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**Annual Progress Report
for Year 2 of NAS/NASA Grant NAG 2-991
“Tools for Analysis and Visualization
of Large Time-Varying CFD Data Sets”
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Principal Investigators**

1 Progress During Year 2

In the second year, we continued to built upon and improve our scanline-based direct volume renderer that we developed in the first year of this grant. This extremely general rendering approach can handle regular or irregular grids, including overlapping multiple grids, and polygon mesh surfaces. It runs in parallel on multi-processors. It can also be used in conjunction with a k-d tree hierarchy, where approximate models and error terms are stored in the nodes of the tree, and approximate fast renderings can be created. A paper (No. 1 below) on this topic was presented at *IEEE Visualization '96*, in October 1996.

We have extended our software to handle time-varying data where the data changes but the grid does not. We are now working on extending it to handle more general time-varying data.

We have also developed a new extension of our direct volume renderer that uses automatic decimation of the 3D grid, as opposed to an explicit hierarchy. We explored this alternative approach as being more appropriate for very large data sets, where the extra expense of a tree may be unacceptable. A paper describing our initial results was submitted to the *IEEE Visualization '97* Conference (see Paper No. 3) below.

We also presented a paper (No. 2 below) at the *ACM Symposium on Volume Visualization* in October 1996. This paper describes a new approach to direct volume rendering using hardware 3D textures and incorporates lighting effects. Volume rendering using hardware 3D textures is extremely fast, and machines capable of using this technique are becoming more moderately priced. While this technique, at present, is limited to use with regular grids, we are pursuing possible algorithms extending the approach to more general grid types.

We have also begun to explore a new method for determining the accuracy of approximate models based on the *light field* method described at ACM SIGGRAPH '96 (see Hanrahan and Levoy *Light Field Modeling* in that conference. In our initial implementation, we automatically image the volume from 32 equi-distant positions on the surface of an enclosing tessellated sphere. We then calculate differences between these images under different conditions of volume approximation or decimation. We are studying whether this will give a quantitative measure of the effects of approximation.

We have created new tools for exploring the differences between images produced by various rendering methods. Images created by our software can be stored in the SGI RGB format. Our *idtools* software reads in pair of images and compares them using various metrics. The differences of the images using the RGB, HSV, and HSL color models can be calculated and shown. We can also calculate the auto-correlation function and the Fourier transform of the image and image differences. We will explore how these image differences compare in

order to find useful metrics for quantifying the success of various visualization approaches. In general, progress was consistent with our research plan for the second year of the grant.

2 List of Publications

From August 1996 to the present, we have produced the following publications. Copies of these publications are attached.

1. Wilhelms, Jane, Allen Van Gelder, Paul Tarantino, and Jonathan Gibbs, 1996. "Hierarchical and Parallelizable Direct Volume Rendering for Irregular and Multiple Grids", appeared in the *Proceedings of the IEEE Visualization '96 Conference*, October, 1996, pages 57-64.

This article describes the general direct volume rendering approach that is the basis for our research into fast, approximate rendering of irregular grids.

2. Van Gelder, Allen, and Kwansik Kim, 1996. "Direct Volume Rendering with Shading", appeared in the *ACM Symposium on Volume Visualization*, October, 1996. See also UCSC technical report UCSC-CRL-96-16.

This paper describes our new approach to direct volume rendering of regular grids using 3D hardware texture maps that incorporates lighting effects on surfaces.

3. Gibbs, Jonathan, Allen Van Gelder, Vivek Verma, and Jane Wilhelms, 1997. "Rapid Decimation for Direct Volume Rendering", submitted to *IEEE Visualization '97*.

Our latest paper describes a new approach to based on automatic decimation of the volume. It is an extension of our scanline-based rendering method described in *Paper 1*, and can work on virtually any grid type. It gives some of the benefit of error-controlled approximate rendering that our k-d tree-based approach offers, but does not require the extra space of an explicit tree.

3 Students Supported

Graduate students Jonathon Gibbs, Kwansik Kim, and Vivek Verma have been partially supported by this project during the second year.. Mr. Gibbs, Mr. Kim, and Mr. Verma are PhD students. Dr. Cathi Colin, a Ph.D. student supervised by P.I. Wilhelms, finished her Ph.D. in summer 1996 on a subject related to this project (point location in 3D curvilinear grids), but she was not funded by this grant.

Dissemination of Report

Copies of this report and the papers discussed have been sent to NAS/NASA Ames in Mountain View, Ca., and to the NASA Center for AeroSpace Information (CASI) in Maryland.