Artistic Metaphors for Interactive Visualization of Multi-Valued 3D Data

Research Comp. Proposal

Daniel Keefe
Computer Science Department: Brown University

April 17, 2000

1 Introduction and Motivation

Visualizing multi-valued 3D data is a difficult problem in scientific research. Researchers in fields such as medicine and aerodynamics routinely collect and study large 3D datasets. These datasets usually contain multiple variables collected directly from an experiment or from a simulation. Often even more variables are derived from this initial data. The resulting dataset can be extremely large, as it contains information for many different characteristics of the volume at each sample point in the volume. The size and complexity of multi-valued 3D datasets make them difficult for researchers to interpret and difficult to display from a data visualization standpoint.

The Artery Simulation project currently underway at Brown University is an effort to produce an interactive virtual reality visualization of blood flow within an artery. The data for the simulation is produced by a Computational Fluid Dynamics (CFD) simulation. Data for several different characteristics of the blood flow within the volume of the artery are calculated. The CFD simulation is also able to quantify several qualities of the artery wall, which acts as a boundary for the flow.

Scientists are interested in this data because very little is known about local flow conditions within an artery. Scientists do know that when plaque builds up within an artery or a bypass is performed, the flow conditions can change dramatically. Over time, these changes may have severe negative effects. For example, if a bypass is performed, and the bypass joins the artery at too sharp an angle, there may be some erosion in the arterial wall near the location of the bypass. However, a different angle, may produce more erosion downstream, or lead to areas of stagnant flow, where plaque has a tendency to build up. Scientists hope to use Brown's Artery Simulation to learn how the blood flow in an artery changes given different arterial geometries and obstructions.

The simulation provides the scientist with the unique perspective of being immersed within an artery. As blood flows past the researcher, he or she examines the characteristics of the flow using data visualization tools. Using these techniques, scientists are able to examine small regions of the flow in great detail. The unique understanding that this immersive experience provides will allow scientists to see and experience the ramifications of a planned bypass, and using this knowledge, plan surgeries which lead to less abrasive arterial blood flow conditions and have more long term success.

Art inspired visualization techniques have shown promise for creating visualizations of multi-valued data in 2D. [1] I propose to extend this work to three dimensions to address the problem of visualizing multiple variables at once within the blood flow of the artery. Currently, there is some support for examining data within the volume of the artery, but it is difficult to make correlations between several variables because only one variable can be displayed at a time. The goal of this project is to use artistic concepts and art as inspiration for developing 3D visualization techniques that are capable of displaying multiple variables at once within a *volume*. Then, apply these techniques to do the following:

1. Locate regions of interest within the volume.
2. Examine multiple variables in detail within these regions.
3. Trace the regions back and forth through the flow to see what caused the interesting effect and determine its ramifications.

2 Methodology

CFD datasets are almost always characterized by a volume in which the flow moves about and a surface that bounds the volume. Data about both the volume and its bounding surface are important. Visualization of multiple variables on the bounding surface could be done using a technique that is almost identical to the 2D art-based visualizations created by Kirby and Laidlaw, since a 3D surface is just a curved version of the 2D planes used in these visualizations. Visualization within the volume, however, is fundamentally different. I will focus on the volume-based visualization for this project.

2.1 Visualization within the Flow Volume

2.1.1 Artistic Basis

Artistic techniques such as layering and varying brush stroke were extremely important in creating art-based 2D multi-valued data visualizations. [1] These visualizations were created by building up the image in layers, as an oil painter or printmaker would do. Data was represented using different "brush strokes". Some strokes were glyphs whose position and orientation were determined by the data. In other strokes, varying color or texture were used to represent the data. Some of these techniques may be applied directly to visualizing data in 3D, and others may not. For example, layering cannot be used exactly as it would be in 2D because we would expect to be able to look at an interactive 3D visualization from any viewpoint.

Art-based 3D visualizations can surely draw upon some concepts from 2D art, but 3D artwork, such as sculpture, especially contemporary work, will probably be the most instrumental in determining sound artistic principles upon which successful 3D data visualizations may be based. Dorothy Gillespie is well known in the contemporary art world. [2] She is a painter and sculptor. Her most successful works are aluminum sculptures which she paints with vivid colors. Many of her sculptures resemble a mass of twisting and turning ribbons all painted with abstract designs. This work is very inspirational for this project because it is an excellent example of contemporary art that occupies a volume and could be modeled with computer graphics. Since it involves some painting, it also provides a link to the 2D visualization work mentioned earlier.

