Global Illumination using ReSTIR DI and Photon-Mapped Virtual Point Lights: An improvement on Instant Radiosity

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1. Introduction

Global illumination (GI) remains computationally expensive for real-time applications. Traditional photon mapping generates virtual point lights (VPLs) but becomes inefficient with uniform sampling as VPL count increases, leading to noise and poor performance.

Our Contribution: We integrate ReSTIR DI [1] with photon-mapped VPLs to improve sampling efficiency and reduce noise in global illumination rendering.

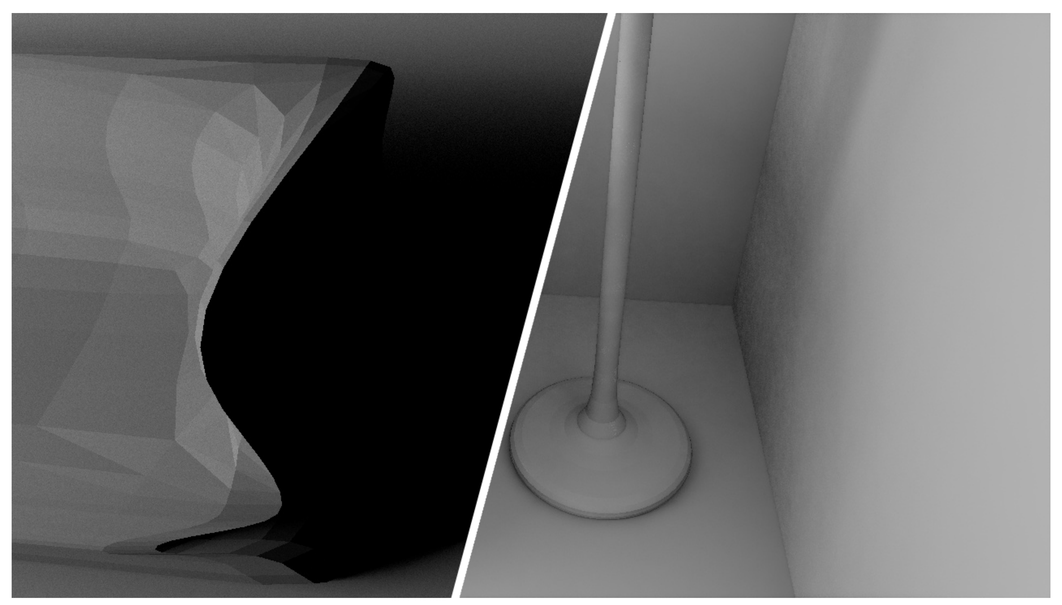

Figure 1. Comparison between direct lighting only (left) and our photon mapping approach with global illumination (right). Notice the improved indirect lighting effects.

2. Background & Related work

ReSTIR DI dramatically improves the quality of rendered scenes by building on resampled importance sampling (RIS), which selects high-contribution samples more effectively. ReSTIR DI extends this by reusing samples across neighboring pixels and prior frames, further reducing noise (Figure 2).

ReSTIR DI is however limited to direct lighting and cannot account for the indirect light interactions necessary for achieving full global illumination. To estimate indirect illumination, we can generate virtual point lights (VPLs). Generating these VPLs can be done using **photon mapping**, or otherwise referred to as Instant Radiosity [2]. This technique traces photons from light sources through the scene (Figure 4).

