IEEE Visualization 2003 Full-Day Tutorial

Interactive Visualization of Volumetric Data on Consumer PC Hardware

Abstract

Interactive visualization is no longer restricted to expensive workstations and dedicated hardware thanks to the fast evolution of consumer graphics. Course participants will learn to leverage new features of graphics hardware to build applications for the interactive visualization of volumetric data. A large body of the course deals with high-quality volume rendering. Beginning with basic texture-based approaches, the algorithms are improved and expanded incrementally, covering illumination, non-polygonal isosurfaces, transfer function design, volumetric effects, and hardware-accelerated high-quality filtering. The final session of the course discusses volumetric flow visualization and aspects of system design. Course participants are provided with documented source code covering details usually omitted in publications.

Course Organizer

Daniel Weiskopf

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Level of the Tutorial

Beginner – intermediate.

The tutorial is aimed at scientific researchers and developers of visualization tools. Participants should have basic programming skills and should be familiar with OpenGL. Basic knowledge of graphics hardware and volume visualization is helpful but not required.

Detailed Course Description

MODULE 1: Introduction to GPU-Based Methods

- Introduction [15 min] (D. Weiskopf):
  Introductory words; motivation; visualization pipeline; overview of the course

- Basics of GPU-Based Programming [45 min] (D. Weiskopf):
  Structure of modern GPUs (graphics processing units); rendering pipeline; low-level programming; shading languages

MODULE 2: Basic GPU-Based Volume Rendering

- Introduction to GPU Volume Rendering [50 min] (M. Hadwiger):
  Physical background; traditional ray casting; 2D texture-based volume rendering; 3D texture-based volume rendering; 2D multi-texture volume rendering; compositing

- Basic Illumination Techniques [30 min] (K. Engel):
  Gradient estimation; per-pixel illumination; reflection mapping; non-polygonal shaded isosurfaces

MODULE 3: Advanced GPU-Based Volume Rendering

- Classification and Transfer Function Design [55 min] (J. Kniss):
  Pre- versus post-classification; transfer functions; implementations; multi-dimensional transfer functions; transfer function design (image-driven and data-driven methods, user interaction and feedback); optical properties

- Advanced Illumination Techniques [45 min] (J. Kniss):
  Alternative lighting strategies; data vs. computation tradeoff; shadowing; translucency; general light transport and global illumination solutions; balancing quality and speed

- Advanced Volume Rendering Techniques [45 min] (K. Engel):
  Pre-integrated classification; texture-based pre-integrated volume rendering; rasterization; isosurfaces using dependent textures; Perlin noise and volumetric FX

- Hardware-Accelerated High-Quality Filtering [30 min] (M. Hadwiger):
  Theoretical background (sampling and reconstruction); filtering with tiled high-resolution filters; filtering with on-the-fly filter kernel evaluation; filtering of volumetric data; combining pre-integrated volume rendering and HQ filtering

MODULE 4: Beyond Static Scalar Fields

- Flow Visualization [35 min] (D. Weiskopf):
  Introduction; line integral convolution (LIC); texture advection; image-based flow visualization; extension to 3D flow visualization

- Performance, Tools, System Design, Computation [55 min] (Aaron Lefohn):
  Performance vs. quality tradeoffs; balancing transform and fill bound pipelines; dynamic range considerations; object oriented OpenGL design for visualization; PDEs and computation on GPUs for advanced visualization; segmentation

Tutorial History

This course is related to three tutorials that were presented last year at three different conferences. First, the IEEE Visualization 2002 full-day Tutorial #2 on "High-Quality Volume Graphics on Consumer PC Hardware" specifically dealt with hardware-based volume visualization. Two of the speakers of this proposal (M. Hadwiger, J. M. Kniss) were also involved in the IEEE Visualization Tutorial. The scope of the proposed tutorial has been broadened to take into account more general aspects of the visualization of volumetric data. Additional topics are considered, such as high-quality filtering of volume data, segmentation, or hardware-based flow visualization. All presented visualization techniques nicely fit into the same conceptional framework of the visualization pipeline and benefit from the use of graphics hardware. Second, the Eurographics 2002 full-day Tutorial T4 on "Programmable Graphics Hardware for Interactive Visualization" covered all aspects of the visualization pipeline. Two of the speakers of this proposal (K. Engel, D. Weiskopf) were also involved in the Eurographics Tutorial. Third, the SIGGRAPH 2002 Course #42 on "High-Quality Volume Graphics on Consumer PC Hardware" once again covered hardware-based volume visualization. There, lectures were given by K. Engel, M. Hadwiger, and J. M. Kniss.

Instructor Information

Klaus Engel
Siemens Corporate Research (SCR) in Princeton/NJ.

