Visualizing Layered Surfaces in Volume Data

Victoria L. Interrante[1]

Introduction

In order to effectively represent the complex spatial relationships between multiple superimposed surfaces in a three-dimensional volume, one must render the overlapping surfaces in such a way that each layer can be both clearly seen and also easily seen through.

Although transparency is a useful device for this purpose, it can often be difficult to adequately perceive the three-dimensional shape of a plain transparent surface, or to judge its relative depth distance from other structures in the same image.

By applying a sparse, stable set of opaque surface markings to a transparent object, we may explicitly convey important shape and depth information. This article outlines several alternative techniques for selectively adding opacity to specific regions of a transparent surface in order to better communicate the essential features of the object without unduly compromising the visibility of underlying structures.

Generic Opacity-Masking Textures

One of the simplest and most generically applicable methods for defining opaque markings on selected portions of a semi-transparent volume-rendered surface is to use a procedurally-defined solid texture as a volume opacity mask [1]. The surface regions rendered with extra opacity are simply the sections of the volume that reside within a predetermined set of voxels. Because this definition is independent of the surface geometry, objects of arbitrary complexity can be textured in this way with relative efficiency and ease.

Better results may potentially be achieved however, if the opaque markings are explicitly defined to convey specific perceptually-relevant surface shape information.

Feature Line Textures

The ability of gifted artists to define a figure with just a few strokes inspires efforts to capture the essence of a surface's shape in a small, stable set of intuitively meaningful lines [2]. Figure 2 gives one example: the locus of valley points, defined as the locations on a surface where the normal curvature in the direction of greatest curvature reaches a local negative maximum. The objective in this image is to illustrate the three-dimensional distribution of radiation dose in the context of the patient anatomy; the function of the valley lines is to succinctly communicate the location of specific soft-tissue structures that must be spared by the radiation beams. Valley and ridge line textures can be useful for portraying familiar objects and other structures that are readily characterized by their prominent shape-based features. To effectively communicate local shape and depth information across smoothly curving surfaces of arbitrary form, a more continuous texturing pattern is required.

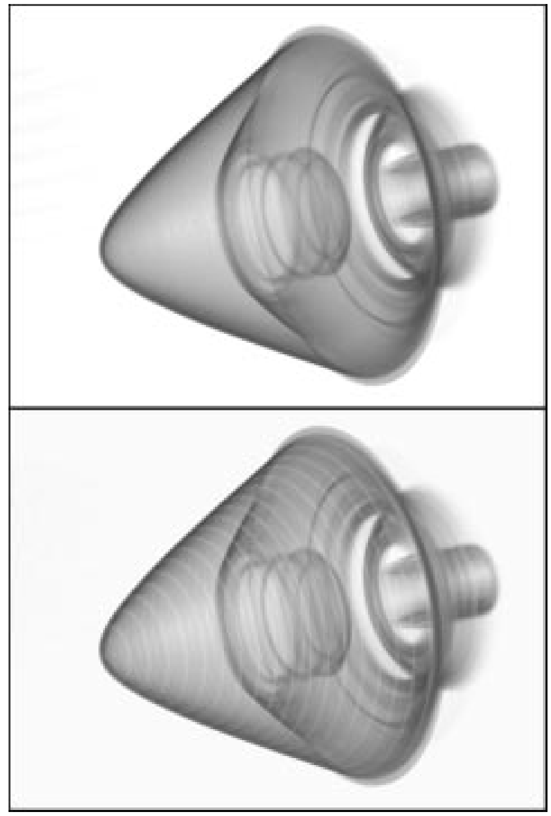

Figure 1: Shock surfaces in an axisymmetric flow, from numerical simulations of a shock interacting with a strong longitudinal vortex by Dr. Gordon Erlebacher. Flow is from left to right. Top: plain; Bottom: with solid line texture.

Curvature-Directed Stroke Textures

Artists and illustrators have historically stressed

[1]Dr. Interrante received her Ph.D. in Computer Science from the University of North Carolina at Chapel Hill, and joined ICASE as a Staff Scientist in March 1996.