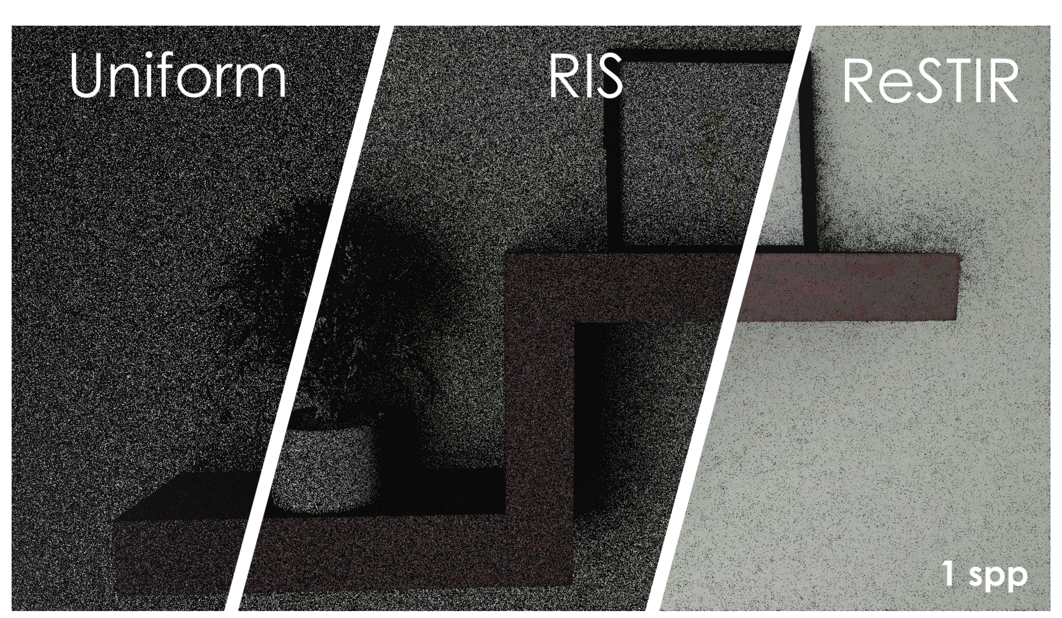

Figure 2. Comparison between uniform light sampling, RIS, and ReSTIR in our renderer.

3. Method Overview

Our approach operates in two main phases:

1. **Photon Mapping Pass:** Photons are emitted from light sources and traced through the scene to produce a set of VPLs. First, area lights are converted to a set of point lights with appropriately scaled flux (Figure 4.2). Then the point lights shoot out 'photons' into the scene to generate VPLs (Figure 4.3). At each intersection point, there's a probability that the photon will reflect from the surface into a random direction (Figure 4.4).
2. **ReSTIR-Based Shading:** Apply ReSTIR DI's spatiotemporal resampling to the unified set of VPLs, improving light candidate generation.

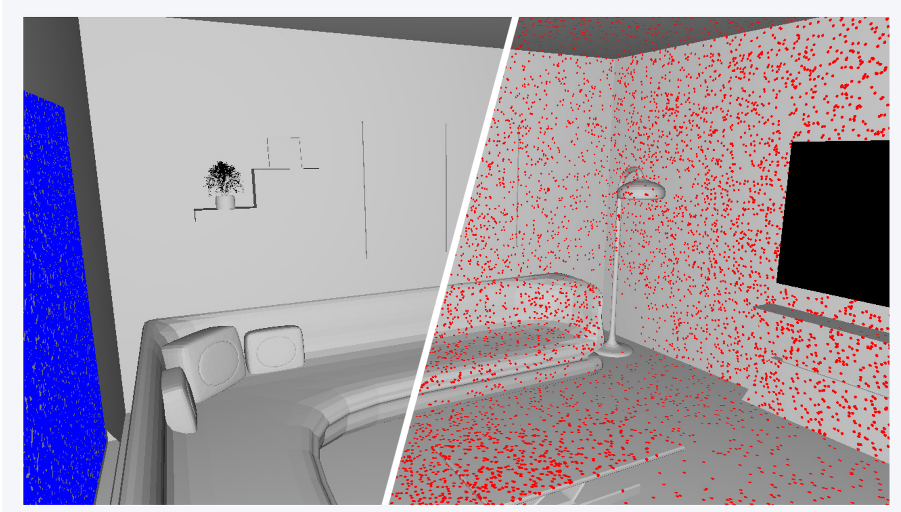

Figure 3. Debug visualization showing VPL generation in living room scene. Blue spheres represent direct lighting VPLs, red spheres represent GI VPLs.

