From Transfer Functions to Level Sets:
Advanced Topics in Volume Image Processing

IEEE Visualization 2001

Tutorial 5

Course Organizers:

Terry S. Yoo
National Library of Medicine, NIH

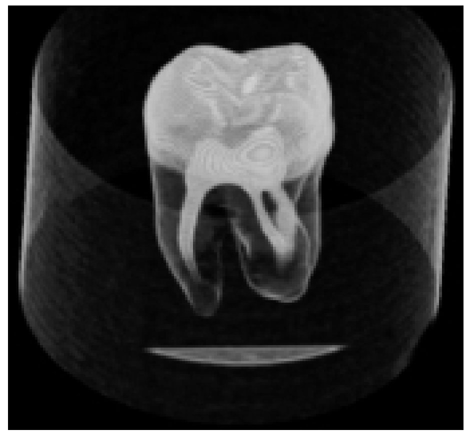
Raghu Machiraju
The Ohio State University

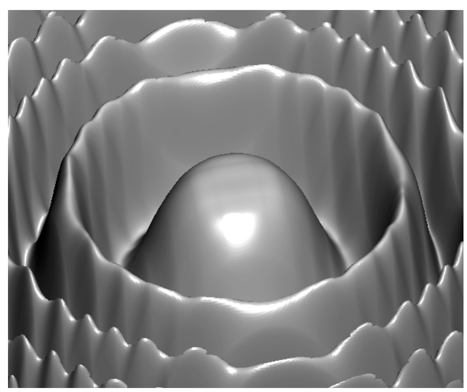
Lecturers:

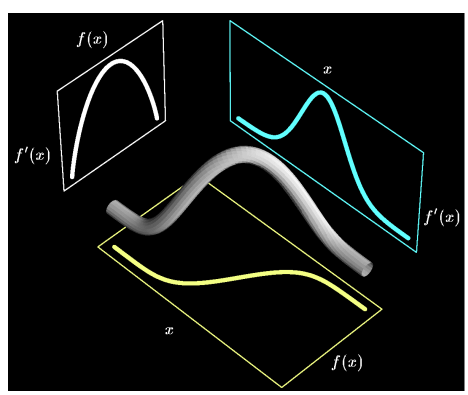
Gordon Kindlmann
University of Utah

Torsten Möller
Simon Fraser University

Ross Whitaker
University of Utah







Forward (revised)

Welcome to our course on volume image processing. The sampling and analysis of digital data is intrinsic to the field of computer graphics and the more specialized area of visualization. Understanding how our image processing choices affect the eventual products of our efforts is an essential element of good visualization design. The purpose of this course is to serve as a review of many of the concepts and theories that serve as the foundations of volume image processing and analysis as well as an introduction to new and emerging concepts in volume image generation. This treatment can be neither comprehensive nor exhaustive, for that would reach beyond the scope of this course. We attempt to introduce each topic and provide pointers to references for more complete background reading and to conferences and journals where active research in these areas is published.

In a 1983 Lucasfilm Ltd. technical memo on digital filtering, later published by Pat Hanrahan as part of a 1991 SIGGRAPH course on volume rendering., Alvy Ray Smith lays out the challenge often associated with image processing in our field.

> Everyone seems to believe that sampling theory is simple, elegant, and straightforward, but it is my experience that whenever two computer graphicists try to discuss the subject they end up quibbling over details, sacrificing intuition in the impossible effort to convince one another that each knows the important details of the basic theory. I think this is because there are several (at least four) ways to look at a sampling process, all equivalent, and each combatant is fluent in only one or two of these ways and never the same ones as his opponent. [A.R. Smith, Lucasfilm Tech. Memo 27, 1983]

The recent introduction of fast volume rendering capabilities in consumer level desktop machines is an indication of the possible growth of volume visualization throughout the world of computing. We believe that a greater appreciation of data filtering and analysis by all visualization practitioners is more needful than ever. We are happy to take up Alvy Ray Smith's challenge to present a coherent picture of this important domain. We hope that you find this presentation useful and enlightening throughout your future explorations in visual communication.

Terry S. Yoo
Raghu Machiraju
31 August 2001

Cover Figures:

Top: This figure shows an image from the Vis2000 Panel, the Transfer Function Shootout. The dataset is the CT Tooth, provided to all of the panelists. The transfer function was selected using VolDG, a design gallery tool for quickly searching a large parameter space. The image was created by Hanspeter Pfister of the Mitsubishi Electric-Research Lab, and Raghu Machiraji and Jinho Lee of the Ohio State University.

