Improved Illumination Estimation for Photon Maps in Architectural Scenes

Robert F. Tobler
VRVis Research Center
Donau-City Str. 1/3
1120 Wien, Austria
rft@vrvis.at

Stefan Maierhofer
VRVis Research Center
Donau-City Str. 1/3
1120 Wien, Austria
sm@vrvis.at

ABSTRACT

The photon map algorithm provides a number of advantages for fast global illumination algorithms. In order to calculate the illumination at each point in a scene, the photon density needs to be estimated. Standard estimation methods will have problems with typical architectural scenes, as walls and corners will lead to undesirable light and shadow leaks.

We introduce a new method for estimating photon density in photon maps, that is especially suited for calculating global illumination in architectural scenes. By providing additional information using a limited number of ray-casts, shadow and light leaks can be significantly reduced, thereby resulting in a significant improvement in the speed and accuracy of global illumination algorithms based on photon maps.

Keywords

Photon mapping, global illumination, density estimation, bias.

1. INTRODUCTION

The standard way of calculating global illumination for architectural scenes, is to simulate the propagation of photons using some ray tracing algorithm. If no information about these rays is stored, and all illumination estimates are independent of each other, no bias is introduced.

In order to speed up the algorithms, information about the rays can be stored. Although this introduces a bias, the resulting algorithms such as irradiance caching [War88, War92] and photon mapping [Jen96] are significantly faster than unbiased methods.

A number of improvements to the original photon map algorithm have been published, that try to reduce the inherent bias. Hey and Purgathofer use an average of several oriented photon maps [Hey01], Lavignotte and Paulin extend the object boundaries for photon storage in polygonal scenes [Lav02]. Other improvements of photon mapping are the use of density control [Suy00, Pet98], and the use of a convex hull [Jen01, Jen02] and the use of a ray-cache based on a set of spheres [Las02]. A very recent approach to reduce the bias is the extension of the photon map to include complete rays [Hav05].

In this paper we will demonstrate techniques that can be used to improve the density estimation for algorithms based on standard photon maps that only store photon locations.

Conference proceedings ISBN 80-86943-03-8
WSCG'2006, January 30-February 3, 2006
Plzen, Czech Republic.

2. THE PHOTON MAP ALGORITHM

The basic algorithm of the photon map is based on the simulation of the propagation of photons starting at the light sources. Each interaction of a photon with a surface is recorded in a data structure that allows fast searches for nearby hits, e.g. a k-d tree. Once enough photons have been simulated, illumination at each point in the scene can be approximated by retrieving the closest photon hits at the query point. Using the k-d tree the n closest hits are retrieved, and due to the resulting distance of the n-th closest photon hit a projected surface area can be computed (see figure 1). Dividing the power of the n closest hits by this projected surface area, results in an estimate for the radiance at the query point.

Changing the metric for retrieving the n closest photons

Due to the nature of the algorithm, the photon hit positions in the k-d tree approximate the surfaces of the geometry used in the simulation. Nevertheless a standard query of the n-th closest photon hits will retrieve photons that may lie on different surfaces. In order to reduce the error in the computation of the projected area, Jensen [Jen02] suggested using a modified metric for computing the n closest photon locations, by stretching space in the direction of the surface normal of the query point. With this modified metric the n-th closest photons around the query point form an ellipsoid that is squashed and approximates the surface near the query point. This improvement reduces the error of including photons from different surfaces in the photon query.

Weighted reconstruction kernel

Another improvement published by Jensen [Jen02] is the use of a weighted reconstruction kernel. Instead of equally weighting all photon hits in the vicinity of the query point, a reconstruction kernel is placed around the query point, emphasizing photons that are close to the query point and deemphasizing photons that are further away from the query point. Typically a cone filter is used.

