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Global Illumination with Photon Map Compensation

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Abstract. We present a new method for the simulation of global illumination by utilization of a photon map. It uses an advanced radiance estimation which, in contrast to classical nearest neighbor area estimation, does not assume that the nearest neighbor photons lie in one plane or that they are uniformly distributed around the illuminated point. This allows us to correcly handle indirect illumination, eg. caustics, at edges and corners of objects without causing illumination artefacts in the vicinity of the edges and corners. We show how high quality results can be achieved by directly visualizing this illumination estimate without the usual low frequency noise of photon maps and without requiring a very large photon map.

1 Introduction

Photon maps allow to simulate global illumination in scenes with general bidirectional scattering distribution functions (BSDF). They store illumination information in the scene in form of photons which are distributed by light paths that are shot from the lightsources. This illumination information can then be used for the image generation with view paths that are shot from the camera.

Classical nearest neighbor area estimation [Jen96a] estimates the radiance at a given point on a surface by searching for the k_p (typically 50) nearest photons. It assumes that these photons lie in a plane inside a circular area with a radius that corresponds to the farest distance of these photons to the point, and that these photons distribute their power over the whole circular area.

This radiance estimation generates artifacts in the adjacency of edges and corners of objects, because those photons which contribute to the illumination of a point in this region are distributed only at one side of the edge or corner, or they do not lie on the same plane as the point of interest, eg. on an adjacent surface with a different normal. The contribution of photons from such adjacent surfaces can be minimized by expanding an ellipsoid, which is oriented according to the tangent plane of the point, instead of a sphere to search for the nearest neighbor photons, but this does not solve the problem that the photons cover only a part of the estimated area. Therefore in such a case this method gives an inappropriate illumination estimate, and the resulting artifact is a region with wrong illumination near the edge or corner (see figure 3a). Such artifacts can be avoided with an adaptive nearest neighbor estimation [Mys97], but this technique requires large quasi-planar surfaces with illumination maps.

Existing photon map-based global illumination methods [JC95, Jen96b, JC98] use this simple illumination estimate at a directly visible surface only to display illumination which is caused by specular light paths (caustics) or if the surface has a low contribution to the image. Such a caustic may be small and high frequent, so that artifacts are hardly visible, but it may as well form a bright low frequent illumination on a large visible scene part, where artifacts at edges and corners will be strongly visible.

Otherwise these methods [Jen96b, JC98] calculate indirect diffuse illumination at a visible point by shooting additional rays from this point which gather a large enough number of radiance estimates from the scene that are averaged so that the effect of a few wrong estimates is minimized [Dri00 p. 183]. This final gathering operation can be accelerated by using irradiance gradients [WH92] and by precalculating irradiance estimates at diffuse surfaces so that each of these irradiance estimates has to be calculated only once [Chr99].

Our new method avoids illumination artifacts at edges and corners by usage of an advanced radiance estimation that compensates the distribution of the nearest neighbor photons of a requested point in the adjacency of edges and corners. We show that high quality results can be achieved by using this calculated illumination directly at visible surfaces without final gathering. Note that our calculated illumination can nevertheless also be used with final gathering.

In section 2 we describe the generation of a photon map in a light pass, and how this illumination information is directly visualized in a view pass which uses the radiance estimation that is presented in section 3. In section 4 we show how high quality results can be achieved by minimizing the typical low frequency noise of a photon map without using a very large photon map. Our implementation and results are described in section 5. We finally present our conclusions in section 6.

2 Light pass and view pass

A photon map is generated in a light pass. The lightsources shoot their energy into the scene by shooting stochastically distributed light paths. At each point after the first bounce where a light path hits an object, information about the incoming indirect light is stored in form of a photon if the object is diffuse or soft glossy. The photon stores the hit position, the incoming direction of the light path and the incoming light power. The photons are organized in a spatial structure, eg. a kd-tree, which represents the photon map [Jen96a]. This way the illumination information is stored without needing a meshing of the scene. If a view pass with final gathering is used then of course a separate caustic photon map [Jen96b] should be used which contains the photons with specular light paths.

After the light pass the illumination information in the photon map is used to render the scene in a view pass. Stochastically distributed view paths that sample the image plane are shot from the camera into the scene. At a hit point of a view path at an object, the view path is continued only if the object is specular or strong glossy. The view path is continued by shooting a ray from the hit point. The outgoing direction of the ray is stochastically distributed according to the BSDF of the object. Alternatively importance sampling by means of the photon map [Jen95] can be used. Otherwise, if the hit object is diffuse or soft glossy, the view path ends at this point and the outgoing radiance of the object at this point into the incoming direction of the view path is computed by means of the k_p (user defined, typically 50) nearest neighbor photons to this point, as described in section 3. Optionally final gathering [Jen96b] may be used for the diffuse indirect illumination. Direct illumination from lightsources is calculated by casting shadow rays to the lightsources to reduce the size of the photon map and to minimize the noise in the generated illumination.

