

4.5	View-Sample Mapping	131
4.6	Shadow-Map Reconstruction	134
4.7	Temporal Reprojection	136
4.8	Cookbook	137
5	Filtered Hard Shadows	139
5.1	Filters and Shadow Maps	140
5.2	Applications of Filtering	144
5.3	Precomputing Larger Filter Kernels	147
5.4	Summary	160
6	Image-Based Soft-Shadow Methods	161
6.1	Introduction	161
6.2	Basics	166
6.3	A Reference Solution	172
6.4	Augmenting Hard Shadows with Penumbrae	174
6.5	Blurring Hard-Shadow-Test Results	178
6.6	Filtering Planar Occluder Images	187
6.7	Reconstructing and Back-Projecting Occluders	191
6.8	Using Multiple Depth Maps	204
6.9	Summary	206
7	Geometry-Based Soft-Shadow Methods	209
7.1	Plausible Shadows by Generating Outer Penumbra	209
7.2	Inner and Outer Penumbra	215
7.3	Soft Shadow Volumes	217
7.4	View-Sample Mapping	225
7.5	Tradeoffs	234
7.6	Summary of Soft-Shadow Algorithms	236
8	Image-Based Transparency	239
8.1	Deep Shadow Maps	240
8.2	Approximating the Transmittance Function	243
8.3	Summary	258
9	Volumetric Shadows	259
9.1	Real-Time Single Scattering in Homogeneous Participating Media	259
9.2	Ray Marching a Shadow Map	261
9.3	Shadow-Volume-Based Approaches	265
9.4	Summary	268
10	Advanced Shadow Topics	269
10.1	Multicolored Light Sources	269
10.2	Multisample Antialiasing	274
10.3	Voxels and Shadows	275
10.4	Ray-Casting Shadows	283
10.5	Environmental Lighting	285
10.6	Precomputed Radiance Transfer	294
11	Conclusion	297
11.1	Hard Shadows	297
11.2	Filtered Hard Shadows	299
11.3	Soft Shadows	299
11.4	Advanced Methods	300
11.5	Welcome Tomorrow	301
A	Down the Graphics Pipeline	303
A.1	Rendering	303
A.2	Per-Fragment Processing—Culling and Blending	306
A.3	The Framebuffer	307
A.4	Geometry Representation	308
A.5	Hardware	309
B	Brief Guide to Graphics APIs	311
B.1	Transformation Matrices	312
B.2	State	316
B.3	Framebuffer and Render Targets	319
B.4	Texture Sampling	320
B.5	Shading Languages	321
C	A Word on Shading	323
C.1	Analytical Shading Models	323
C.2	Approximating Incoming Radiance	327
D	Fast GPU Filtering Techniques	329
D.1	Mipmap	329
D.2	N-Buffer and Multiscale Map	332
D.3	Summed-Area Table	336
D.4	Summary	340
E	More For Less: Deferred Shading and Upsampling	341
E.1	Deferred Shading	341
E.2	Upsampling	343
E.3	Summary	349

Contents

Preface	xi
1 Introduction	1
1.1 Definition	3
1.2 Importance of Shadows	12
1.3 Difficulty of Computing Shadows	15
1.4 Overview	19
1.5 General Information for the Reader	20
2 Basic Shadow Techniques	21
2.1 Projection Shadows	22
2.2 Shadow Mapping	31
2.3 Shadow Volumes	44
2.4 Stencil Shadow Volumes	48
2.5 Transparency	72
2.6 Summary	73
3 Shadow-Map Aliasing	75
3.1 Shadow Mapping as Signal Reconstruction	75
3.2 Initial Sampling Error—Undersampling	81
3.3 Resampling Error	87
4 Shadow-Map Sampling	89
4.1 Fitting	89
4.2 Warping	93
4.3 Global Partitioning	110
4.4 Adaptive Partitioning	123

REAL-TIME SHADOWS

EISEMANN • SCHWARZ
ASSARSSON • WIMMER

Shadows, important elements of games, movies, and other computer-generated content, provide important visual cues and are crucial for enhancing realism. *Real-Time Shadows* is a comprehensive guide to the theory and practice of real-time shadow techniques. It covers a large variety of approaches for creating various effects, including hard, soft, volumetric, and semi-transparent shadows. Source code, videos, and more are available on the book's website.

"Shadows are one of the most visually important effects in computer graphics. Far from being a solved problem, generating efficient and robust shadows is one of the most active research topics in real-time rendering. Fortunately, four of the world's foremost experts in real-time shadows have come together to write this excellent book, covering everything from the basics of simple shadow mapping to the state-of-the-art research in GPU-enabled soft and hard shadow techniques. If you work in games or real-time graphics, you owe it to yourself to get this book."

—David Luebke, Director, NVIDIA Research

"*Real-Time Shadows* is a wonderful book about a very important topic in computer graphics, and I hope it will cast a long and soft-edged shadow on the real-time graphics industry. This way, future games can look even better, and I am certain that this book will also serve as inspiration for more advanced research."

—Tomas Akenine-Möller, Lund University and Intel Corporation and coauthor of *Real-Time Rendering*

"There is a multitude of shadowing methods distributed across a wide variety of books and papers, each capitalizing on different combinations of various scene configurations, shape representations, lighting effects, aliasing situations, and computational resources. This book does a great job of collecting all of these together into a single volume of concise algorithm descriptions to make it easier to find the right shadowing method and then implement it."

—John C. Hart, Professor, University of Illinois at Urbana-Champaign,
and Past Editor-in-Chief, ACM Trans. Graph.

"At first glance, shadows seem to be a solved problem, but with limited time budget in real-time games they're not. There is a zoo of shadow rendering techniques, and finally here is a book that covers them all. The authors are among the most knowledgeable people on all kinds of occlusion problems. They describe the various quality and performance tradeoffs that need to be made."

—Martin Mittring, Senior Graphics Architect, Epic Games,
formerly Lead Graphics/Network Programmer at Crytek (Far Cry, Crysis)



CRC Press

Taylor & Francis Group
an informa business

www.taylorandfrancisgroup.com

Computer Graphics/Computer Game Programming

6000 Broken Sound Parkway, NW
Suite 300, Boca Raton, FL 33487
711 Third Avenue
New York, NY 10017
2 Park Square, Milton Park
Abingdon, Oxon OX14 4RN, UK

K13063

ISBN 978-1-56881-438-4



9 781568 814384

www.crcpress.com

NE