A Pyramidal Hemisphere Subdivision Method for Monte Carlo Radiosity

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Abstract

In this paper we present a new method to improve Monte Carlo radiosity by sending more rays towards selected directions. More precisely, we determine regions of the scene where the distribution of the power must be done more accurately. The number of rays sent in a direction is a function of the number of patches contained in a region, a region being a pyramid defined by the centre of the shooting patch and a spherical triangle on the surface of a hemisphere surrounding the patch. Thus, the rays shot from a patch do not have all the same power. The new method allows us not only to obtain fine details much sooner and with lower cost, but also the overall efficiency is considerably increased.

Keywords: *Monte Carlo radiosity, hemisphere subdivision, heuristic search.*

1. Introduction

Radiosity has been introduced in Computer Graphics in 1984 by Goral et al. [6]. The original radiosity method is based on a discretisation of the environment into flat polygons. It assumed that all surfaces are perfect Lambertian reflectors and radiosity is constant across the surface of each patch. The computation of form factors is the most time-consuming part of this method. Several papers have proposed various methods to reduce this cost [4, 3, 7].

Another class of radiosity algorithms [2, 5, 8, 9, 10, 11, 12, 13] tries to reduce the computational cost by using Monte Carlo techniques based on shooting rays. The new method presented in this paper belongs to this class of radiosity algorithms.

The problem with conventional Monte Carlo methods is that ray-shooting does not take into account the complexity of the different regions of a scene. The same number of rays is approximately shot in all directions, according to cosine distribution.

Pyramidal hemisphere subdivision is an alternative to conventional Monte Carlo techniques. The scene is subdivided in regions and the density of each region is computed in a global manner by using triangular pyramids.

In section 2, we will present the pyramidal hemisphere subdivision method, while results of this new method will be given in section 3. We will conclude in section 4.

2. Regular Hemisphere Subdivision by using a Pyramid

The main idea of the Pyramidal Hemisphere method presented in this paper is to determine regions of the scene where the distribution of power must be done more precisely because the scene is more complex in these regions.

To identify all regions of the scene from a patch, we construct a hemisphere on the patch surrounding its centre. The

Published by the Eurographics Association, ISSN 1017-4656.

hemisphere is subdivided into four spherical triangles. Then, if the regions of the scene have to be discretized more precisely, each spherical triangle is subdivided into new spherical triangles. The subdivision criterion is the density of a region, that is, roughly, the number of patches belonging to the region.

At the end of the subdivision process, N_{tr} triangular pyramids are obtained, sampling the scene into N_{tr} regions. Each pyramid is defined by the centre of the patch and three planes. Each plane is defined by two vectors. These vectors have as origin the centre of the patch and as direction a vertex of a spherical triangle (see figure1).

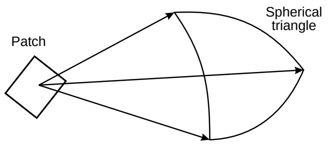

Figure 1: *Triangular pyramid associated with a spherical triangle*

For each pyramid, its density is calculated. The density of a pyramid determines the fraction of rays to send in the pyramid from the total number of rays sent by the patch in the whole hemisphere.

The density of a pyramid is a function of two criteria. The first criterion is the ratio of the number of patches contained in the pyramid, to the number of patches inside the region defined by the plane of the patch and its normal. The second criterion is the fraction of power contained in the pyramid. So, for a hemisphere surrounding a patch i divided in N_{tr} spherical triangles, we calculate the density of a pyramid p using the following formula:

$$density_{i,p} = h(f_{i,p}, n_{i,p}), \sum_{j=1}^{N_{tr}} density_{i,j} = 1$$

where $density_{i,p}$ is the density in the pyramid p for the patch i, $f_{i,p}$ is the fraction of energy of the patch i propagated in the pyramid p, $n_{i,p}$ is the number of patches contained in p and h is a heuristic function.

The fraction of power propagated in a pyramid is independent of the patch $f_{i,p} = f_p$.

