JACOBS UNIVERSITY

Direct Surface Extraction from Unstructured Point-based Volume Data

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A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Computer Science

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Date of Defense: April 30, 2009
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Berichte aus der Informatik

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Shaker Verlag
Aachen 2009

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Jacobs University Bremen, Diss., 2009

Printed in Germany.

ISBN 978-3-8322-8359-9
ISSN 0945-0807

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

To Sabine

Executive Summary

Surface extraction is a standard visualization method for scalar volume data and has been subject to research for decades. Many algorithms for surface extraction from various data structures and types exist. However, for unstructured point-based volume data, where no topology or connectivity between data points is given, most approaches propose to reconstruct the scalar field over a grid and apply standard surface extraction techniques for the obtained grids. This work introduces a new method that directly extracts surfaces from unstructured volume data without three-dimensional mesh generation or reconstruction over a structured grid. The presented approach consists of two major processing steps: a geometry extraction step and a point-cloud rendering step.

The geometry extraction step computes points on the isosurface by linearly interpolating between neighboring pairs of samples. The needed neighbor information is retrieved by approximating natural neighbors as provided by Voronoi diagrams. One presented approximation approach is the generation of a three-dimensional discrete Voronoi diagram. This is done with the aid of today's graphics hardware to achieve reasonably fast results. A second approach for approximating natural neighbors is partitioning the three-dimensional domain into cells using a kd-tree. The cells are merely described by their index and bitwise index operations allow for a fast determination of potential neighbors. An angle criterion is used to select appropriate neighbors from the small set of candidates. The approach is evaluated on several synthetic data sets and is significantly faster than previously developed algorithms while assuring nearly the same accuracy. Moreover, it is much more accurate than reconstructing the scalar field over a regular grid.

In sparsely sampled regions, extracted isosurfaces could be rough especially when dealing with noisy data. To avoid such issues, a level-set approach can be applied to the data before isosurface extraction. This results in smoother segmenting surfaces when extracting the geometry of the zero level set. In contrast to existing level-set approaches, which operate on gridded data and mainly on regular structured grids, an approach is presented that directly computes level sets on unstructured point-based volume data without prior resampling or mesh generation. To suffice the needs of smooth segmentation regarding an isovalue, a level-set method is chosen that combines hyperbolic advection to the isovalue and mean curvature flow. The needed function properties like gradient and mean curvature are approximated in each sample point by a consistent least-squares approach operating in four dimensions. Since the approach uses an explicit time-integration scheme, time steps are bounded by the Courant-Friedrichs-Lewy condition. To avoid small global time steps, asynchronous local integration can be applied. The practicality of this approach is shown on simulated smoothed particle hydrodynamics data.

The output of the geometry extraction step is a point-cloud representation of the isosurface, where each point only holds its position information and a vector inducing the surface orientation. A point cloud containing surface normal information is generated using a least-squares approach. The final rendering step uses point-based rendering techniques to visualize the point cloud. If a fast and interactive rendering is needed, an algorithm based on image-space operations is used. The lit point cloud is directly rendered to screen space, possibly resulting in holes in the rendered surface. These holes are detected using image-space filters and filled with neighboring surface color information. A final smoothing filter assures a smooth surface rendering. If the rendering should include photorealistic effects, a ray-tracing approach is preferable. The surface is approximated using circular splats with attached normal field. These splats are then rendered with ray tracing to achieve photorealism.

The presented direct surface extraction algorithm for unstructured point-based volume data produces results of high quality. By applying the level-set approach in a preprocessing phase, it allows for a smooth yet correct surface extraction also for data sets with highly varying point density. Nevertheless, the proposed methods are competitive with similar powerful approaches in terms of computation speed.

Acknowledgments

First, I want to express my sincere gratitude to my thesis supervisor Lars Linsen. He was the man, turning me, a pure mathematician addicted to computer games, to a computer scientist actually able to write this thesis. I thank him for accepting me as doctoral candidate and introducing me into the exciting and diversified field of visualization. Thank you also, for the various valuable discussions and the guidance through numerous papers and finally this thesis.

My special thanks go to my dearest, Sabine. Without her, I would have never studied mathematics and would have never discovered the wonderful world of natural sciences. She always supported me in good and in bad times, tried to understand and follow my sometimes confusing ideas, traveled with me to numerous conferences, always listened to my problems – or solutions, and finally read this thesis several times.

A special gratitude goes also to Stephan Rosswog, for making my research useful by providing his data sets, for various discussions, and for valuable input from a different point of view. In this context, I also want to thank Horst Hahn and Daniel Weiskopf for reviewing this thesis and my colleagues Tatyana Ivanovska, Steffen Brasch, Petar Dobrev, Steffen Hauth, and Tran Van Long for their productive collaboration.

Furthermore, I want to thank the Jacobs University in Bremen for facilitating this Ph.D. project and offering so nice study conditions. Finally, I thank my whole family for supporting me materially and ideally at all times.

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