Automatic Shape Interpolation for Glyph-based Information Visualization

David S. Ebert [1] James M. Kukla [2] Christopher D. Shaw [3] Amen Zwa [4]
Ian Soboroff [5] D. Aaron Roberts [6]

Abstract

Information visualization of multivariate data is a difficult task. Glyph-based rendering is an attempt to discretize the data visually so that individual visual elements of the final display such as color, size, position, etc. encode some information about the data. We propose a simple new method for allowing the use of shape for quantitative, continuous data by generating glyph shape automatically using procedural techniques. This abstracts the burden of glyph design away from the user in a procedural fashion while still allowing the user a high level, directorial control over the shape design. We introduce the use of superquadric ellipsoid surfaces [1] for this task and discuss the perceptual validity of this type of shape for pre-attentive discrimination. Furthermore, we discuss the generalization of this technique to include many other traditional procedural methods from computer graphics.

1 Introduction

The data presented in information visualization applications do not necessarily have any obvious visual representation that can be called upon to display them. This is both a curse and a boon, for while these abstract data may not provide a simple visual solution, they eagerly accept more abstract means of visual representation.

While color, opacity, size, and position are basically one dimensional visual continua, shape has an altogether more disturbing complexity. However, if we can make some use of procedural techniques, this complexity may move from a hindrance in design to an aid in discrimination.

2 Background

In previous work, we explored the usefulness of stereo-viewing and two-handed interaction to intensify the perceptual cues in glyph-based visualization. The Stereoscopic Field Analyzer (SFA) [4] combines glyph-based volume rendering with a two-handed minimally-immersive interaction metaphor to provide interactive visualization, manipulation, and exploration of multivariate, volumetric data. SFA uses a glyph's location, 3D size, color and opacity to encode up to 8 attributes of scalar data per glyph. We are extending this work to combine glyph rendering with other visually salient features to increase the number of data dimensions simultaneously viewable.

We chose to explore shape variation based on its priority in human perception. Cleveland [3] cites experimental evidence that shows the most accurate method to visually decode a quantitative variable in 2D is to display position along a scale. This is followed in decreasing order of accuracy by interval length, slope angle, area, volume, and color. Bertin offers a similar hierarchy in his treatise on thematic cartography [2].

Therefore, the next opportunity for encoding a scalar value is shape. One of the most difficult problems in glyph visualization is the design of meaningful glyphs. Glyph shape variation must be able to convey changes in associated data values in a comprehensible manner [9]. This difficulty is sometimes avoided by adopting a single base shape and scaling it non-uniformly in 3 dimensions. However, the lack of a more general shape interpolation method has precluded the use of shape beyond the signification of categorical values [2]. This paper proposes a new system for the procedural generation of glyph shapes for glyph-based volumetric visualization [6] using superquadrics [1].

[1] Computer Science and Electrical Engineering Department, University of Maryland Baltimore County, 1000 Hilltop Circle , Baltimore, MD 21250, Phone: (410)455-3541, email: ebert@cs.umbc.edu

[2] Computer Science and Electrical Engineering Department, University of Maryland Baltimore County, 1000 Hilltop Circle , Baltimore, MD 21250, Phone: (410)455-6339, email: jkukla1@cs.umbc.edu

[3] Department of Computer Science, University of Regina, Regina, Saskatchewan, Canada S4S 0A2, Phone: (306) 585-4632, email: cdshaw@cs.uregina.ca

[4] Computer Science and Electrical Engineering Department, University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, Phone: (410)455-3541, email: zwa@cs.umbc.edu

[5] Computer Science and Electrical Engineering Department, University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, Phone: (410)455-3541, email: ian@cs.umbc.edu

[6] NASA Goddard Space Flight Center Mailstop 692.0, Greenbelt, MD 20771, roberts@ra.gsfc.nasa.gov

2.1 Procedural shape visualization using superquadrics

Because of the need for meaningful glyph design and the complexity of the problem, we opted for a procedural approach, which allows flexibility, data abstraction, and freedom from specification of detailed shapes [5].

Our goal for glyph design was to allow the automatic mapping of data to shape in a comprehensible, easily controllable manner. Superquadrics are a natural choice to satisfy this goal. Superquadrics [1] are extensions of quadric surfaces where the trigonometric terms are each raised to exponents. Superquadrics come in four main families: hyperboloid of one sheet, hyperboloid of two sheets, ellipsoid, and toroid.

