

# **Master's Thesis Proposal**

## **Real-time Global Illumination using Voxel-based Ray-bundles**

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### **Abstract**

Real-time global illumination has gained more and more interests in recent years due to the rapid evolvement of GPU computing power. Several approaches have been developed to try to simulate global illumination as accurate as possible by implementing robust ray-tracing algorithms using Shader Model 5 features of current GPUs. For example, bidirectional path tracing is employed to resolve the classic singularity issue of instant radiosity. While the rendering speed is acceptable for a certain level of scene complexity, maintaining high frame rates for arbitrary scenes is still a challenging work. In this thesis, we propose a novel hybrid rendering system that combines bidirectional path tracing and scene voxelization to accelerate virtual point light (VPL) visibility tests and global ray-bundles generation. Meanwhile, we show that caustic maps can be integrated into the system easily as well.

Keywords: real-time global illumination, instant radiosity, global ray-bundles, scene voxelization, caustic maps

### **1. Introduction**

Global illumination is an important lighting effect that simulates light propagation behavior in 3D space. It increases fidelity of computer generated images dramatically and thus has been an active research area in the field of image synthesis. Since the formal introduction of the rendering equation [Kajiya 1986], many CPU-based off-line algorithms have been invented to solve it. While these techniques generate physically correct images, the speed of creating them are usually slow. Figure 1 shows an image generated by PBRT, a CPU-based global illumination rendering system.



**Figure 1. Image courtesy of PBRT. Modern villa scene by Florent Boyer.**

In order to implement global illumination for real-time applications such as video games, many approaches are proposed. One class of these approaches is called many-light based method, derived from [Keller 1997]. It provides a simple lighting computation framework that transforms the problem of solving lighting transport equation to the calculation of the direct illumination from many virtual light sources. This makes it a hardware-friendly algorithm which could be implemented on modern GPUs easily.

Another class of real-time global illumination methods make use of so called “voxel” to discretize to original scene representation. There are several advantages using scene voxelization: First, it is a geometry-independent scene description and some fast scene voxelization methods have been developed. Second, ray-geometry intersection and visibility tests can be performed very fast on such data structure. Third, high quality anti-aliasing techniques can be implemented using voxelization as well [Crassin 2011].

In this thesis, we introduce a hybrid real-time global illumination system which combines the many-light method, global ray-bundles and scene voxelization together. By doing so, both good rendering quality and speed could be achieved.

## 2. Related Work

Instant Radiosity [Keller 1997] is a theoretical correct and hardware-friendly algorithm that solves the light transport equation [Kajiya 1986] efficiently. It supports fully dynamic scenes very well, which is important for interactive applications such as video games.

To improve the rendering quality, [Tokuyoshi 2012] changes the sampling strategy of VPL to bidirectional path tracing. This algorithm is known to be robust and resolves the failure of VPL sampling strategy successfully. They implement the algorithm on Shader Model 5 featured GPU by using global ray-bundles [Sbert 1996] and GPU concurrent link list [Yang 2010].

However, global ray-bundles introduces additional burdens, since every time a VPL is used, they also have to rasterize the scene polygon again in order to create a global ray-bundles.

Voxel-based methods discretize the scene description and store discretized data in 3D grid cells. An outstanding feature of it is that scene voxelization is extremely fast (usually several million-seconds on current commodity GPUs). A drawback of using regular grid for voxelization is the high consumption of GPU memory. To solve this problem, [Crassin 2011] develops a sparse voxel octree (SVO) based data structure and uses it for their high quality global illumination rendering: they employ a pre-filtering process to filter the geometric data in a bottom-up fashion. The resulting hierarchical octree structure is then used for their voxel cone tracing.

Caustics is another important lighting phenomenon that have gained much attention in the field of real-time rendering in recent years. [Shah et al. 2007] proposes Caustics Mapping, a technique simulates caustics in image space.

### **3. Proposed Work**

We propose employing many-light, global ray-bundles and scene voxelization methods together to implement a robust and efficient real-time global illumination rendering system. Our novel rendering system shall be implemented fully based on shader model 5 features of commodity GPUs. Meanwhile, we will integrate an improved version of caustic maps technique into the system.