The contemporary art world is just starting to embrace computer generated art. Keefe, Acevedo Feliz, and Moscovich are currently creating a new form of 3D computer art at Brown called Cave Painting. Cave Painting is a 3D virtual painting system which runs in Brown's Cave Environment. It provides an almost unlimited tool for artistic creativity in this new medium, and will be extremely important to this project since computer graphics in the Cave will be our medium for data visualization.

Many researchers have used 3D computer graphics to obtain an artistic result, and several of these are particularly inspirational for this project.. [3] [4] [5] Recently, non-photorealistic rendering techniques have proven to be an effective artistic means of conveying information. [6] [7] However, none of these art-based techniques have been applied to the problem of 3D data visualization.

2.1.2 Creating "Strokes" that Represent Data

Just as 2D brush strokes may be controlled by data, 3D "strokes", which may be made up of shapes, points, or geometric primitives, may be controlled by data to produce a visualization of the data. Creating an interactive 3D visualization using these strokes is more challenging than creating a 2D visualization because we want to be able to view this visualization from any vantage point. This means that cluttering and losing sight of some important stroke because another is in front of it become obstacles to the goal of creating a useful visualization. I hope to avoid these obstacles as much as possible by basing the strokes which represent the data, as well as the methods used to compose the strokes into a scene, on strong artistic principles. I plan to consult artists as well as cognitive scientists in the development of the data strokes. In fact, several artists associated with RISD have already expressed interest in this project.

Appropriate use of transparency and textures may help in solving the occlusion and cluttering problems that I anticipate. Victoria Interrante's work may be particularly applicable to solving this problem. [8] [9] [10] Delmarcelle and Hesselink's 3D visualizations using hyperstreamlines will also be of interest in determining the types of strokes which best represent 3D data. [11]

2.1.3 Interaction for Exploring Data

I plan to use these 3D data strokes to locate interesting regions of blood flow within the artery, examine multiple variables within these regions, and trace the cause and effect of the regions within the flow. With a dataset as large as the artery, it would be impossible to view all the data at once and maintain interactive frame rates. Even if computer resources would allow us to do this, we would most likely find that this is too much data for researchers to see at once. To make this visualization platform complete, we need interaction techniques for using data strokes to locate regions of interest. We will also need interaction techniques for varying the level of detail of the data displayed and the number of variables displayed. Coupled with an intuitive interface, these art-inspired visualization techniques will provide a powerful new method of visualizing multiple variables within a 3D dataset.

2.2 Evaluation

Evaluation of the success of this project will be based on feedback from fluid dynamics researchers. Researchers will be asked to evaluate the system in three main areas: 1) Ability to locate regions of interest within the flow. 2) Ability to examine these regions in sufficient detail and make visual correlations between the different variables. 3) Ability to trace the cause and effect of an anomaly in the data which is identified as a region of interest. In their evaluation, the researchers will be asked to compare the art-based techniques to the visualization techniques that are currently used in the artery simulation. These provide some limited interaction with the data and do not have any support for displaying multiple variables at once. The goals of the evaluation are to determine whether the art-based techniques provide more useful information to the researchers as compared to the more traditional techniques used in the current version of the artery simulation, and whether the display of multiple variables at once in 3D makes it easier for one to draw visual correlations between several variables.

3 Timeline

3.1 Examine Regions

- June '00: Evaluate whether it's better to continue to use jot and build on the current artery code, or start using World Toolkit. If WTK, import the artery geometry along with the framework for accessing the CFD simulation data. Begin by having the user define strokes through the data. Link these to the data so that they change color/shape/etc.. based on the data. Use this simple interface to experiment with many different types of strokes for representing data and combine these together to see which ones work well together visually. Get artists and cognitive scientists involved for feedback.

- July '00: Continue experimenting with different types of strokes to find the best ones for conveying the data. Try animated strokes. Develop a method for selecting a region of the flow. To start, have the user define a box. Confine the strokes to this region.

- August '00: Develop good methods for combining the strokes together to form a visualization that is not too cluttered. Try a "smart" stroke placement strategy vs. an interactive placement strategy or some combination of the two.

- September '00: Support interactive changing of the level of detail or the number of variables currently displayed.

3.2 Locate Regions

- October '00: Modify strokes so that they act on a more global scale. Develop appropriate strokes for locating regions of interest.

- November '00: Develop intuitive interaction techniques for generating these strokes. Animated strokes may work well for locating regions.

3.3 Trace Regions

- December '00: Tracing regions also needs an intuitive interface. Some time will be needed here for developing algorithms that trace regions of the flow before we can even start to visualize them. At this point, start planning the actual tasks to be performed for the user evaluation. Determine how exactly the evaluation will be done. For example, can you use the real artery data? Should you use made up data? What questions will be asked?

