Advanced Research in Graphics Hardware

Department of Computer Science University of North Carolina at Chapel Hill August 2007

The Challenge

With the advent of powerful graphics hardware, developers of real time applications are looking beyond local illumination models toward more complicated global illumination models. Global illumination, which incorporates inter-object effects such as shadows and reflections, attains a compelling level of visual realism that is difficult to achieve with local illumination models. We are investigating approaches for real time computation of global illumination, which involves both implementing algorithms on currently available commodity hardware and developing novel algorithms and architectures for future hardware.

Specific Research Areas

Radiosity on Graphics Hardware

We have developed a system for computing radiosity that performs all of the computation on the GPU. Radiosity is a finite-element approach to the problem of global illumination that breaks the scene into many small elements and calculates the energy transfer between the elements. The fraction of energy transferred between each pair of elements is described by an equation called the form factor. The form factor, which is the core computational kernel of radiosity, is implemented on programmable graphics hardware. The texels of the scene polygons are the elements of the radiosity equations, and the progressive refinement algorithm is inverted to fit the stream-processing model of graphics hardware.

Figure 1: This image demonstrates the compelling global illumination effects, such as soft shadows and indirect lighting, that can be obtained with our system.

Highlights

Global illumination, which incorporates inter-object lighting effects such as shadows and reflections, is widely used in films, architecture and games. We are pursuing two strategies for the interactive computation of global illumination:

- **We are modifying existing algorithms to implement them on currently available commodity hardware.**
- **We are developing novel algorithms and architectures for future hardware.**

In order to render complex scenes, we use several acceleration techniques. We use a hybrid hierarchy that consists of a coarse adaptive geometry subdivision combined with a fine uniform texture subdivision. We avoid bandwidth limitations by localizing all of the data and computation on the card through the use of z-buffer sorting and hemisphere projection. Using our system on current hardware, we have been able to compute and render 10K element scenes at interactive rates.

Fast Summed-Area Table Generation and its Applications

We have developed a technique to rapidly generate summed-area tables using graphics hardware. Summed area tables, originally introduced by Crow, provide a way to filter arbitrarily large rectangular regions of an image in a constant amount of time. Our algorithm for generating summed-area tables, similar to a technique used in scientific computing called recursive doubling, allows the generation of a summed-area table in O(log n) time.

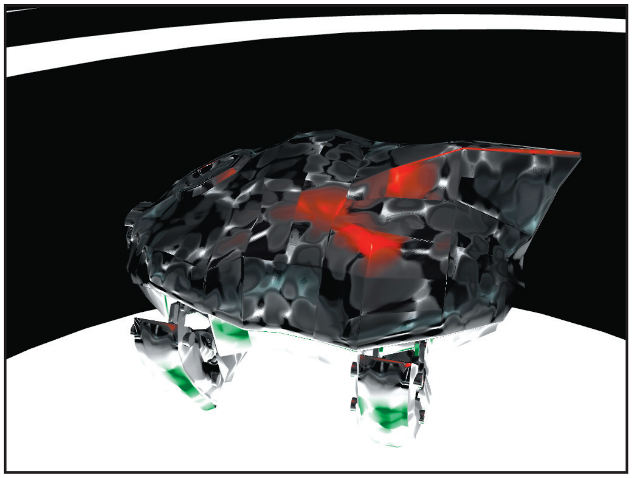

Figure 2: A time-varying procedural texture is used to modulate the glossiness of the reflective object on a per pixel basis.

We have also developed techniques to mitigate the precision requirements of summed area tables. The ability to calculate and use summed-area tables at interactive rates enables numerous interesting rendering effects. Several of the possible applications include: using a summed-area tables to render realtime, interactive glossy environmental reflections, rendering glossy planar reflections with varying blurriness dependent on a reflected object's distance to the reflector, rendering translucent objects, and rendering depth-of-field effects. All of these example applications run at interactive rates on commodity graphics hardware.

Reordering for Cache Conscious Photon Mapping

Photon mapping is a global illumination algorithm for generating and visualizing a sparse representation of the incident radiance on surfaces. Photon mapping places an enormous burden on the memory hierarchy. A 512×512 image using the standard kd-tree data structure requires more than 196GB of raw bandwidth to access the photon map. This bandwidth is a major obstacle to our long-term goal of designing hardware capable of real time photon mapping.

