SIGGRAPH 1992

19th International Conference On Computer Graphics and Interactive Techniques

McCormick Place, Chicago
July 26 - 31

COURSE NOTES 11

RADIOSITY

Organizer
Michael F. Cohen
Princeton University

Lecturers
A.T. Campbell III
ALFA Engineering, Inc.

Donald P. Greenberg
Cornell University

Patrick M. Hanrahan
Princeton University

Holly Rushmeier
National Institute for Standards and Technology

François X. Sillion
Ecole Normale Superieure

John R. Wallace
3D/EYE, Inc.

SIGGRAPH 1992

RADIOSITY

Contents

Part I Introduction

Michael F. Cohen

1. Radiosity

The focus of this course is a body of realistic image synthesis algorithms related to the radiosity formulation found in the radiative heat transfer literature. The radiosity methods attempt to simulate the propagation of light energy within an environment, and subsequently display the results as if viewed by an imaginary observer.

2. Course Objectives

The course first briefly covers the basic concepts underlying all image synthesis algorithms. It then discusses the formulation of the radiosity method through the development of energy equilibrium integral equations and the discretization of such equations that enable a computable solution. The next section of the course focuses on the algorithms that have been developed to make the radiosity method an attractive alternative for image synthesis.

The second half of the course focuses on many of the problems encountered in developing and using radiosity algorithms. This includes methods for discretizing (or meshing) the environment, and what implications the choice of meshing techniques has for computational complexity and accuracy of the final image. Another section looks at the often neglected area of the interaction between human perception, image synthesis algorithm and the display device, and how knowledge about these interactions can help in the selection of efficient algorithms that create perceptually accurate images. Although the original radiosity methods applied only to diffuse environments, a number of methods that have been suggested include specular phenomena. These are explored in the last section.

3. Intended Audience

The material in the course is covered at an INTERMEDIATE level, appropriate for those with a working knowledge of the issues and techniques involved in the image synthesis problem. It is furthermore assumed that the attendee (reader) has a working knowledge of college level calculus. The course should be of particular interest to those involved in the development of algorithms for image synthesis, or the design of systems that can take advantage of image synthesis techniques. Users of such systems will also find material of interest as the course should help develop realistic expectations for what can be achieved with current and potential future technology. Many of the problems discussed are issues encountered by researchers and developers who have implemented the early radiosity systems.

4. These Notes

These notes are intended to provide a reference and a document to be read after the course to reinforce the information presented. The notes include material that does not appear in the published articles, and deals particularly with some underlying theoretical issues and implementation details. More concise descriptions of the algorithms can be found in the published literature. A number of articles that are the most relevant to the topics discussed here are also included in the appendix. The reader is encouraged to go through these, as well as to seek out the referenced work to gain a fuller understanding of the radiosity method for image synthesis.

5. Outline

I.	Introduction	Michael F. Cohen
II.	From Radiometry to the Rendering Equation	Patrick M. Hanrahan
III.	Basic Radiosity Formulation	Michael F. Cohen
IV.	Progressive Refinement Solutions	Donald P. Greenberg
V.	Hierarchical Radiosity	Patrick M. Hanrahan
VI.	Meshing, Reconstruction	A. John R. Wallace B. A. T. Campbell C. Daniel Lischinski and Filippo Tampieri
VII.	Radiosity with Non-Diffuse Reflectors	François X. Sillion
VIII.	Radiosity Input/Output	Holly E. Rushmeier

6. Reprints

The reprints:

- "The Hemicube: A Radiosity Solution for Complex Environments" by Michael F. Cohen and Donald P. Greenberg
- "A Two-Pass Approach to the Rendering Equation: A Synthesis of Ray Tracing and Radiosity Methods" by John R. Wallace, Michael F. Cohen, and Donald P. Greenberg
- "A Progressive Refinement Approach to Fast Radiosity Image Generation" by Michael F. Cohen, Shenchang Eric Chen, John R. Wallace, and Donald P. Greenberg
- "A Ray Tracing Algorithm for Progressive Radiosity" by John R. Wallace, Kells A. Elmquist, and Eric A. Haines
- "A Rapid Hierarchical Radiosity Algorithm" by Pat Hanrahan, David Salzman, and Larry Aupperle
- "A Global Illumination Solution for General Reflectance Distributions" by François X. Sillion, James R. Arvo, Stephen H. Westin, and Donald P. Greenberg
- "Tone Reproduction for Realistic Computer Generated Images" by Jack Tumblin and Holly E. Rushmeier