Separating global illumination and specular effects

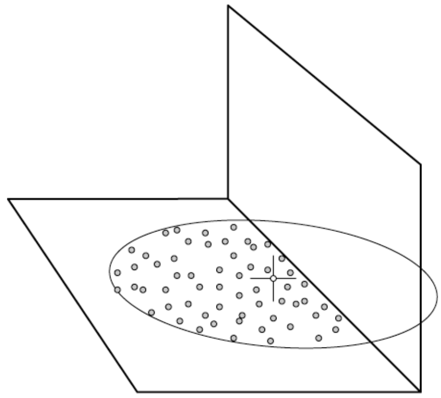
In order to compute the caustic effects produced by highly specular reflection and refraction, Jensen proposed to separate the simulation of photons reflected at highly specular surfaces from standard global illumination computation: global illumination calculation can be performed with less photons, if effects with high spatial frequency need not be computed, whereas the computation of caustic illumination effects needs high photon density for accurate simulation. Thus a low number of photons designated for global illumination are simulated, and a separate simulation with photons directed at highly specular surfaces is used for computing caustics.

3. PROBLEMS WITH PHOTON MAPS

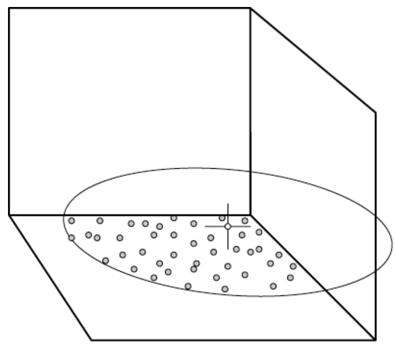
As already mentioned, the photon map constitutes a biased global illumination algorithm. The reason for the bias is the necessity to estimate illumination based on a finite sized kernel encompassing the n closest photons around a query point. This estimation can lead to various problems, the most visible of them being light- and shadow leaks. Especially in architectural scenes, walls in a building can exhibit both these problems.

Shadow Leaks

In a number of geometric configurations that are quite common in architectural scenes, the described way of estimating photon density will lead to an overestimation of the area covered by the photons that have been retrieved. This leads to shadow leaks , a special case of boundary bias, close to the edges and corners of rooms. Figure 1 shows two examples of such geometric configurations.



(a) Illumination estimate near wall



(b) Illumination estimate near corner

Figure 1. Geometric configurations leading to shadow leaks: note that photons on the vertical faces of the walls are not shown, as they do not contribute to the projected area. Photon hits are marked by small circles, the query point is marked by the cross-hair.

Light leaks

Another type of artifacts, namely a so-called occlusion bias, of the photon map algorithm happens in geometric configurations where photons in the vicinity of the query point should not contribute to the illumination, but are included as they are the closest photons. This typically happens close to walls, and leads to unwanted light leaks. Figure 2 demonstrates a geometric configuration leading to such a light leak.

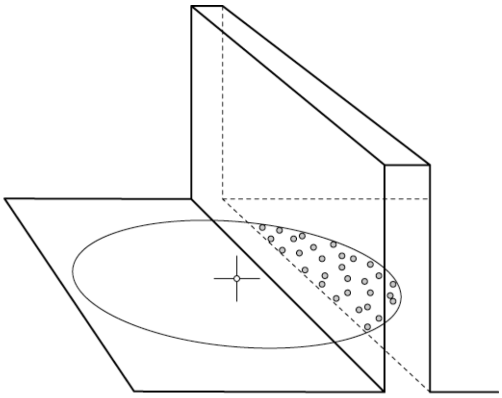


Figure 2. A geometric configuration leading to a light leak.

4. IMPROVED DENSITY ESTIMATION FOR PHOTON MAPS

In order to improve the density estimation for a query point it is necessary to compute a better estimate of the area covered by the n closest photon hits. These improved area computations should not slow down the query process, while giving a significantly improved estimate of the actual area.

Based on this requirement, some variant of 2D bounding boxes around the closest photon hits seems to be a promising approach. However standard bounding boxes overestimate the covered area in the case of constant photon density: the query method for calculating the n closest photons will return a nearly circular set of photons, and the bounding box of these photons will be about 27% larger than the actual area (area ratio of the 2D bounding box to the disk of retrieved photons).

8-sided 2D Bounding Boxes: OctoBoxes

In order to improve the estimate we use extended bounding boxes, that maintain additional extreme values in the four median directions (45º, 135º, 225º, and 315º). These 8-sided 2D bounding boxes, we call OctoBoxes, can be implemented to work nearly as fast as the standard bounding boxes, and will result in a significantly improved estimate of the area estimate of the n closest photons. This is a fast and simplified implementation of the convex hull idea presented by Jensen [Jen01, Jen02].