Thus, we calculate beforehand this fraction f_p for all the pyramids of the hemisphere.

The heuristic function depends on the fraction of energy f_p and on the number of patches, $n_{i,p}$, contained into a pyramid. We can define a general form for this function:

$$h(f_p, n_{i,p}) = \frac{\alpha_1 f_p + \alpha_2 g(n_{i,p})}{\alpha_1 + \alpha_2}$$

where $g(n)$ is the ratio of the patches contained in a pyramid.

The general algorithm of this method can be decomposed in two parts. The first part is a preprocessing phase where the density of each pyramid is estimated for all the patches. The second part is a conventional Monte Carlo method using a new technique to shoot rays. The number of rays shot from patch i is approximately the same as in the Monte Carlo radiosity method, but their distribution is different, proportional to the density of each pyramid.

The implementation of the spherical triangle sampling is based on Arvo's method [1]. According to this method, random points uniformly distributed on the spherical triangle surface are chosen. To keep an accurate distribution of the energy, we must calculate the power sent by a ray. This power is proportional to the cosine of the angle θ between the direction of the ray and the normal to the patch. The distributed energy Φ_p in a pyramid p defined by a spherical triangle Ω_p is:

$$\Phi_p = \Phi_i \frac{\int_{\Omega_p} \cos\theta \, d\omega}{\pi}$$

where Φ_i is the unsent power of the patch i surrounded by the hemisphere.

Now, selecting uniformly a point on the triangle to obtain a direction is the same as solving by Monte Carlo integration the above integral with the following uniform pdf:

$$pdf = \frac{1}{\int_{\Omega_p} d\omega} = \frac{1}{\Delta_p}$$

where Δ_p is the area of the spherical triangle Ω_p that defines the pyramid p.

This means that, if we select points uniformly on the spherical triangle Ω_p, the value of Φ_p is approximated by:

$$\Phi_p = \sum_{j=1}^{r_p} \frac{\Phi_i \Delta_p \cos\theta_j}{\pi r_p}$$

where r_p is the number of rays shot in the pyramid.

This can be done by choosing the power sent by a ray in the spherical triangle as follows:

$$\phi_{ray} = \frac{\Phi_i \Delta_p \cos\theta}{\pi r_p}$$

An early attempt of this method was done at [8, 9], where non transporting energy rays were used to drive subdivision. The main drawback of this approach was its lack of accuracy. This problem has been solved with the method presented here.

3. Results and Discussion

The Pyramidal Hemisphere Subdivision (PHS) method has been applied to several scenes and compared with the Progressive Monte Carlo Radiosity (PMCR) method [5].

The time is practically the same for the two methods, the preprocessing time being negligible for the scenes considered. The additional memory required by PHS method is approximately of 1 Mb for a scene composed of about 15000 patches.

The test scene chosen for this paper, contains 1450 patches and 1186 vertices. Figure 2 in the color plate shows four images. The first one is the reference scene. The second is the final image of a part of the reference scene.The two remaining images are images of the same part of the scene rendered using the PMCR method and the PHS method respectively. The number of rays shot is approximately 45000 rays for the two methods.

It is easy to see that the image obtained by PHS is better than the one obtained by PMCR because of a more precise sampling used in the former method.

We expected to render the fine details much sooner and with lower cost, but we surprisingly also obtained a considerable increase in the overall efficiency. We interpret this as a consequence of the more clever ray distribution (and hence, of the energy).

4. Conclusion and Future Work

A new technique, the pyramidal hemisphere subdivision technique, has been presented in this paper. This technique produces a useful image of the scene much sooner than with the progressive refinement Monte Carlo radiosity algorithm. Moreover, the pyramidal subdivision technique permits a more accurate processing of complex regions of the scene. We are actually working on a variant of this method using an adaptive subdivision of the hemisphere and on the implementation of this method in the Hierarchical Monte Carlo Radiosity [2].

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Figure 2: *A test scene and details (first and second image) rendered with Monte Carlo Radiosity (third image) and with the Pyramidal Hemisphere Subdivision method (last image)*