#### **3.1 Investigating Instant Radiosity and many-light based methods**

Naïve many-light based method creates many virtual point lights (VPL) in each rendering frame by sampling the scene description and then uses shadow maps to do the visibility tests when shading a fragment. Although intuitive and simple to implement, this method will hurt the frame rates a lot since VPL shadow maps creation requires sampling the scene description many times (usually 100 -1000). To accelerate the rendering speed. We investigate the following methods:

Reflective shadow maps [Dachsbacher and Stamminger 2005] captures scene surface points visible to light sources efficiently but ignores visibility test for VPLs. [Segovia 2006] uses interleaved sampling [Keller and Heidrich 2001] to reduce the number of VPLs needed for each pixel being shaded. [Lane et al 2007] maintains a set of VPLs and regenerate a subset of them incrementally to reduce the overhead of VPL shadow map regeneration. [Ritschel et al. 2008] employs point-based rendering for the VPL shadow maps. The key idea is that instead of using original scene polygon, they use a set of point samples for the primitive rasterization process, which is much faster than the original polygon primitive rasterization. While using few VPLs is desirable, it leads to downsampling issues such as flickering especially when part of the scene is animated. To address this issue, [Knecht 2009] exploits temporal coherence [Nehab et al. 2007] to filter out high frequency signals between consecutive frames.

#### **3.2 Investigating voxel-based global illumination methods**

Many-light method is a biased method. While bias could be reduced by increasing the number of virtual light sources, frame rates will suffer if too many virtual light sources are generated and used for rendering. Most existing many-light based real-time approaches use shadow maps to do the visibility tests for indirect illumination calculation, which is currently the main bottle neck of them. To resolve the bottle neck issue, we study voxel-based methods and employ voxel data structure to do the visibility tests for VPLs.

#### **3.3 Investigating Real-time Bidirectional Path Tracing via Rasterization**

General real-time many-light methods also suffer from a singularity issue caused by failure of the sampling strategy at corners of scene geometry, where the distance between shading point and virtual light source is too close. One way of resolving this problem is clamping, which leads to incorrect rendering result. [Tokuyoshi 2012] introduces a better solution using bidirectional path tracing on GPU. They combine the many-light method with global ray-bundles method to construct a lighting path from both the virtual light source and the camera. Thus the overall rendering quality is improved. However, using global ray-bundles further increases the burden, because additional scene rendering task must be issued to create a ray-bundles for each virtual light source. Thus we will focus on improving the rendering efficiency of this method.

### **3.4 Implementing a hybrid real-time global illumination system**

We will replace the expensive VPL shadow maps generation task with a fast scene voxelization technique. Furthermore, we will use this voxelized scene description to generate voxel-based ray-bundles. This task should be much faster than the original method in [Tokuyoshi 2012].

### **3.5 Investigating Adaptive Caustic Maps**

Generic caustic maps method consists of three steps: first, photon buffer is created from light's view. Second, caustic map is generated by splitting points in photon buffer. Finally, caustic map is used for caustics rendering. Traditionally, the first step involves a two-pass rendering of the refractor geometry which leads to inefficiency. Moreover, to ensure good caustics quality, more photons have to be used. This is the main bottle neck of the algorithm. [Wyman and Nichols 2009] introduced adaptive caustic maps to reduce the cost of caustic map generation. The key idea is using a lazy algorithm that refines a coarse level buffer base on need (Add more photons where refractors exist). We will implement an improved version of caustics maps using GPU concurrent link list [Yang 2010]. Integration of this technique into our system shall be designed and implemented fully using Shader Model 5 features.

## **4. Research Schedule**

### **January – April 2014**

Learn OpenGL shader programming, Spherical harmonics, Light Propagation Volume, Reflective Shadow Maps, SSDO, Instant Radiosity, Many-light methods then Implement SSDO.

### **May – August 2014**

Learn OpenCL and OpenGL compute shader programming, Real-time Bidirectional Ray Tracing via Rasterization, GPU concurrent link list technique, Global Ray-bundles, Imperfect Shadow Maps, Incremental Instant Radiosity and Interleaved Sampling. Meanwhile, implement Reflective Shadow Maps, GPU concurrent link list and global ray-bundles.

### **September – December 2014**

Learn OpenGL geometry and tessellation shader programming then investigate Real-time voxelization, Temporal Coherence, Paraboloid Shadow Map, Caustic Maps. Meanwhile, implement VPL demo, voxelization demo and combine VPL and voxelization together to support voxel-based VPL visibility test.

### **January – March 2015**

Implement voxel-based global ray-bundles and combine all the sub-systems together, then integrate caustic maps into the system.

### **March – April 2015**

Write thesis, do thesis presentation and submission.

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