With this modification, the overestimation of the area in the limit case of a constant photon density is reduced to 5.5% (area ratio of the enclosing octagon to the disk of retrieved photons). Figure 3 shows an example of the improved estimate of the projected area possible with such OctoBoxes.

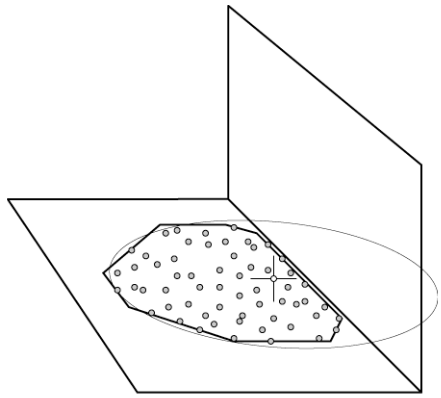


Figure 3. Improved estimate of projected area with OctoBoxes.

The use of OctoBoxes will eliminate shadow leaks close to the edges and corners of architectural scenes and thereby improve the illumination estimates of the photon mapping algorithm significantly. However there are still configurations that lead to unwanted shadow leaks. Figure 4 shows an example of a geometric configuration that leads to a shadow leak, even if OctoBoxes are used for computing the projected area of the n closest photons.

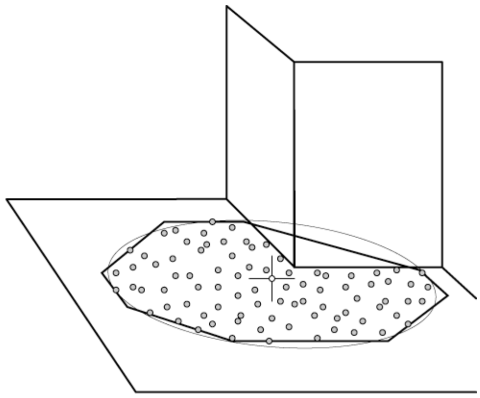


Figure 4. Geometric configurations leading to shadow leaks even if OctoBoxes are used.

Per Octant OctoBoxes

The problem with such configurations is, that the set of the n closest photons is not convex anymore. In order to overcome this problem, we use more than one OctoBox: based on the query point we partition the tangent plane into its 8 octants. For each of these octants we maintain a separate OctoBox for estimating the area of those of the n closest photons that fall within the respective octant. Thereby, we can calculate an improved estimate for the area of the n closest photons, for a number of cases in which these photons cover a non-convex area. Two examples of geometric configurations that can be handled by this improved heuristic can be seen in figure 5.

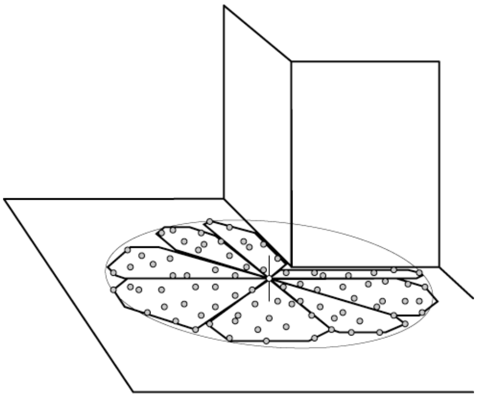


Figure 5. An example geometric configuration that can be handled with 8 OctoBoxes.

The use of a separate OctoBox for each octant will improve the area estimate in a number of cases, but as it is a simple heuristic, there are more complex illumination cases where this method will not generate an adequate result.

In cases of walls or corners at an angle between the octant angles (e.g. at 22.5°) the OctoBoxes will lead to their maximal possible error: in extreme cases, e.g. a very thin illuminated ribbon at an angle of 22.5°, the error can get arbitrarily large, however these cases are very rare, so in most situations the heuristics work pretty well.