7. Lecturers

A. T. Campbell III

A. T. Campbell, III has recently completed his Ph.D. in Computer Sciences at the University of Texas at Austin with a dissertation entitled "Modeling Global Diffuse Illumination for Image Synthesis." He previously received BA and MS degrees in Computer Sciences, also from the University of Texas at Austin. Since 1986, he has been working at ALFA Engineering, Inc. where he is in charge of computer animation operations. Previously, he worked at Cray Research and Synercom Technology, Inc. He has published papers in conferences held by ACM SIGGRAPH and the Society of Automotive Engineers. His research interests include global illumination, efficient algorithm design, animation, and artistic applications of computer graphics.

Michael F. Cohen, chair

Michael Cohen is currently an assistant professor of computer science at Princeton University. He holds a Ph.D. degree from the University of Utah, an M.S. from Cornell University, a B.S. from Rutgers University and a B.A. from Beloit College. From 1985 until 1988, he was on the faculty of the Program of Computer Graphics at Cornell University where he conducted research in the area of realistic image synthesis. In particular, he worked on the development of the Radiosity method which has been reported in publications at SIGGRAPH conferences and elsewhere. Between 1988 and 1991 he was on the faculty at the University of Utah where he continued research on image synthesis, scientific visualization and computer animation. Dr. Cohen has lectured widely in the area of image synthesis. Current interests include constrained optimization for animation, image synthesis, interactive graphical user interfaces, and scientific visualization.

Donald P. Greenberg

Donald Greenberg is the Jacob Gould Schurman Professor of Computer Graphics at Cornell University and director of the Program in Computer Graphics. Since 1966, he has been researching and teaching in the field of computer graphics. He is currently also director of the new National Science Foundation Science and Technology Center for Computer Graphics and Scientific Visualization. Dr. Greenberg won the 1987 Steven A. Coons award for Outstanding Creative Contributions to Computer Graphics as well as the 1989 NCGA Academic Award. He was also recently appointed to the National Academy of Engineering. Dr. Greenberg has published widely, including two articles in Scientific American and many articles appearing in the SIGGRAPH proceedings. He has lectured extensively both nationally and internationally on the development and use of computer graphics techniques. His primary interests are in hidden surface algorithms, geometric modeling, color science, and realistic image synthesis.

Patrick M. Hanrahan

Patrick Hanrahan is an associate professor of computer science at Princeton University where he teaches computer graphics. Before joining the faculty at Princeton University, he worked at Pixar where he developed volume rendering software and was the chief architect of the RenderMan® Interface, a protocol that allows modeling programs to describe scenes to high quality rendering programs. Previous to Pixar, he directed the 3D computer graphics group in the Computer Graphics Laboratory at the New York Institute of Technology. Dr.

Hanrahan is the author of numerous articles on image synthesis and scientific visualization. His current research involves volume rendering, image synthesis, and graphics systems and architectures.

Daniel Lischinski

Daniel Lischinski is currently a doctoral student in the Program of Computer Graphics in the Department of Computer Science at Cornell University. He received his B.Sc. in Computer Science in 1987 and his M.Sc. in Computer Science in 1989 at the Hebrew University of Jerusalem, Israel. His interests in computer graphics include realistic image synthesis and geometric modeling.

Holly E. Rushmeier

Holly Rushmeier is a researcher at the National Institute of Standards and Technology. Until recently, she was an Assistant Professor in the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology. She received BS, MS, and PhD degrees in Mechanical Engineering from Cornell University. Following receipt of the BS degree she worked as an engineer at the Boeing Commercial Airplane Company, and at the Washington Natural Gas Company (both in Seattle, WA). She is the author of numerous articles both in the field of computer graphics and in radiative heat transfer. Her research interests include computer graphics synthetic image generation, infrared signature analysis, and radiant heat transfer.

