

Accelerated Volume Rendering on Structured Adaptive Meshes

vorgelegt von

Ralf Kähler

Am Fachbereich Mathematik und Informatik
der Freien Universität Berlin
zur Erlangung des akademischen Grades
eines Doktors der Naturwissenschaften
eingereichte Dissertation

Februar 2005

Betreuer:

Prof. Dr. Dr. h. c. Peter Deuflhard
Konrad-Zuse-Zentrum für Informationstechnik Berlin (ZIB)
Takustr. 7
14195 Berlin
und Freie Universität Berlin

Gutachter:

Prof. Dr. Dr. h. c. Peter Deuflhard
Prof. Dr. Edward Seidel (Louisiana State University)
Priv. Doz. Dr. Konrad Polthier (ZIB)

Datum der Disputation:

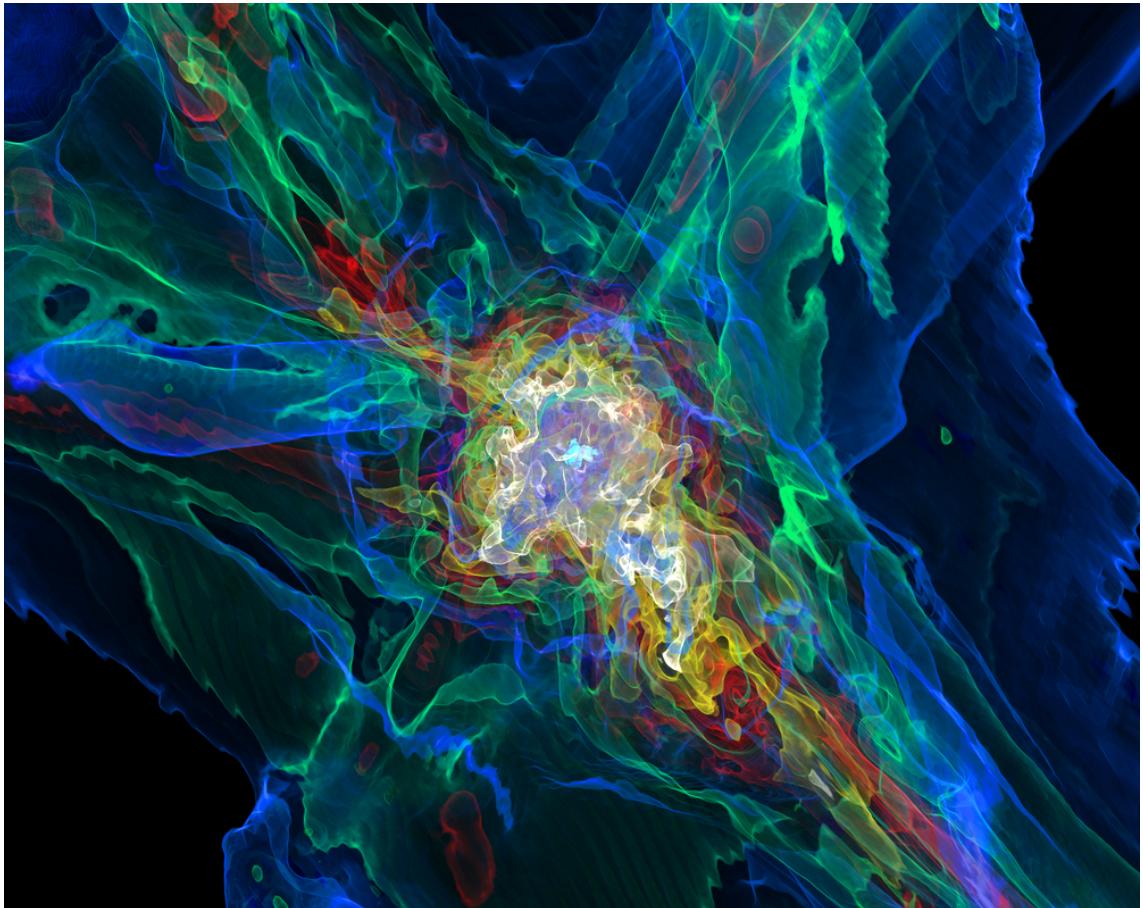
19. September 2005

Acknowledgments

The work described in this thesis has been carried out at the department of Scientific Visualization at the Zuse Institute Berlin (ZIB) in cooperation with the Max-Planck-Institute for Gravitational Physics (Albert-Einstein-Institute, AEI). First of all I would like to thank Prof. Dr. Dr. h. c. Peter Deuflhard and Hon. Prof. Hans-Christian Hege for the opportunity to graduate in the exciting and innovative field of scientific visualization. Without their support and encouragement this work would not have been possible.