In the case the of superellipsoids, the trigonometric terms are assigned exponents as follows:

$$\underline{x}(\eta,\omega) = \begin{bmatrix} a_1 & \cos^{\epsilon 1}\eta & \cos^{\epsilon 2}\omega \\ a_2 & \cos^{\epsilon 1}\eta & \cos^{\epsilon 2}\omega \\ & a_3 \ \sin^{\epsilon 1}\eta & \end{bmatrix}, \quad \begin{array}{c} -\pi/2 \le \eta \le \pi/2 \\ -\pi \le \omega < pi \end{array}$$

These exponents allow continuous control over the characteristics (in some sense the "roundness" or "pointiness") of the shape in the two major planes which intersect to form the shape, allowing a very simple, intuitive, abstract schema of shape specification.

As can be seen in Figure 1, varying the exponents achieves smooth, understandable transitions in shape. Therefore, mapping data values to the exponents provides not only a continuous, automatic control over the shape's overall flavor, but a comprehensible shape mapping as well.

By using superquadrics, we can provide the appropriate shape visual cues for discerning data dimensions mapped to glyph shape while not distracting from the cognition of global data patterns.

Glyph shape is a valuable visualization component because of the human visual system's pre-attentive ability to discern shape. Shapes can be distinguished at the pre-attentive stage [7] using curvature information of the 2D silhouette contour and, for 3D objects, curvature information from surface shading. Unlike an arbitrary collection of icons, curvature has a visual order, since a surface of higher curvature looks more jagged than a surface of low curvature. Therefore, generating glyph shapes by maintaining control of their curvature will maintain a visual order. This allows us to generate a range of glyphs which interpolate between extremes of curvature, thereby allowing the user to read scalar values from the glyph's shape. Pre-attentive shape recognition allows quick analysis of shapes and provides useful dimensions for comprehensible visualization.

To produce understandable, intuitive shapes, we are relying on the ability of superquadrics to create graphically distinct [10, 11], yet related shapes. We are encoding up to two data dimensions to glyph shape in a manner that allows the easy separation of the shape characteristics by mapping either one independent variable to both glyph exponents or two related variables, one to each glyph exponent, to ensure the understandability of the shapes.

Since size and spatial location are more significant cues than shape, the importance mapping of data values should be done in a corresponding order. In decreasing order of data importance, data values were mapped to location, size, color, and shape. In our experience, shape is very useful for local area comparisons among glyphs: seeing local patterns, rates of change, outliers, anomalies.

3 Results

For information visualization, we have chosen an example of the visualization of "thematic" document similarities. Figure 2 shows a visualization of document similarities generated with the Telltale system [8]. The document corpus consists of 1833 articles from *The Wall Street Journal* from September and October 1989. Each glyph in Figure 2 represents a document in the corpus, and the document's X, Y, and Z position, color and shape each represent the similarity of the document to one of 5 themes.

Document similarity to *gold prices*, the *foreign exchange rate of the U.S. dollar*, and *federal reserve* are respectively mapped to the X, Y, and Z axes. The Y axis is visually indicated in Figure 2 by the vertical line, with the X axis going to the right and the Z axis going to the left. The bulk of the documents have very low similarity to all 3 of these themes, so their glyphs are clustered near the origin at the bottom center.

The documents outside this cluster exhibit two spatial patterns: a cluster of 9 documents to the bottom right and a vertical branch on the left. The right cluster indicates the small number of documents in the corpus that discuss both *gold prices* and the *foreign exchange rate of the U.S. dollar*. The vertical branch depicts a larger collection of documents that discuss both *foreign exchange rate of the U.S. dollar* and the *federal reserve*.

Glyph color is mapped inversely to similarity to *Manuel Noriega*. Most of the documents fall in the turquoise and purple range, indicating no significant relationship. However, the documents in the orange, red, and yellow-green range represent documents with a significant relationship to *Manuel Noriega*. Many of these documents mention the effect of the coup attempt against *Manuel Noriega* and its effect on the *foreign exchange rate of the U.S. dollar* (vertical axis). The fact that these orange, red, and yellow-green documents are not in either of the branches indicates that these articles did not relate heavily to either *federal reserve* or *gold prices*.