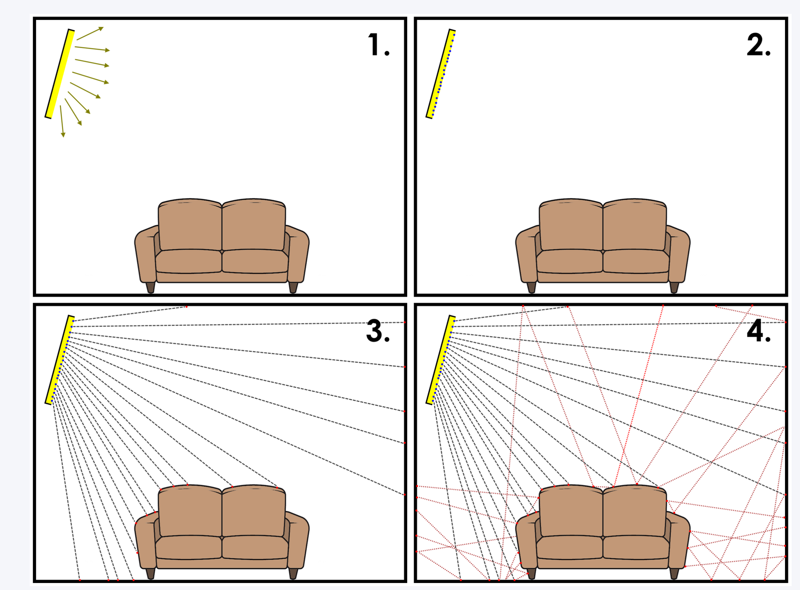

Figure 4. A diagram visually describing our photon mapping implementation.

4. Results

Visual Quality & Performance: ReSTIR achieves **74.1% average RMSE improvement** across all test scenes compared to uniform sampling, with significantly cleaner results at 1 SPP.

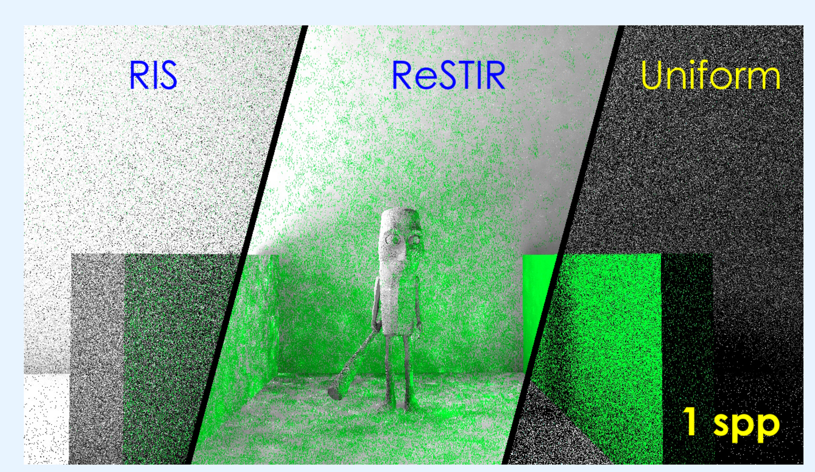

Figure 5. Comparison at 1 sample per pixel. Left to right: RIS, ReSTIR, uniform sampling. ReSTIR achieves the cleanest result with reduced noise.

Scene	RIS	ReSTIR
Cornell Box	-64.3%	-78.6%
Living Room	-41.5%	-73.2%
Sahur	-38.6%	-70.5%
Average	-48.1%	-74.1%

Table 1. RMSE Improvement at 20 frames compared against uniform light sampling

Artifact Mitigation: Applied Yuksel's point light attenuation [4] to eliminate firefly artifacts while maintaining visual plausibility. Current implementation shows 4-7x increase in frame time due to unoptimized ReSTIR, highlighting need for GPU acceleration.