I also thank Prof. Dr. Ed Seidel for his constant interest and motivation and for giving me the possibility to collaborate with several international research groups.

I would like to thank all members of the Scientific Visualization department at ZIB and the Numerical Relativity group at AEI for many fruitful and inspiring discussions. Special thanks deserves Dr. Detlev Stalling for sharing his knowledge and insight. Finally I thank Prof. Dr. Tom Abel for the inspiring cooperation and for providing his exciting datasets.



Volume Rendering of a cosmological adaptive mesh refinement (AMR) simulation. The semi-transparent shells depict areas of constant gas density inside a proto-galaxy. Since many length scales had to be considered to correctly model the physical phenomena, ranging from 18,000 light years to cover the galaxy down to several light hours, to resolve the evolving proto-star in the central region, adaptive techniques were indispensable. The simulation was carried out on a time-dependent structured AMR grid with up to 30 levels of refinement. (*dataset courtesy of T. Abel, Stanford University*)

Contents

1	Introduction	1
1.1	Problem Formulation	1
1.2	Outline	2
2	Function Approximation on Discrete Grids	5
2.1	Computational Grids	5
2.1.1	Structured Grids	6
2.1.2	Unstructured Grids	8
2.1.3	Block-Structured, Overlaid and Hybrid Grids	8
2.1.4	Grid Adaption and Local Refinement	9
2.2	Adaptive Mesh Refinement (AMR)	10
2.2.1	Structured Adaptive Mesh Refinement (SAMR)	11
2.2.2	Notations	11
2.2.3	A Clustering Algorithm	13
2.2.4	Temporal Refinement Scheme	14
2.3	Interpolation	17
2.4	Spatial Access Methods	21
3	Visualization Methods for Scalar Data	25
3.1	The Visualization Pipeline	25
3.2	Visualization Methods for 3D Scalar Data	27
3.3	Indirect Volume Rendering	28
3.3.1	Slice-Based Techniques	28
3.3.2	Isosurface Extraction	29
3.4	Direct Volume Rendering	33
3.4.1	Transfer Functions	35
3.4.2	Emission-Absorption Models	36
3.4.3	Raycasting	38
3.5	Texture-Based Volume Rendering	39
3.5.1	2D Texture-Based Volume Rendering	40
3.5.2	3D Texture-Based Volume Rendering	41

4 Accelerated Volume Rendering	45
4.1 Related Work on Software-Based Volume Rendering	45
4.2 Related Work on Hardware-Accelerated Approaches	46
4.3 Acceleration by Adaptive Integration	48
4.3.1 Numerical Background	48
4.3.2 Application to Volume Rendering	50
4.3.3 Results and Discussion	51
4.4 Acceleration by Exploiting Sparsity of Data	54
4.4.1 Motivation	54
4.4.2 Ansatz	54
4.4.3 Data Structure Requirements	55
4.4.4 Octree Generation	56
4.4.5 Adaptive Approach	57
4.4.6 Opacity as Relevance Criterion	59
4.4.7 Rendering	59
4.4.8 Texture Packing	60
4.4.9 View-Consistent Node Traversal	61
4.4.10 Generation of the Proxy Geometries	61
4.4.11 The Applications	62
4.4.11.1 The Datasets	62
4.4.11.2 Results	63
4.4.12 Discussion and Conclusions	63
5 Visualization of Structured Adaptive Mesh Refinement Data	69
5.1 Related Work	70
5.2 Point Location for AMR Data	71
5.3 Interpolation	75
5.3.0.1 Vertex-Centered Data	76
5.3.0.2 Cell-Centered Data	77
5.4 Indirect Volume Rendering	79
5.4.1 Planar Slices	79
5.4.2 Height Fields	80
5.4.3 Isosurfaces	83
5.4.3.1 Cell-Centered Data	83
5.4.3.2 Vertex-Centered Data	83
5.4.3.3 Conforming Split	85
5.4.3.4 Results and Discussion	87
5.5 Direct Volume Rendering for Structured AMR Data	89
5.5.1 3D Texture-Based Volume Rendering	89
5.5.2 Opacity Corrections	90
5.5.3 Raycasting	91
5.5.4 Adaptive Block Selection	91
5.5.5 Results and Discussion	92

5.6	Visualization of Time-Dependent AMR Data	95
5.6.1	Generation of Intermediate Grids	96
5.6.2	Temporal Interpolation of Grid Functions	97
5.6.3	Results and Discussion	99
5.6.4	Future Work	101
5.7	Rendering the First Star in the Universe - A Case Study	102
5.7.1	The Simulation	102
5.7.2	VR Environment	103
5.7.3	Results	105
6	Summary and Concluding Remarks	107