If any of the octants receive a very small number of photons, the resulting estimate can be statistically unstable. In order to avoid such cases, we interpolate between the simpler heuristic (only one OctoBox) and the more sophisticated heuristic (one OctoBox per octant), based on the number of photons. If each octant receives enough photons (more than about 50) we use the sophisticated heuristic exclusively.

Note that the use of these OctoBoxes does not significantly slow down the algorithm.

Although these techniques based on OctoBoxes result in a significant improvement by eliminating most instances of shadow leaks in architectural scenes, they cannot eliminate light leaks, as no additional information about the geometric configuration around the query point is obtained.

Geometry Feelers

In order to overcome the problem of light leaks, a number of purely statistical methods have been tested, that evaluate the distribution of the n closest photons. However none of these statistical methods were stable enough to eliminate typical light leaks in architectural scenes. For this reason a different approach was chosen. By shooting so-called geometry feelers, i.e. rays that return the distance to the closest object, the geometry in the vicinity of the query point can be investigated. By shooting rays parallel to the plane of the projected area of the illumination query, that start from the query point and run in four or eight major directions around the query point, an estimate about the free space around the query point can be made (see figure 6).

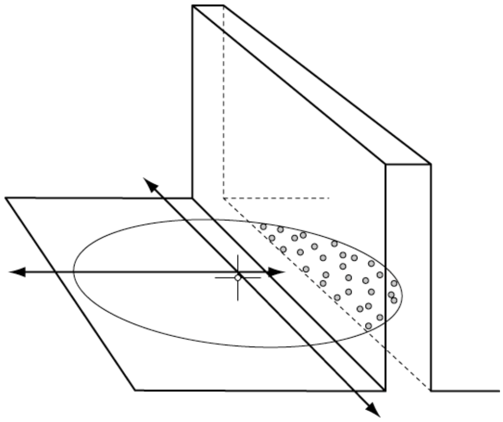


Figure 6. Geometry Feelers for estimating free space around the query point.

The geometry feelers are then used, to create a bounding box or OctoBox around the query point that is used as a filter for all photons: only photons inside this box are used for illumination estimates.

We tested this heuristic with a number of architectural scenes, and found out, that 4 geometry feelers can still lead to visible artifacts, whereas 8 geometry feelers per query point will eliminate most light leaks in architectural scenes.

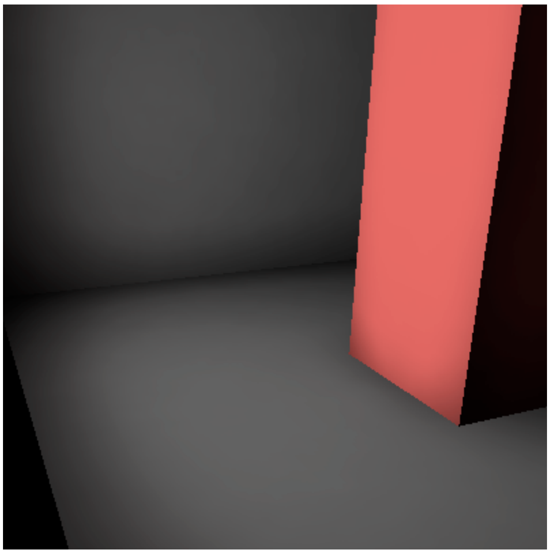
The use of the geometry feelers does slow down the computation of the photon map somewhat. Note that the actual reduction in computation speed is dependent on the relative performance of the k-d tree query with respect to the ray-casting implementation. In typical examples the observed slow-down was between 15% and 40%.

Note that the technique is not guaranteed to eliminate all light leaks. It is possible to find geometric configurations, where the geometry feelers do not adequately represent the surrounding geometry, e.g. when the geometry feelers exactly go through small holes in otherwise solid walls. Nevertheless these configurations are very unlikely in typical architectural scenes, and thus the heuristic works quite well.