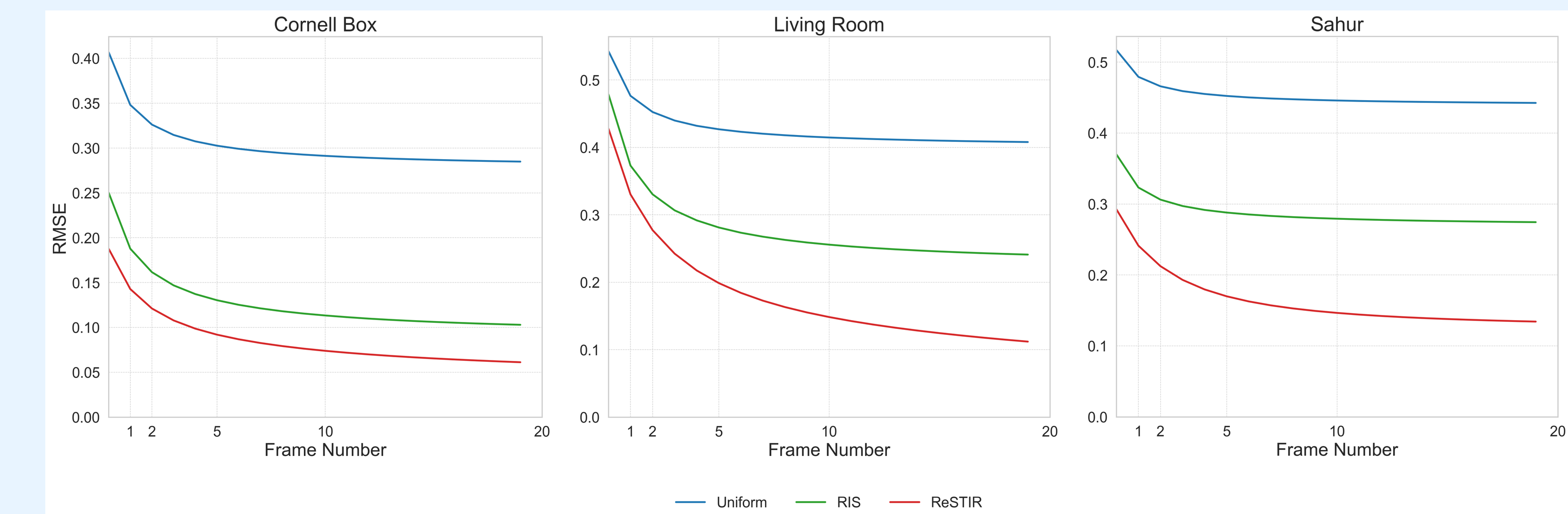

Figure 6. RMSE convergence over 20 frames. ReSTIR (red) consistently achieves lowest error and fastest convergence across Cornell Box, Living Room, and Sahur scenes.

5. Conclusions & Future Work

Key Achievements:

- Successfully integrated ReSTIR DI with photon mapping for improved GI sampling
- Demonstrated **57.4%** average RMSE improvement over uniform sampling
- Established unified light abstraction for seamless VPL integration

Limitations & Future Directions:

- Performance optimization needed (GPU implementation)
- Occasional blotting artifacts in high VPL density regions (Figure 5)
- Comparison with ReSTIR GI [3] for comprehensive evaluation
- Exploration of bias-free firefly mitigation techniques

Impact: This work establishes the feasibility of extending ReSTIR DI to handle photon-mapped global illumination, providing a foundation for more efficient VPL-based rendering techniques.

References

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[2] Alexander Keller. Instant radiosity. In *Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '97, page 49–56, USA, 1997. ACM Press/Addison-Wesley Publishing Co.

[3] Y. Ouyang, S. Liu, M. Kettunen, M. Pharr, and Jacopo Pantaleoni. Restir gi: Path resampling for real-time path tracing. *Computer Graphics Forum*, 40:17–29, 11 2021.

[4] Cem Yuksel. Point light attenuation without singularity. In *ACM SIGGRAPH 2020 Talks*, SIGGRAPH 2020, New York, NY, USA, 8 2020. ACM.

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