Middle: This is a test figure used in the analysis of image reconstruction, sampling and interpolation. For details, see:

Möller, T., R. Machiraju, K. Mueller, and R. Yagel. 1996. Classification and Local Error Estimation of Interpolation and Derivative Filters for Volume Rendering. Proceedings of the 1996 ACM Symposium on Volume Visualization. 71-78.

Bottom: This figure portrays the transfer function parameter curve as it traverses a intensity derivative feature space. For details, see:

Kindlmann, G. and J.W. Durkin. 1998. Semi-Automatic Generation of Transfer Functions for Direct Volume Rendering. Proceedings of the 1998 Symposium on Volume Visualization. ACM: New York. 79-86

Vision is the art of seeing things invisible.

- Jonathan Swift

Abstract
From Transfer Functions to Level Sets

What are the elements for quality in volume graphics? What do you have to know about image analysis for volume graphics? Efficiency is not the problem; in many cases adding computer power does not improve the image. Rather, additional graphics pipelines simply reduce the time needed to create a flawed image. When brute force fails, research must fall back on the mathematical principles of the geometry and the underlying nature of sampled volume data.

The conventional volume rendering pipeline has been effectively used to visualize volume data that is often considered a sampled density map. However, more and more people are looking at data that has noise, occluding surfaces, density fluctuations, limited resolution, etc. These factors require users to do more "processing". Advanced volume processing is what enables people to do 1) linear and nonlinear filtering, 2) interpolation, 3) reconstruction, 4) feature extraction, and 5) model fitting. We describe the problem as a pipeline from the reconstruction of the continuous model from the sampled data, through the application of transfer functions for shading and classification, to the transformation sampling and projection of the reconstructed values for visualization. The goal is to extract or locate structures hidden within the data. A tacit requirement is to do so without masking detail with unwanted artifacts. Thus, the emphasis will be on factors which affect final image quality.

Beyond improving the volume visualizations that we are used to seeing, faster systems are allowing users the freedom to explore and interact with their data. Designers of visualization systems are supplementing viewpoint and clip-plane control with a variety of interactive tools for controlling opacity, color, texture, and other attributes of the presented image. Moreover, more sophisticated means of analyzing volume data leads to broader dimensions of the visualization space. Complex data requires more than simple isosurfaces, and effective visualization requires a blend of mathematics, statistics, and aesthetic design to quickly and clearly convey the intended message.

We are proposing a course that will cover elements all along the volume rendering pipeline. Beyond an introduction to volume rendering, we will target specific problems encountered in the creation of volume visualizations and the mathematics required to address them. This is not intended as a superficial survey course on volume mathematics, but rather a series of studies designed to take the attendee through many of the deep problems in volume visualization. Case studies and examples are an integral part of the course. We will also present methods for navigating and interactively exploring volume data through the use of transfer functions, level sets and implicit models.

Emerging topics in volume mathematics

The afternoon will be dedicated to exploring emerging techniques relevant to both 3D image processing and volume graphics. Proposed topics for discussion include multiscale methods, implicit techniques, and level set theory. These methods represent active areas of research that should interest audience members who wish to explore new ideas in volume graphics and visualization research. For instance, multiscale methods, will be described as a natural extension of the filtering techniques for function reconstruction described earlier in the morning. The advantages of these techniques will be illustrated for analysis through suitable examples. Wavelet techniques will be described. Less emphasis will be paid to the actual design issues of such filters. Rather, the emphasis will be on the utility of these techniques.

Contents

Speaker Biographies

Gordon Kindlmann has been a doctoral student in the Computer Science department at the University of Utah since 1997. In 1995 he received a BA in mathematics from Cornell University, and in 1999 he finished his MS in computer graphics under Donald Greenberg in the Program of Computer Graphics at Cornell University. His Masters research was on the *Semi-Automatic Generation of Transfer Functions for Direct Volume Rendering*. His current research continues to focus on volume rendering while extending into the areas of medical imaging, segmentation, and color science.

Raghu Machiraju is an Assistant Professor of Computer and Information Science at the Ohio State University. His research interests include visualization, graphics, image analysis and high performance computing. He obtained his Doctorate from the Ohio State University in 1996. Previously he served as an Assistant Professor of Computer Science at Mississippi State and as a research scientist at the NSF ERC for Computational Field Simulation. He received the NSF Faculty Early Career Award for his proposal, "On the Assessment of Volume Rendering Algorithms in Visual Computing" in 1998. Raghu has participated in related tutorials at IEEE Vis 2000.

Torsten Möller received his PhD in Computer and Information Science from Ohio State University in June 1999. He received a Vordiplom (BSc) in mathematical computer science from Humboldt University of Berlin, Germany. He is currently an assistant professor at the School Of Computing Science at Simon Fraser University, where he is co-director of the Graphics, Usability and Visualization Lab. His research interests include the fields of Scientific Visualization and Computer Graphics. He is especially interested in interactive and accurate volume rendering methods for regular and irregular data.