A fifth attribute, similarity to *stock prices*, is inversely mapped to both superquadric exponents of the glyph shape. This inversion maps the highest values to cuboids, with lower values mapping to spheres, diamonds, and finally, the lowest values, to stars. Referring to the square array of sample glyphs in Figure 1, the similarity to *stock prices* maps to glyphs on the diagonal from the upper left to the lower right of Figure 1, with upper left indicating high similarity, and lower right indicating low similarity.

In Figure 2 the larger, more convex shapes along the vertical branch exhibit some significant relationship to *stock prices* while the more numerous star-shaped glyphs do not. Clearly the vertical branch contains articles relating *foreign exchange*, *federal reserve* and *stock prices*.

4 Conclusions and Ongoing Work

The use of shape as a visual dimension of data display is a logical extension of current glyph-based volume rendering techniques. We feel that the work begun here truly shows the simple way in which the complex nature of this problem can be integrated smoothly into these systems using procedural techniques. Our initial work has shown great promise for the use of superquadrics as interpolated shapes in glyph-based rendering systems, and at the same time does not preclude the expansion of this technique to include other varieties of procedurally generated shapes.

REFERENCES

[1] A. Barr. Superquadrics and angle-preserving transformations. *IEEE Computer Graphics and Applications*, 1(1):11–23, 1981.

[2] J. Bertin. *Semiology of Graphics*. The University of Wisconsin Press, 1983.

[3] William S. Cleveland. *The Elements of Graphing Data*. Wadsworth Advanced Books and Software, Monterey, Ca., 1985.

[4] David Ebert, Chris Shaw, Amen Zwa, and Cindy Starr. Two-handed interactive stereoscopic visualization. *Proceedings IEEE Visualization '96*, October 1996.

[5] David S. Ebert. Advanced geometric modeling. In Jr. Allen Tucker, editor, *The Computer Science and Engineering Handbook*, chapter 56. CRC Press, 1997.

[6] J. D. Foley and C. F. McMath. Dynamic process visualization. *IEEE Computer Graphics and Applications*, 6(3):16–25, March 1986.

[7] Andrew J Parker, Chris Christou, Bruce G Cumming, Elizabeth B Johnston, Michael J Hawken, and Andrew Zisserman. The analysis of 3D shape: Psychophysical principles and neural mechanisms. In Glyn W Humphreys, editor, *Understanding Vision*, chapter 8. Blackwell, 1992.

[8] Claudia E. Pearce. *A Dynamic Hypertext Environment Through n-gram Analysis*. PhD thesis, University of Maryland Baltimore County, 1994.

[9] Frank J. Post, Theo van Walsum, Frits H. Post, and Deborah Silver. Iconic techniques for feature visualization. In *Proceedings Visualization '95*, pages 288–295, October 1995.

[10] H. Senay and E. Ignatius. A knowledge-based system for visualization design. *IEEE Computer Graphics and Applications*, 14(6):36–47, November 1994.

[11] H. Senay and E. Ignatius. Rules and principles of scientific data visualization. *ACM SIGGRAPH HyperVis Project, http://ironduke.cs.gsu.edu/classes/hypervis/percept/visrules.htm*, 1996.

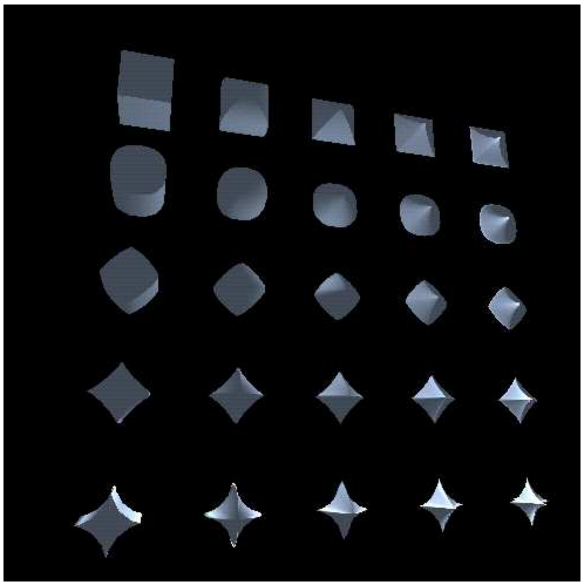

Figure 1: Example superquadric shapes created by varying each exponent from 0 to 4.