- January '01: Determine whether a collection of strokes makes sense for tracing regions, or whether new strokes which represent entire regions of the flow need to be developed. Continue to plan user evaluation.

- February '01: Continue to develop these strokes and the algorithms which define them. Continue to plan user evaluation.

3.4 Evaluation and Presentation

- March '01: Should have been talking to researchers all along, but now do a more formal analysis of the techniques with a small user study as described in section 2.2.

- April '01: Write a paper on the project.

This is a relatively ambitious schedule. My priority in the project is the "Examine Regions" phase. I want to develop strokes which work from a visual and scientific standpoint for examining 3D data in detail. I think that I can modify these strokes to work on a more global scale without too much trouble. This will allow researchers to visualize their data in a global exploration mode. (This is the locate regions phase of the project.) If these tasks take longer than I anticipate, I will implement only simple techniques for tracing regions, such as the inverse streamline technique currently used in the artery project, and I will shift the focus of the user evaluation toward the first phases of the project.

4 Contribution and Conclusion

The main contribution of this work will be the development of a promising, new approach for visualizing multiple variables at once in complex 3D data. This has applications in an almost unlimited number of disciplines. The medical application addressed in this project may help scientists to plan better bypass surgeries. From a computer science standpoint, the novel visualization and interaction techniques to be developed in this project will be of interest to researchers visualizing data in virtual environments.

By working closely with artists and taking advantage of artistic power of expression, this project will attempt to provide a solution to the difficult problem of producing an intuitive, interactive visualization of a complex multiple-variable 3D dataset. The success of the project will be judged based on user evaluation of the 3D visualization techniques applied to the artery simulation project currently underway at Brown.

References

[1] R. M. Kirby, H. Marmanis, and David H. Laidlaw. Visualizing multivalued data from 2d incompressible flows using concepts from painting. *IEEE Visualization '99*, pages 333–340, October 1999. ISBN 0-7803-5897-X. Held in San Francisco, California.

[2] Richard Martin, Frances Jr. Martin, Virginia Rembert, George Bolge S., Marcia Corbino, Kyra Belan, and Tom Hicks. *Dorothy Gillespie*. Radford University Foundation Press, Radford, Virginia, 1998.

[3] Stephen Schkolne. Surface drawing. *Master's thesis*, 1999. Caltech.

[4] Maneesh Agrawala, Andrew C. Beers, and Marc Levoy. 3d painting on scanned surfaces. *1995 Symposium on Interactive 3D Graphics*, pages 145–150, April 1995. ISBN 0-89791-736-7.

[5] Tinsley A. Galyean and John F. Hughes. Sculpting: An interactive volumetric modeling technique. *Computer Graphics (Proceedings of SIGGRAPH 91)*, 25(4):267–274, July 1991. ISBN 0-201-56291-X. Held in Las Vegas, Nevada.

[6] Lee Markosian, Michael A. Kowalski, Samuel J. Trychin, Lubomir D. Bourdev, Daniel Goldstein, and John F. Hughes. Real-time nonphotorealistic rendering. *Proceedings of SIGGRAPH 97*, pages 415–420, August 1997. ISBN 0-89791-896-7. Held in Los Angeles, California.

[7] Michael A. Kowalski, Lee Markosian, J. D. Northrup, Lubomir Bourdev, Ronen Barzel, Loring S. Holden, and John Hughes. Art-based rendering of fur, grass, and trees. *Proceedings of SIGGRAPH 99*, pages 433–438, August 1999. ISBN 0-20148-560-5. Held in Los Angeles, California.

[8] Victoria Interrante and Chester Grosch. Visualizing 3d flow. *IEEE Computer Graphics & Applications*, 18(4):49–53, July - August 1998. ISSN 0272-1716.

[9] Victoria Interrante, Henry Fuchs, and Stephen M. Pizer. Conveying the 3d shape of smoothly curving transparent surfaces via texture. *IEEE Transactions on Visualization and Computer Graphics*, 3(2), April - June 1997. ISSN 1077-2626.

[10] Victoria Interrante, Henry Fuchs, and Stephen Pizer. Illustrating transparent surfaces with curvature-directed strokes. *IEEE Visualization '96*, pages 211–218, October 1996. ISBN 0-89791-864-9.

[11] Thierry Delmarcelle and Lambertus Hesselink. Visualizing second-order tensor fields with hyperstream lines. *IEEE Computer Graphics & Applications*, 13(4):25–33, July 1993.