François X. Sillion

François Sillion is a researcher at the Ecole Normale Supérieure, in Paris, France. He received an undergraduate education in math and physics, a graduate degree in Solid State Physics in 1986, and a Ph.D. in computer science in 1989 at the Ecole Normale Supérieure. From 1989-1991 he was a post-doctoral associate in the Program of Computer Graphics at Cornell University. He has co-authored several research papers on image synthesis, including several published in the SIGGRAPH proceedings. His research interests include light reflection modeling, global illumination algorithms, interactive simulation, and evaluation of image quality.

Filippo Tampieri

Filippo Tampieri is a PhD candidate in the Program of Computer Graphics at Cornell University. He received his Laurea in computer and information science from Universitá degli

Studi di Milano, Italy, in 1986 and his MS degrees in computer graphics and in computer science from Cornell University in 1988 and 1990, respectively. His research interests include radiosity, ray tracing, and parallel and distributed computation for realistic image synthesis.

John R. Wallace

John Wallace is a software engineer at 3D/EYE, Inc., where he is the project leader for the development of Hewlett-Packard's ARTCore radiosity and ray tracing library. He received his MS in 1988 from the Program of Computer Graphics at Cornell and BS in physics from the University of Maryland in 1980. He is the author of several articles on the topic of radiosity that have appeared in the SIGGRAPH proceedings. His research interests include image synthesis, lighting specification, reflection models and computer generated illustration.

8. Acknowledgements

These notes are the result of a great effort over a number of years by the authors and others. The contributions of speakers in the radiosity course from past years, in particular Roy Hall, have greatly influenced the outcome. This year's notes were formatted into a coherent document by Rebecca Davies. Invaluable editing assistance was provided by Jutta Joesch.

Figure 1: Simulated Steel Mill (Stuart Feldman, John Wallace Program of Computer Graphics, Cornell University.) The image was created using a modified version of the hemicube radiosity Algorithm, computed on a VAX 8700 and displayed on a Hewlett-packard Renaissance Display. The environment consists of approximately 2000 patches and 55,000 elements. The image was computed using the progressive refinement algorithm (Part IV).

Figure 2: Constructivist Museum (Shenchang Eric Chen, Stuart I. Feldman, Julie M. O'Brien Program of Computer Graphics, Cornell University.) The image of a constructivist museum was rendered using the progressive refinement radiosity method. The model includes more than 20,000 elements and 200 discrete area light sources. The complexity of the environment as well as the indirect diffuse skylighting illumination from above would have made it impractical to render with traditional radiosity methods and impossible to simulate using standard ray tracing methods. The computations were performed on Hewlett Packard 825 SRX workstations and display at a resolution of 1200 × 1024.