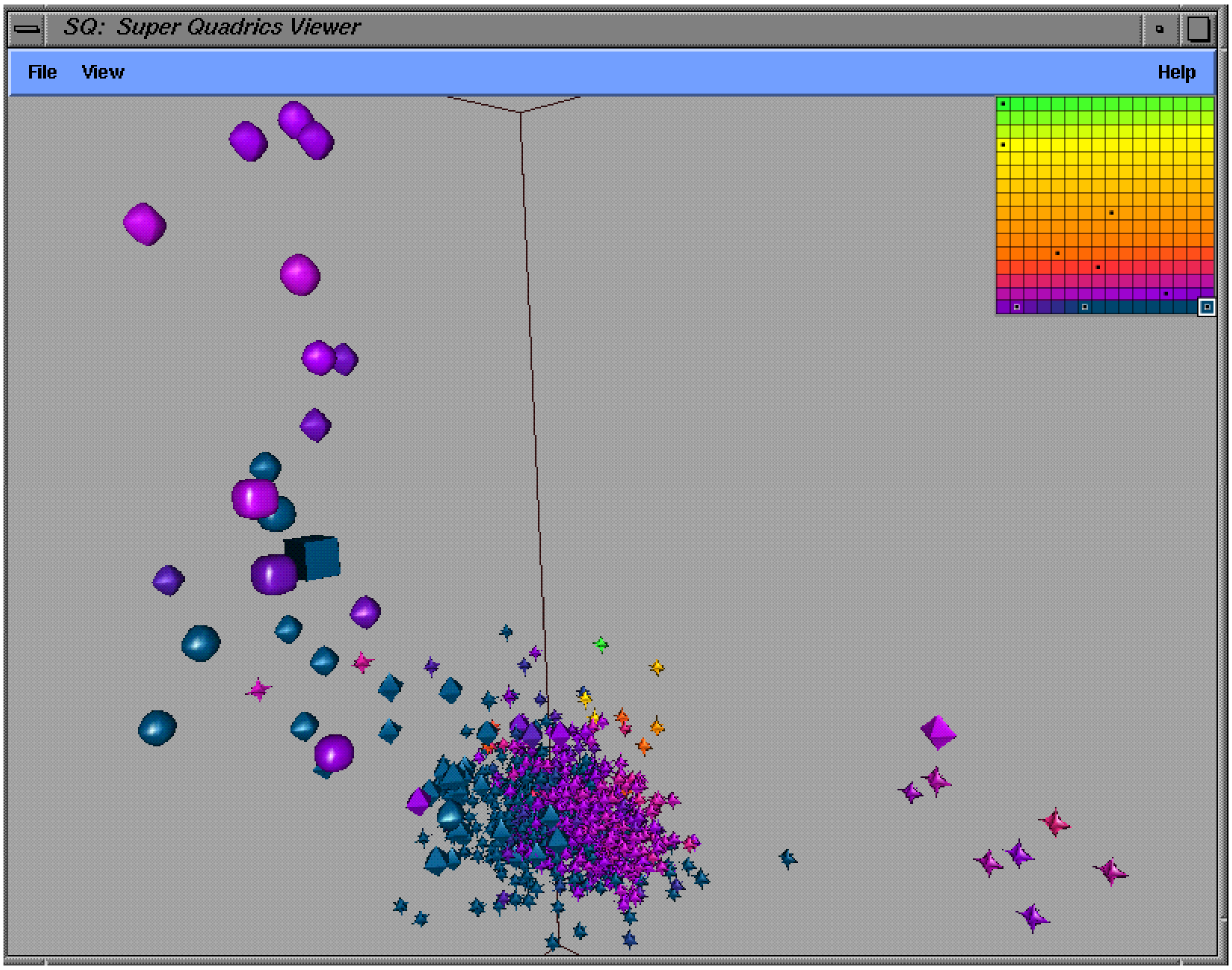

Figure 2: Three-dimensional visualization of 1833 documents' relationship to gold prices, foreign exchange, the federal reserve, stock prices, and Manuel Noriega.