3 Radiance estimation

To calculate the radiance of a given point x we expand an axis aligned cube, which is centered at x, until it contains k_p photons. In particluar at edges and corners of objects these nearest neighbor photons will not lie in one plane, and of course they will not lie in areas of the cube where no object surface is (see figure 1).

Each nearest neighbor photon has a target area A_p, which corresponds to the projection of the diffuse or soft glossy geometry inside the cube onto a plane perpendicular to the photon´s incoming direction Ψ_p (see figure 2). Each nearest neighbor photon distributes the flux Φ_p that it carries over this target area. This yields the photon´s flux area density u_p in its target area.

$$u_p = \frac{\Phi_p}{A_p} \tag{1}$$

The photon´s irradiance at x, which has the surface normal N, is therefore

$$E_p = \frac{\Phi_p}{A_p} \Psi_p N \ . \tag{2}$$

This finally gives us the estimate for the radiance L of x into the incoming direction Ψ_i of the view path. f_r is the BSDF at x from Ψ_p to Ψ_i.

$$L \approx \sum_{p=1}^{k_p} \frac{\Phi_p}{A_p} \Psi_p N f_r(x, \Psi_p, \Psi_i) \tag{3}$$

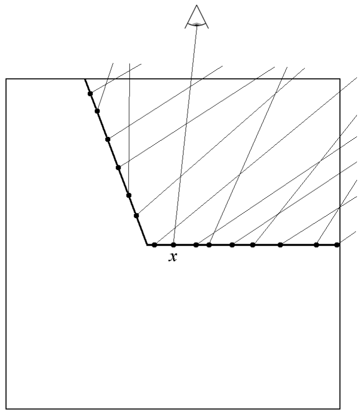

Fig. 1. Geometry and nearest neighbor photons (with incoming directions) in their bounding cube around the requested point *x*.

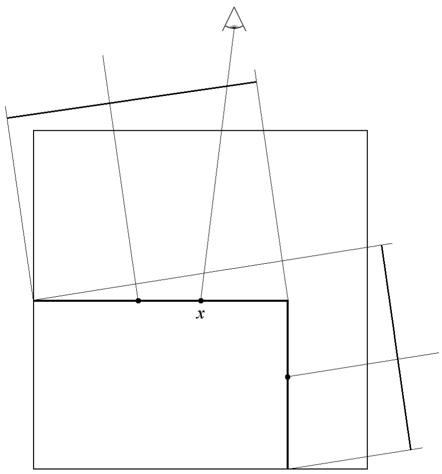

Fig. 2. Each nearest neighbor photon has an individual target area, dependent on its incoming direction from which it hits the diffuse or soft glossy geometry in the cube around the requested point *x*.

The only remaining question is how to calculate A_p. To do this we first clip all diffuse or soft glossy objects that intersect the cube into the cube. For non-polygonal objects we realize this by tesselating their parts that intersect the cube into polygons. Note that the tesselation is only needed here to calculate A_p, raycasting can still be done with the original object representations. Usually this results in only very few polygons due to the small extent of the cube. We then calculate for each of these polygons its area A_g inside the cube. This, of course, has to be done only once for *x*.

We then calculate the target area of a nearest neighbor photon as

$$A_p = \sum_{g \in P_p} A_g \Psi_p N_g \ . \qquad (4)$$

N_g is the polygon´s normal and P_p is the set of diffuse or soft glossy polygons inside the cube which are frontfacing to the photon ($0<\Psi_p N_g$). This assumes that the frontfacing polygons are not overlapping in the photon´s target area, which is justifiable because usually the cube will contain only a very small and simple piece of geometry with very few polygons.

4 Noise reduction

We minimize the noise in the generated illumination, and we simultaneously minimize the memory requirements by repeating the light pass and the view pass several times with a separate small photon map for each pair of light pass and view pass. This corresponds to averaging several images which are generated with different photon maps. For each of these view passes only a low average number of view paths per pixel is necessary, so that for complex scenes the total number of view paths is approximately the same as if a single view pass with a single large photon map would be used.

If a single pair of light pass and view pass would be used instead then a larger number of nearest neighbor photons would be required to achieve the same level of noise reduction, and their single photon map would therefore have to contain as many photons as all the small photon maps together to achieve the same low level of blurring. Additionally density control for photon maps [SW00] may be used to limit the size of the photon map to the necessary photon density.

This solution supports the generation of images with successively increasing quality by adding pairs of light passes and view passes until the achieved image quality is good enough. This of course also allows to generate fast preview images. Furthermore it allows to simulate motion blurring by selecting a separate point in time of the scene for each pair of light pass and view pass and its corresponding photon map.

