Uses of Shading Techniques, Artistic Devices and Interaction to Improve the Visual Understanding of Multiple Interpenetrating Volume Data Sets

Dissertation Proposal
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Victoria Interrante

Thesis:

Advanced shading models, artistic enhancements and user interaction can be combined to significantly improve the perception of the shapes and relative locations of objects in multiple volume data sets.

Background:

The visualization of multiple volume data sets is an important and difficult problem in computer graphics. There are many applications in which this capability is useful, and the one upon which I plan to focus during this work is radiation therapy treatment planning. In radiation therapy, a major task of the oncologist is to determine an optimum configuration of one or more beams which will deliver a prescribed amount of radiation to the physician-defined target volume while minimizing the dose delivered to surrounding healthy tissues. An ability to accurately visualize the three-dimensional distribution of dose in the context of anatomy is vital to the achievement of a good treatment plan. In this work, I hope to provide useful insights into graphics techniques which can significantly improve the quality and comprehensibility of images containing such complex 3D information. A considerable amount of excellent work has been recently done to improve the quality of volume rendered images, but problems remain in the visualization of multiple overlapping or interpenetrating data sets.

In order to catch up with the state-of-the-art, there are several issues which need to be addressed in our current method of shading transparent objects. In particular, we need to maintain visible specular highlights on transparent objects and to increase the accuracy of color computation in the shading of successive layers of semi-transparent surfaces.

Further work in this area could include finding a better physical model for the semi-transparent polygonal surfaces currently used to represent objects such as radiation beams. Perfectly transparent glass is difficult to see even in the physical world, and a more appropriate model might be translucent plastic (which scatters light within the surface to produce a blurred view through the object), textured glass or gauze.

Plan for work: Software

1. Hybrid Rendering

In order to achieve an optimal rendering of two very different kinds of data, I intend to combine the use of the crisp, exact isodensity surface representation suitable for some data sets with the nonbinary, composited representation which is most useful for others. Current hybrid rendering systems make no attempt to optimize the computation of ray/polygon intersections and hence are relatively slow for data sets containing large numbers of polygons. I propose to implement a fast, efficient algorithm for the detection and rendering of exact isosurfaces during the raytracing step of our current volume rendering program, which I hope can prove to be an important contribution to the state of the art. I am currently working on two hybrid algorithms, and plan to compare the accuracy and efficiency of each.

2. Artistic Enhancements of Shading

I believe that the use of artistic devices will be key to achieving a greater visual understanding of the shapes and interrelationships between multiple volume data sets.

As a first step, I plan to prove that emphasizing polygon/polygon, polygon/volume, and volume/volume intersections provides essential visual cues to the relative positions of the multiple data sets in an image. A physical basis for this type of shading can be found in global illumination, and it is a technique used almost universally in artistic illustration.

In addition, I hope to show that the complexity of images containing multiple intersecting semi-transparent polygonally-defined objects can be substantially reduced through the use of a CSG boundary representation, which restricts the set of visible polygons and eliminates nonessential information.

Probably the greatest potential for significant advancement beyond the current state of the art in data visualization lies in texturing. In particular I believe that through the use of surface textures, whose properties are derived from the solid shape of the volume, it will be possible to achieve a rendering in which the 3D shape of multiple semi-transparent objects can be seen with greater accuracy and ease than in current displays. I intend to investigate the use of curves which follow ridges and valleys and Chebychev or other nets in which the angles at the corners of the mesh vary with the curvature of the surface.

Solid textures also show some promise as a useful tool for 3D shape description. For example, solid line segments which follow the gradient from points on one isovalue surface to points on another might prove to be helpful for showing gradient information in volume data. Another possibility would be to use a "fur" texture in which the angles of the "hairs" reflect the magnitude of the density gradient. To show density distribution within a volume, a distribution of small particles could be used as a model, with fog added as an attenuating medium to improve depth perception and with particle size, concentration, color and/or opacity defined as a function of the volume density or density gradient at each voxel.

3. Interaction

In the display of multiple overlapping and interpenetrating data sets, interactive manipulation may prove to be essential to the accurate comprehension of the shapes and relative orientations of the component volumes. I intend to clarify the role of interactivity in enhancing the visual understanding of shape by examining the effectiveness of various interactive techniques in improving the comprehensibility of the display. Devices that I plan to look at include cutplanes which can be used to selectively sand away or render semi-transparent one or more data sets while leaving the others unchanged, and opaque planes, transparent outside the volume of interest, onto which volume information can be mapped.

Plan for work: Hardware

The shading model and hybrid rendering enhancements are intended primarily to improve the appearance of individual images, and thus would be implemented on the curent software base (the Levoy renderer), along with the artistic devices, which are designed as static enhancements to a volume model. The proposed interactive work could be simulated using an extension of the current volume rendering software, but would have to be implemented on Pixel-Planes 5 to be of actual practical value.

Verification:

In any dissertation of as subjective a nature as this one, it is necessary to develop a plan for verifying the existence and extent of any real improvements in the results obtained.

I hope that the images I am able to produce through this work will be of such quality that an advancement over the current state of the art will be readily apparent to most casual observers. In this case, I plan to use a small number of measured comparisons along with a larger number of descriptive comparisons to show that the visual understanding of images containing multiple volume data sets has been significantly improved as a result of my work. (These user-study experiments will most likely measure the ability of an observer to estimate distances between objects, to determine whether two objects intersect and where, and to estimate the amount of one object which is contained within another. The format of these experiments will allow a comparison of various subsets of the enhancements against the current state-of-the-art as represented by the Levoy renderer. Although I intend to obtain the input of several physicians from Radiation Oncology for this study, most of the subjects will be untrained).

In the event that my images are less than outstanding, however, I am prepared to design a rigorous user study to examine the effectiveness of a range of visualization paradigms, leading to an improved understanding of the graphics techniques necessary for an accurate perception of three-dimensional scenes.