Optimized Photon Tracing Using Spherical Harmonic Light Maps

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Abstract

Photon mapping is a widely used technique for global illumination [Jensen 2001]. However, current techniques can be slow and/or can take up prohibitively large amounts of memory. We optimize photon tracing using spherical harmonic light maps (SHLMs) to represent photon accumulation on parameterized surfaces. We use a photon tracing algorithm where SHLMs replace the traditional photon map data structure. The SHLM stores irradiance environment maps [Ramamoorthi and Hanrahan 2001] across all surfaces. This gives us many advantages over traditional photon map renderers. Our photon tracing time is faster since there is no kd-tree insertion for photon storage. Our memory usage and density estimation time stay constant regardless of how many photons have been traced through the scene. Finally, SHLMs can be used in conjunction with any normal map to light realtime scenes.

1 Method

One major limitation of photon mapping is the memory required to get good results in a complex scene. This memory limitation results in an upper bound on the number of photons the algorithm can store. As scene complexity grows the photon density required for good results becomes difficult to store in memory.

We solve this by replacing the photon map data structure with SHLMs. These SHLMs are equivalent to traditional light maps except where traditional light maps store an RGB value per texel, the SHLMs store a set of spherical harmonic (SH) coefficients per texel. Each texel's SH coefficients represent that texel's irradiance environment map [Ramamoorthi and Hanrahan 2001]. This allows us to have a low frequency lighting environment per texel. The SHLM gives us similar functionality to the photon map data structure. A typical photon map would store many individual photons in a given space. We instead sum the contributions of all the photons that hit a texel into a set of SH coefficients. We treat each photon as an infinite directional light source shining on a diffuse surface, which makes the function we are trying to approximate with the SH coefficients a simple clamped cosine. We use the technique presented by [Ramamoorthi and Hanrahan 2001] to calculate the coefficients.

This allows us to represent the contributions from an arbitrary number of photons using a single SHLM texel, without losing the directional information present in traditional photon map data structures. Accumulating diffuse lighting into SH coefficients is a constant time operation, which ends up being much faster than the tree insertion needed for a photon map data structure. The SHLM is limited to storing diffuse lighting since it uses SH irradiance environment maps to store the lighting.

The SHLM has light direction information in each texel that can be used to render normal mapped surfaces. This can be used in a realtime renderer to achieve pre-computed lighting that supports normal maps. This would not be possible with traditional light maps.

For nearest neighbor searching, we have a spatial tree of texels analogous to a typical photon map. Instead of searching a photon map kd-tree, we search a texel map kd-tree. This tree is used during searching, but not during photon tracing. Since the tree contains texels, not individual photons, the time taken by the search is not dependent on how many photons have been traced in the scene. This allows the search time to be faster for high lighting detail scenes where there is more than one photon accumulated per texel. The kd-tree's memory usage will remain constant regardless of how many photons have been traced in the scene. This allows accumulation of photon contributions to continue indefinitely in order to achieve maximum convergence without requiring an ever-increasing amount of memory.

For density estimation, we combine the nearest neighbor SH coefficients, weighted by their projected texel areas. Using our parameterized SHLM surfaces we calculate an accurate area for each SHLM texel. In the fragment program used for final rendering, we evaluate the SH basis functions for the normal of the fragment that we are rendering. This yields the fragment's irradiance.

Figure 1: We were able to accumulate over a billion photon hits in this scene using a desktop PC.

2 Future Work and Extensions

We would like to explore different kinds of parameterization or the removal of that constraint. Storing non-diffuse lighting in the SHLMs would also be useful to explore.

References

JENSEN, H. W. 2001. *Realistic Image Synthesis Using Photon Mapping*. A K Peters, Ltd.

RAMAMOORTHI, R., AND HANRAHAN, P. 2001. An efficient representation for irradiance environment maps. In *Proceedings of SIGGRAPH 2001*, ACM Press / ACM SIGGRAPH, Computer Graphics Proceedings, Annual Conference Series, ACM, 497–500.

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