5 Implementation and results

We have implemented and compared classical nearest neighbor area estimation [Jen96a] and our new radiance estimation. For both methods we have applied the noise reduction as described in section 4. In the images in figure 3 we have used the same set of photon maps for both methods (see figure 3c). These photon maps are generated and visualized in 50 pairs or light passes and view passes per image. Each photon map contains between 1.048.758 and 1.065.686 photons. We have not optimized the memory consumption of our implementation, because we have implemented it upon an existing rendering system[1], and for sake of simplicity we have used its default data types, because it supports several different multi-spectral color representations (for our tests we have nevertheless used rgb colors). Therefore we needed 96 bytes per photon. Nevertheless the photon map could as well be stored in a more compact format [Jen96a]. Additionally density control [SW00] could be used to achieve a more uniform photon distribution and therefore a smaller number of photons. In the view passes we have used k_p=50 for both methods. We have done the distinction between soft and strong glossy surfaces according to a shininess threshold. This static solution proved to produce less noise than using russian roulette to decide if the surface at a hit point is soft or strong glossy.

In the scene in figure 3 most parts of the scene are exclusively indirectly illuminated. Only a part of the walls and ceiling is directly illuminated by the lightsources. The scene contains several surfaces which are soft or strong glossy. In particular the large strong glossy floor (Blinn reflection model) has a high contribution to the indirect illumination in the room. Fig. 3a uses classical nearest neighbor area estimation to calculate the illumination, which results in illumination artifacts at edges (eg. on the table and chairs) and corners (eg. on the walls). Fig. 3b uses our new radiance estimation which avoids these artifacts.

6 Conclusion

We have presented a new method to calculate global illumation with photon maps. In our results we have shown that it also gives correct artifact free illumination results in the regions near edges and corners without using final gathering, as it is necessary eg. for caustics. This is due to a new radiance estimation which compensates the distribution of the nearest neighbor photons of an illuminated point in such a region. Future work includes the parallelization of this technique that utilizes the independence of the light passes and view passes and their photon maps.

Acknowledgments

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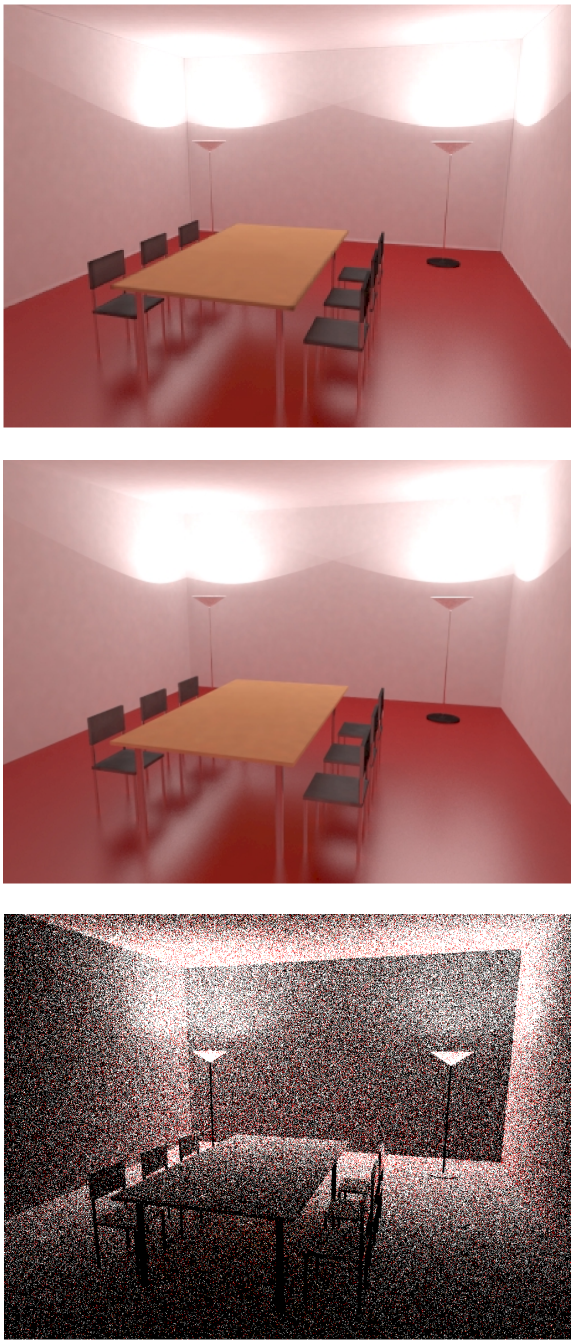

Fig. 3. a (top): Classical nearest neighbor area estimation generates illumination artefacts at edges and corners. **b** (middle): Our new radiance estimation avoids these artifacts. **c** (bottom): One of the photonmaps which were used for both methods.