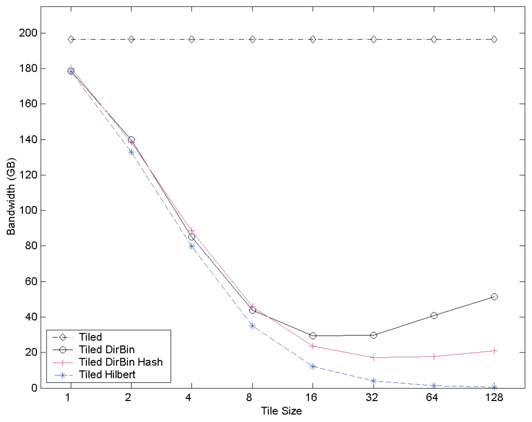

Figure 3 For this particular image the benefits of query reordering are obtainable at reasonable tile sizes. 16×16 times allow for over an order of magnitude reduction in bandwidth from the naïve ordering.

We have investigated two approaches for reducing the required bandwidth: 1) reordering the kNN searches; and 2) cache conscious data structures. Using a Hilbert curve reordering across the entire image, we demonstrate an approximate lower bound of 15MB of bandwidth for the kNN searches. This improvement of four orders of magnitude requires a prohibitive amount of intermediate storage so we restrict the reordering to square tiles. We demonstrate three cost effective algorithms that reduce the bandwidth by an order of magnitude, the most practical uses 24GB with 1MB of storage on 16×16 tiles. We found that the choice of data structure cannot, by itself, achieve an improvement this large.

PHATextures: A Surface-Based Data Structure for Interactive Rendering of Glossy Surfaces

We propose a hardware friendly data structure for the interactive rendering of glossy surfaces by storing a pre-computed, view-independent representation of the incident radiance. The data structure and rendering algorithm approximates the Monte Carlo integration techniques commonly used in global illumination algorithms. The algorithm is applied to photon mapping and achieves interactive results on current graphics hardware. Due to its nature, the data structure is well suited to dynamic updates.

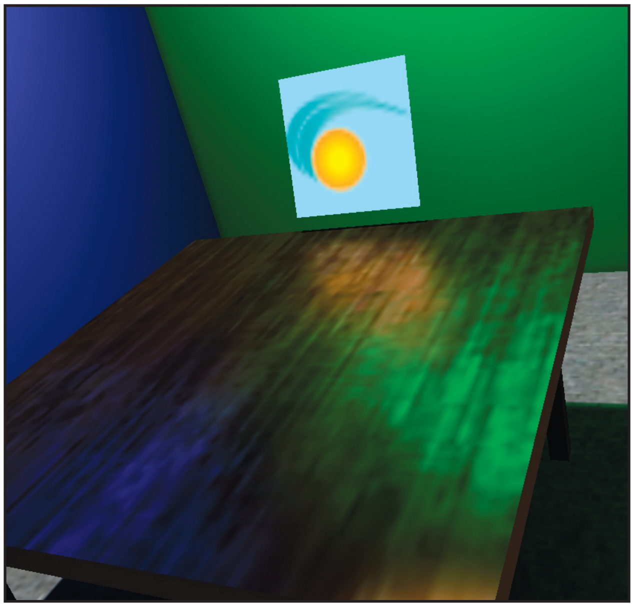

Figure 4: A glossy tabletop reflects a textured object as well as the walls. This scene runs at interactive rates on current graphics hardware.

Project Leaders

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Graduate Research Assistants

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Research Sponsors

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Selected Publications

Fast Summed-Area Table Generation and its Applications. Justin Hensley, Thorsten Scheuermann, Greg Coombe, Montek Singh, and Anselmo Lastra. Submitted for review.

Reordering for Cache Conscious Photon Mapping. Joshua Steinhurst, Greg Coombe, Anselmo Lastra. *Proceedings of Graphics Interface 2005*. To appear.

Progressive Refinement Radiosity. Greg Coombe and Mark Harris. *GPU Gems 2*, ed. Matt Pharr, Addison Wesley.

Radiosity on Graphics Hardware. Greg Coombe, Mark Harris and Anselmo Lastra. *Proceedings of Graphics Interface 2004*.

PHATextures: A Surface-Based Data Structure for Interactive Rendering of Glossy Surfaces. Justin Hensley; Josh Steinhurst; Greg Coombe; Anselmo Lastra. *TR03-019 Department of Computer Science, University of North Carolina at Chapel Hill.*

For More Information

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