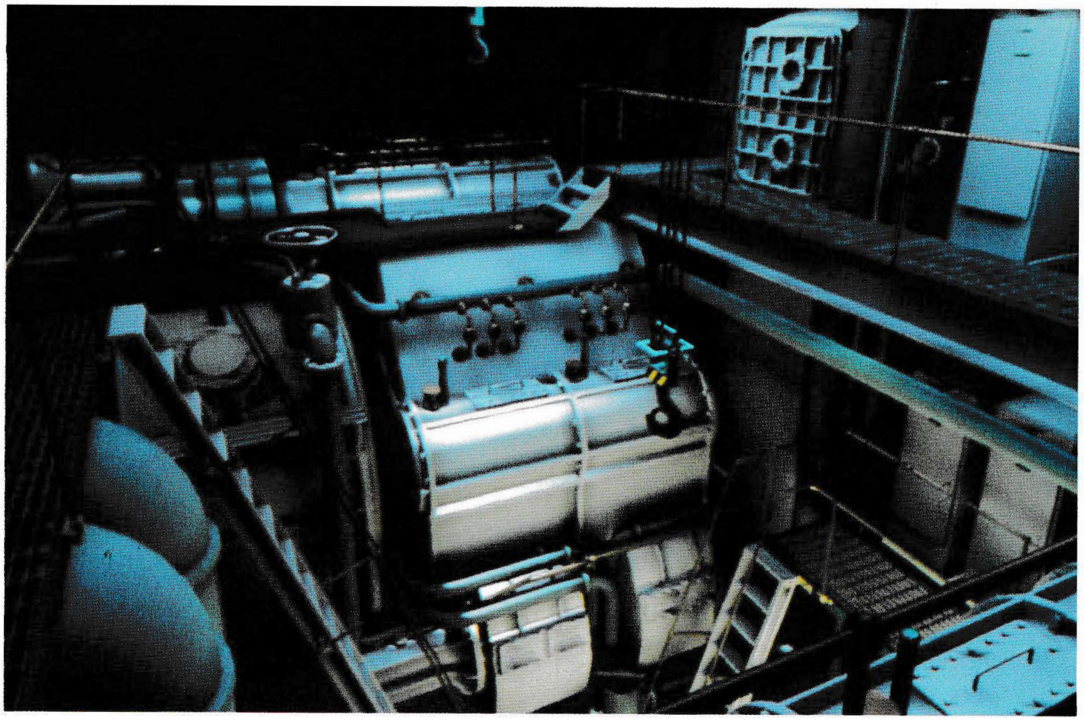

Figure 3: BOILERROOM (John Lin, John Wallace, 3D/EYE) The scene, composed of eight light sources, and approximately 285,000 vertices was rendered using a progressive refinement algorithm with ray-tracing form factors. Specular highlights were added during a postprocessing step. The image was computed and rendered on an HP835 SRX workstation.

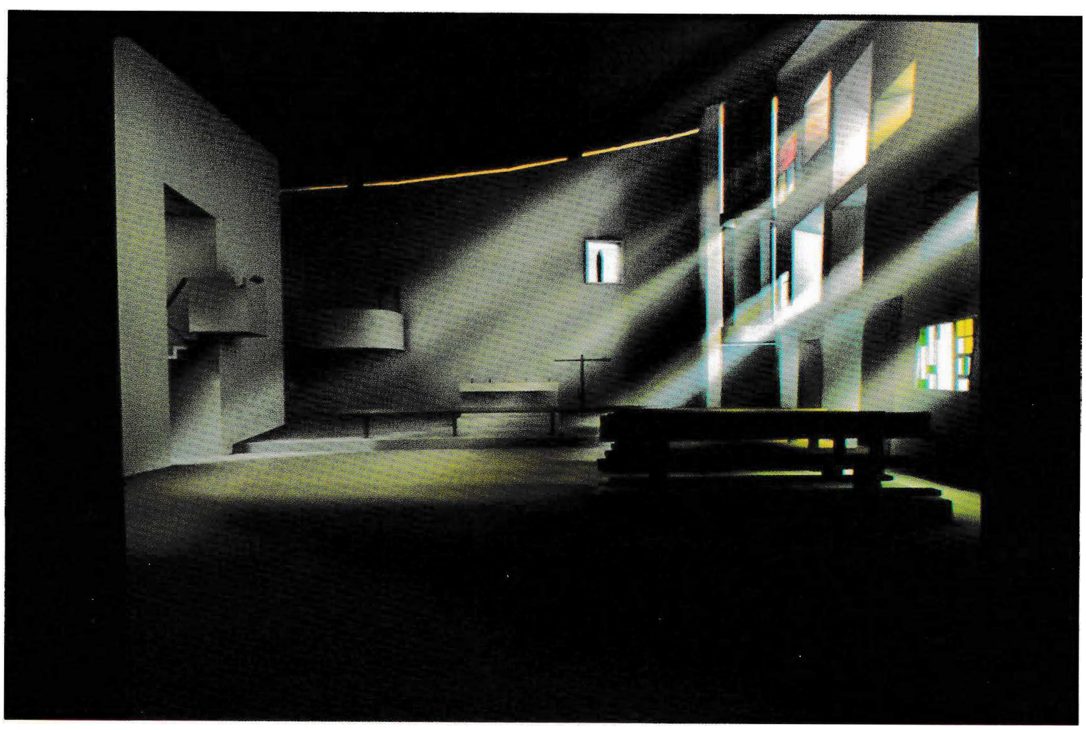

Figure 4: RONCHAMP The chapel designed by Le Corbusier, was modeled using Hewlett-Packard's ME30 modeling system and was rendered using their advanced rendering software which includes both ray tracing and radiosity. The images were first created by running the radiosity solution so that a "walk through" of the space could be obtained. The light beams were added using a ray tracing technique. Both images are displayed on a Hewlett-Packard 835 turbo SRX workstation. (Keith Howie, Paul Bourdeau, Eric Haines, John Wallace, 3D/EYE, Inc.)