Since 2003, Klaus Engel has been a researcher at Siemens Corporate Research (SCR) in Princeton/NJ. He received a PhD in computer science from the University of Stuttgart in 2002 and a Diplom (Masters) of computer science from the University of Erlangen in 1997. From January 1998 to December 2000, he was a research assistant at the Computer Graphics Group at the University of Erlangen-Nuremberg. From 2000 to 2002, he was a research assistant at the Visualization and Interactive Systems Group of Prof. Thomas Ertl at the University of Stuttgart. He has presented the results of his research at international conferences, including IEEE Visualization, Visualization Symposium and Graphics Hardware. In 2001, his paper "High-Quality Pre-Integrated Volume Rendering Using Hardware-Accelerated Pixel Shading" has won the best paper award at the SIGGRAPH/Eurographics Workshop on Graphics Hardware. He has regularly taught courses and seminars on computer graphics, visualization and computer games algorithms. In his PhD thesis he investigated "Strategies and Algorithms for Distributed Volume-Visualization on Different Graphics-Hardware Architectures".

Detailed information about this research projects are available online at:
http://wwwvis.informatik.uni-stuttgart.de/~engel/

Markus Hadwiger
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Markus Hadwiger is a researcher in the "Basic Research in Visualization" group at the VRVis Research Center in Vienna, Austria, and a PhD student at the Vienna University of Technology. The focus of his current research is exploiting consumer graphics hardware for high quality visualization at interactive rates, especially volume rendering for scientific visualization. First results on high quality filtering and reconstruction of volumetric data have been presented as technical sketch at SIGGRAPH 2001, and as a paper at Vision, Modeling, and Visualization 2001. He is regularly teaching courses and seminars on computer graphics, visualization, and game programming. Before concentrating on scientific visualization, he was working in the area of computer games and interactive entertainment. His master's thesis "Design and Architecture of a Portable and Extensible Multiplayer 3D Game Engine" describes the game engine of Parsec (http://www.parsec.org/), a still active cross-platform game project, whose early test builds have been downloaded by over 100.000 people, and were also included on several Red Hat and SuSE Linux distributions.

Information about current research projects can be found at:
http://www.VRVis.at/vis/
http://www.VRVis.at/vis/research/hq-hw-reco/

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Joe Kniss recently recieved his Masters degeree in computer science from the University of Utah, where he is currently pursuing his PhD and a member of the Scientific Computing and Imaging Institute. His current research focuses on interactive volume rendering techniques for scientific discovery and visualization. His current interests are volume light transport (global illumination), user interfaces for scientific visualization, and hardware rendering techniques. He has published numerous papers on these topics and organized two courses that have provided an extensive and in depth overview of volume rendering techniques.

Current research activities can be found on line at:
http://www.cs.utah.edu/~jmk/research.html
http://www.cs.utah.edu/~jmk/simian/index.html

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Aaron Lefohn is a master's student in the School of Computing at the University of Utah. His current research focuses on the development of graphics hardware-based algorithms to accelerate deformable implicit surface (level set) techniques. This work has produced significant speedups for these versatile, volumetric methods. In addition, this research has led to new methods for compactly representing and efficiently rendering isosurfaces on graphics processors (GPUs). Aaron comes to computer science from a background in the physical sciences. His M.S. degree in theoretical chemistry focused on the development of a new simulation model for water. Aaron has published in both the physical chemistry and computer graphics literature as well as given many lectures on physically-based simulation, rendering methods, and the use of GPUs for general computation.

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Daniel Weiskopf is senior researcher and teacher of computer science at the Institute for Visualization and Interactive Systems (led by Prof. Thomas Ertl) at the University of Stuttgart (Germany). He studied physics at the University of Tübingen (Germany), San Francisco State University, and the University of California at Berkeley. He received a Diplom (Masters) of physics in 1997 and a PhD in theoretical astrophysics in 2001, both from the University of Tübingen. Daniel Weiskopf authored several articles on scientific visualization and computer graphics; he won the Best Case Study award at IEEE Visualization 2000 for his paper on general relativistic ray tracing. He is regularly teaching courses and seminars on computer graphics, visualization, geometric modeling, and computer animation; and he was co-organizer and speaker of the SIGGRAPH 2001 Course on "Visualizing Relativity". In addition to his research on computer graphics, he is interested in using visualization for communicating complex physical concepts to the public: several of his films were featured at major European festivals of scientific animations and TV broadcasts; his visualizations have been included in a number of popular-science publications. His research interests include scientific visualization, real-time graphics, virtual reality, interaction techniques, non-photorealistic rendering, computer animation, special and general relativity.

Detailed information about this research projects are available online at:
http://www.vis.uni-stuttgart.de/˜weiskopf