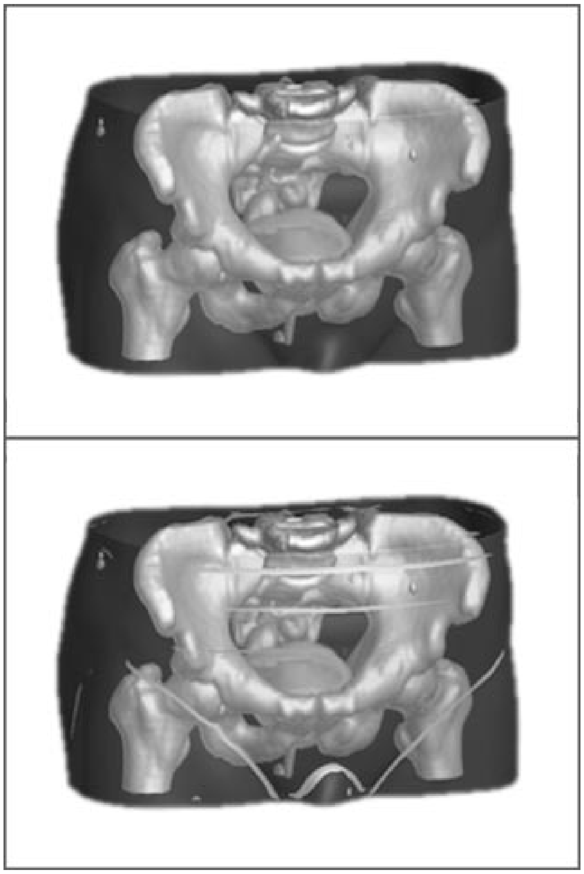

Figure 2: A radiation treatment plan for prostate cancer. Data courtesy of Dr. Julian Rosenman, UNC Hospitals. Top: plain; Bottom: with opaque valley lines.

the importance of stroke direction in line art. Noting that objects tend to appear "flattened" when the strokes used to describe them are applied in a uniform direction across the entire image (vertically-oriented strokes accentuate height, while horizontally-oriented strokes emphasize width), they suggest that the three-dimensional shape of an object can be portrayed most effectively by defining the stroke direction according to the curvature of the form.

One possible method [3] for computing a curvature-directed stroke texture and applying it to isovalue surfaces in volume data can be summarized as follows: 1) select, from the outermost occupied voxels, an evenly-distributed set of stroke origin points; 2) compute the principal directions and principal curvatures of the isolevel surface that passes through each of these points based on the first and second derivatives of the volume data; 3) define an opacity mask consisting of elongated regions around each point, in which the direction of

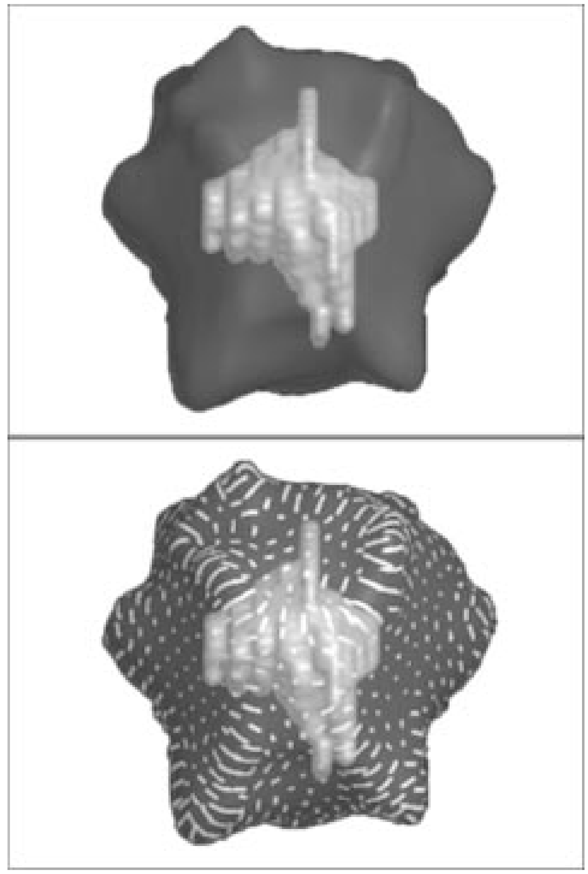

Figure 3: An isointensity surface of radiation dose surrounding a tumor volume. Data courtesy of Dr. Julian Rosenman, UNC Hospitals. Top: plain; Bottom: with curvature-directed stroke texture.