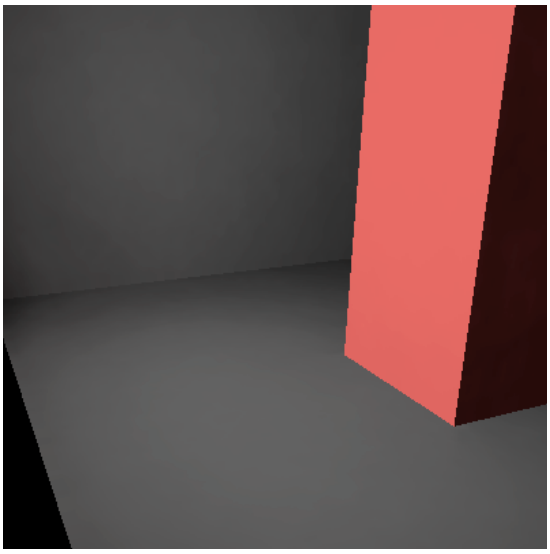
5. RESULTS

All the introduced heuristics have been built into a global illumination system, that precalculates illumination for interactive walkthroughs. The illumination is stored as light maps that are maintained in parallel to the texture maps for each object, and rendered using multiple texturing. The following examples show the improvements that have been obtained with the heuristics.

The first example shows the effect of the use of the OctoBoxes in order to fix shadow leaks (figures 7).



(a) shadow leaks



(b) no shadow leaks with OctoBoxes

Figure 7. Fixing shadow leaks with the use of OctoBoxes.

The second example shows the effect of the geometry feelers for fixing light leaks (figure 8).

(a) light leaks

(b) no light leaks with geometry feelers

Figure 8. Fixing light leaks with the use of geometry feelers.

Finally in the last examples (figure 9) we show a global illumination solution for a typical architectural scene, calculated using the presented improved heuristics.

Figure 9. Examples of global illumination in architectural scenes calculated using the presented heuristics.

6. CONCLUSION

We presented two heuristics that significantly increase the quality of photon map illumination estimation, by improving the area estimate of the projected area of the n closest photons, and preventing the propagation of illumination through geometric obstacles.

Although these heuristics do not result in a complete removal of the problematic light and shadow-leaks, and they are geared towards scenes with architectural characteristics such as walls and corners, it has been shown that they work well for architectural scenes.

7. REFERENCES

[Hav05] Havran, V., Bittner, J., Herzog, R., and Seidel, H.-P. Ray Maps for Global Illumination in Rendering Techniques 2005, July 2005.

[Hey01] Hey, H., Purgathofer, W., Global Illumination with Photon Mapping Compensation. Tech. Rep. TR-186-2-01-04. Vienna University of Technology, January 2001.

[Jen96] Jensen, H. W. Global Illumination using Photon Maps in Rendering Tecniques '96, pp.21-30, June 1996.

[Jen01] Jensen, H. W. Realistic Image Synthesis using Photon Mapping. A. K. Peters, Ltd., 2001.

[Jen02] Jensen, H. W. A practical Guide to Global Illumination Using Photon Mapping in Siggraph 2002 Course Notes CD-ROM, Course 43, July 2002.

[Las02] Lastra, M., Urena, C, Revelles, C, Montes, R. A Particle-Path-based Method for Monte-Carlo Density Estimation. Poster Paper Proceedings of the 13th Eurographics Workshop on Rendering, pp. 33-40, June 2002.

[Lav02] Lavignotte, F., Paulin, M. A New Approach of Density Estimation for Global Illumination. In Proceedings of WSCG 2002, pp. 263-270, 2002.

[Pet98] Peter, I., Pietrek, G., Importance Driven Construction of Photon Maps. In Rendering Techniques '98, Drettakis G., Max, N., (Eds.), pp. 269-280, 1998.

[Suy00] Suykens, F., Willems, Y. D. Density Control for Photon Maps. In Rendering Techniques 2000, Peroche B., Rushmeier H., (Eds.), pp. 23-34, June 2000.

[War88] Ward, G. J., Rubinstein, F. M., Clear, R. D. A Ray Tracing Solution for Diffuse Interreflection. In SIGGRAPH '88: Proceedings of the 15th annual conference on Computer graphics and interactive techniques, New York, USA, vol.22, ACM Press, pp. 85-92, Aug 1988.

[War92] Ward, G. J., Heckbert, P. Irradiance Gradients in Proceedings of the Third Eurographics Workshop on Rendering, Course pp. 85-98, May 1992.