

While the use of shading provides instant recognition of the patterns of distortion, it causes some problems. Finding the right balance between light and dark intensities is difficult to achieve, especially if one wants to have convincing shading both on the screen and in print.

Presently, user access to the parameters that affect distortion patterns is unconstrained, therefore it is possible to create curves that obscure some context. However, just what has been obscured is always evident and the actions are readily reversible.

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