the elongation is specified by the direction of greatest normal curvature and the amount of the elongation is determined by the magnitude of the surface curvature in this direction.

Care must be taken to ensure that the boldness of the indication of a particular direction at any point is in correspondence with the perceptual importance of that specific direction on the surface. Line textures such as these have been successfully used to communicate surface shape in applications in which there is no pre-established alternative definition of a "direction" at a point. The viability of using this kind of approach to portray scalar functions associated with a fluid flow remains to be determined.

Flow-directed Textures

When vector data exists, it can be used to define a texture of flow lines across a transparent surface. In Figure 4, streamlines were scan-converted into

Figure 4: Shock surfaces textured with projected velocity lines.

the surface-occupied voxels via a three-dimensional line integral convolution and a smooth representation of the flow across the surface was obtained by locally projecting the velocity vectors onto the surface defined by the gradients of the scalar data.

Directions for Future Research

To successfully represent multiple layered transparent surfaces with opaque surface markings, it will be necessary to understand the ways in which various texture patterns interact and interfere with one another. Techniques that work well in isolation may not function in combination; it will be particularly important to maintain the perceptual cohesion of discrete texture elements.

References

Levoy, M., Fuchs, H., Pizer, S., Rosenman, J., Chaney, E., Sherouse, G., Interrante, V., and Kiel, J., "Volume Rendering in Radiation Treatment Planning," *Proc. First Conf. on Visualization in Biomedical Computing*, IEEE Computer Society Press, 1990.

Interrante, V., Fuchs, H., and Pizer, S., "Enhancing Transparent Skin Surfaces with Ridge and Valley Lines," *Proc. Vis. '95*, 1995.

Interrante, V., Fuchs, H., and Pizer, S., "Illustrating Transparent Surfaces with Curvature-Directed Strokes," to appear in *Proc. Vis. 1996.*

Workshop on Computational Electromagnetics

ICASE and NASA Langley Research Center conducted a Workshop on Computational Electromagnetics and Its Applications at the Omni Hotel Newport News, VA, from May 29 through May 31, 1996. The meeting was organized by Thomas Campbell and Fred Beck of the Electromagnetics Research Branch, NASA Langley Research Center, Manuel Salas, ICASE Director, and Roy Nicolaides, Professor at Carnegie Mellon University.

The workshop was confined to the area of high frequency electromagnetics. As the tendency toward higher operating frequencies combined with smaller packaging of electronic devices continues to evolve, it becomes increasingly important to have accurate field simulations available to simplify and reduce the cost of design. While these field simulations have been performed for a considerable period of time, it is only recently that issues of extreme geometric complexity coupled with very high frequency excitations have become amenable to routine computation. In addition to these microwave circuit computations, the workshop also covered electromagnetic scattering by large bodies and optimization.

Approximately 70 participants representing industry, government, and academia attended the workshop. The speakers covered a variety of numerical simulation techniques, design optimization algorithms, and computer science issues. In addition, there was a historical overview of electromagnetic computation and an interesting panel discussion of the issues raised by the speakers.

The workshop brought together a wide spectrum of researchers from industry, academia, and research institutions, to exchange ideas at the leading edge of computational electromagnetics. A concensus on the need for more accurate, more robust numerical techniques was reached on the final day. The panel discussions brought out a need for better code validation, stringent tests, and well-chosen model problems to test the various algorithms. Optimization algorithms running on desktop workstations were also seen as an essential ingredient to industrial acceptance.

The proceedings of the workshop will be published by Kluwer Academic Publishers.