Ross Whitaker is currently an assistant professor at the University of Utah, Department of Computer Science. His research interests include: computer vision, image processing, medical imaging, and computer graphics/visualization. He received his B.S. degree in Electrical Engineering and Engineering Physics from Princeton University in 1986 and his Ph.D. in Computer Science from the University of North Carolina at Chapel Hill in 1993. Previously he has been a research scientist in the User Interaction and Visualization Group at the European Computer-Industry Research Centre in Munich, Germany and an assistant professor of Electrical and Computer Engineering at the University of Tennessee.

Terry S. Yoo is a Computer Scientist in the Office of High Performance Computing and Communications, National Library of Medicine, NIH, where he explores the processing and visualizing of 3D medical data, interactive 3D graphics, and computational geometry. Previously as a professor of Radiology, he managed a research program in Interventional MRI with the University of Mississippi. Terry holds an A.B. in Biology from Harvard, and a M.S. and Ph.D. in Computer Science from UNC Chapel Hill.

Speaker Information

Gordon Kindlmann
School of Computing
50 S. Central Campus Dr. #3490
Salt Lake City, UT 84112-9205

(801) 918-0281
fax: (801) 585-6513
gk@cs.utah.edu

Torsten Möller
Assistant Professor
School of Computing Science
8888 University St.
Simon Fraser University
Burnaby, B.C. V5A 1S6
Canada

(604) 291-3774
torsten@cs.sfu.ca

Raghu Machiraju
Assistant Professor
Department of Computer and Information Science
The Ohio State University
395 Dreese Laboratories
2014 Neil Avenue
Columbus, OH 43210-1277, USA

(614) 292-6730
fax: (614) 292-2911
raghu@cis.ohio-state.edu

Ross T. Whitaker
Assistant Professor
School of Computing
4540 Merrill Engineering Building
The University of Utah
Salt Lake City, UT 84112-9205

(801) 581-8224
fax: (801) 581-5843
whitaker@cs.utah.edu

Terry S. Yoo
Computer Scientist
National Library of Medicine
National Institutes of Health
8600 Rockville Pike
Bethesda, MD 20894, USA

(301) 435-3268
fax: (301) 402-4080
yoo@nlm.nih.gov

Course Syllabus and Schedule

8:30 AM - Begin

Volume Data For Computer Graphics [Yoo]
- Mathematics and visualization
- Sources of volume data:
- Topics to be covered and not to be covered, & what we hope to accomplish.

Filtering And Frequency Fundamentals [Yoo]
- Filters
- Frequency – a biological example
- Fourier Transforms
- The convolution theorem and the Fourier slice theorem

Evaluation And Design Of Filters [Möller]
- Derivatives of volume data.
- Sources of error and error propagation in filtering.
- Approximation, interpolation, and anti-aliasing.

9:45 – 10:15 AM ---BREAK (30 min.)---

Evaluation And Design Of Filters (contined)

Transfer Functions For Volume Rendering [Kindlmann]
- Function Reconstruction from Discrete Data.
- Exploring transfer functions for volume rendering: Cause and effect examples.

12:15 PM ---LUNCH---

1:45 PM - Resume

Wavelets And Multiresolution Techniques [Machiraju]
- Introduction to wavelets.
- My favorite wavelets.
- Applications - representation, analysis, and compression
- Examples.

Constrained Implicit Surfaces [Yoo]
- Introduction to implicit surfaces
- Interpolating implicit surfaces (incl. high-dimensional models for shape interpolation)
- Complex constrained implicit surfaces for the visualization of solid shape.
- Examples.

3:30 – 4:00 PM ---BREAK (30 min.)---

Level Sets [Whitaker]
- Blobby models and beyond.
- Level set basics.
- Evolving isosurfaces.
- Applications of level set methods to morphing and reconstruction of range data.

Wrapup [Yoo or Machiraju]
- Suggested reading.
- Suggested venues, journals, and conferences.

5:30 PM - End

A word on these course notes:

These course notes are provided as an aid for those attending the course at Visualization 2001. They contain mostly the slides used in the presentation, although the actual presentations are expected to undergo revisions between the time of this writing and the delivery of the course and its materials. Supplemental materials, papers, animations, etc. are available on the conference DVD-ROM as are the electronic versions of these chapters/slides.

In the interests of making the latest materials available, we have also constructed a web site where these and other materials may be found. Final versions of the materials used in the tutorial should be available there. The URL for the web page is:

http://visual.nlm.nih.gov/tutorials/vis2001

We hope you find these materials useful and enjoy the course.