Exploring GPU-Based Monte-Carlo Methods for Global Illumination and Dynamic Irradiance Field Probes: Theory to Implementation

AUSTIN J. MADDISON, Mahidol University International College, Thailand

Global illumination (GI) is fundamental in achieving photorealistic rendering by simulating the indirect interactions of light in a scene. Traditional Monte Carlo ray tracing methods, while highly accurate, are computationally expensive and impractical for real-time applications. This report explores the implementation of Monte Carlo-based global illumination techniques and their adaptation to real-time rendering through the use of irradiance field probes. I discuss the theoretical foundations of Monte Carlo ray tracing, the challenges of real-time global illumination, and bringing global ilumination to real time using irradiance field probes in balancing performance and visual quality.

CCS Concepts: • **Computing methodologies → Rendering**.

Additional Key Words and Phrases: Global illumination, raytracing, offline rendering, real-time rendering

1 INTRODUCTION

Global illumination (GI) plays a critical role in achieving photorealistic rendering by simulating the complex interactions of light within a scene. Unlike direct illumination, which models light traveling directly from a light source to an object, global illumination accounts for the way light bounces off surfaces and illuminates other objects in the environment. This results in more natural, grounded, and visually cohesive scenes, where light interactions between surfaces are fully realized.

In this work, we explore both offline and real-time techniques for computing global illumination, with a focus on implementing Monte Carlo ray tracing methods to simulate the necessary light transport. While many algorithms have been developed over the years to compute GI, the core principle behind them remains Monte Carlo ray tracing, a statistical approach to solving complex lighting equations.

This report delves into the theoretical aspects of Monte Carlo ray tracing for global illumination, followed by an exploration of practical implementations and their translation into real-time rendering. Given the computational challenges associated with real-time GI, this work focuses on a following up with techniques to have dynamic irradiance field probes. These probes are advantageous because they decouple the lighting information from the scene's geometry, allowing for scalable, flexible, and efficient rendering.

The report is structured as follows:

- **Overview of Global Illumination and Related Works**: Introducing the concept and its significance in realistic rendering.
- **Render Pipeline and SDF Scene Representation**: Describing my custom 2D render pipeline and how Signed Distance Field (SDF) representation enhances scene rendering.
- **Monte Carlo Ray Tracing for GI**: Detailed exploration of the Monte Carlo method and its application to global illumination.
- **Reaching Real-Time Performance**: Examining strategies such as coarse tracing, texture and vertex baking, and the use of irradiance field probes to bridge the gap between offline and real-time GI.
- **Dynamic Irradiance Field Probes**: Starting with irradiance probes and extending it with update logic to update GI as scene changes.
- **Performance Comparison**: A thorough evaluation comparing the performance and visual quality of dynamic irradiance field probes versus traditional Monte Carlo ray tracing.

By the end of this report, the aim is to present a comprehensive exploration of how advanced Monte Carlo techniques can be adapted to real-time environments, with a specific focus on irradiance field probes as a promising solution for scalable and flexible global illumination in real-time rendering.

ACKNOWLEDGMENTS

All my friends and peers <3.

REFERENCES

Last modified Saturday 5th April, 2025

Author's Contact Information: Austin J. Maddison, austin.mad@student.mahidol.edu, Mahidol University International College, Nakhon Pathom, Nakhon Pathom Province, Thailand.