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An Application of Automatic Differentiation to Photon Mapping for Efficient Image Synthesis with Global Illumination

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Abstract—Efficent image synthesis has been more important in computer graphics as viewers have been wanted more photorealistic images which need longer computation time. Some results have been shown by authors in the case of application of automatic differentiation to ray tracing technique and mesh subdivision. In this paper, the technique is applied into an image synthesis by photon mapping, which can represent global illumination including caustics, half shadows, half shades and half highlights.

1 Introduction

Ray tracing[1] is well known as one of the most popular rendering techniques in computer graphics. In the method, light rays are traced backwards from a viewpoint to the light sources. Since this approach can only handle mirror reflections, refractions and direct illumination, important effects such as depth of field, motion blur, caustics, indirect illumination, and glossy reflection cannot be visualized by the method.

One of the efficient techniques to simulate global illumination among these effects is photon mapping[2]. The photon map is used in a certain of bidirectional ray tracing. In the first place, by the ray tracing from light sources the map consists of information on a set of photons, which are emitted from the light sources and reflect/refract surfaces in a given scene. Considering the information, an image with global illumination is efficiently rendered by the ray tracing from a viewpoint.

Since quality of images depends on number of photons representing illumination around them, enough photons must be generated from light sources. However, too enough photons cause long computation time. Actually, many photons are not always needed when they are located on “flat” illuminated surfaces. Therefore, an adaptive definition of photons should be developed for efficient photon mapping.

We have been studying applications of automatic differentiation technique[3] into computer graphics technology for more efficient image synthesis with higher quality[4, 5]. Based on this idea, in previous paper, we proposed an adaptive photon mapping[6], which applies the automatic differentiation technique to detecting edges of surfaces and emitting photons efficiently. Combining the proposed method with the automatic differentiation more strongly, in this paper we will propose an improved algorithm, which can generate images more efficiently with global illumination including caustics, half shadows, half shades and half highlights.

2 Photon Mapping

The photon mapping is a two-pass method which consists of photon tracing and rendering:

Photon tracing:
Photon map is defined by tracing photons from light sources. All photons arriving at diffuse surfaces are stored on the map, after no or single/multiple reflections/refractions on specular and/or refractive surfaces (see Figure 1).

Rendering:
The photon map can be visualized directly by the simple ray tracing. For all diffuse surfaces the radiance is determined by the obtained photon map, while the one for specular and refractive surfaces is determined by the conventional ray tracing (see Figure 2).

The full global illumination consists of the four components; direct, specular, caustics, and indirect illumination. The direct illumination and the specular reflection (or transmissions) can be rendered by the conventional ray tracing. On the other hand, the caustics are rendered by radiance determined by caustic photon map, which is defined by tracing and storing photons only towards specular surfaces in the scene. Indirect diffuse illumination is also approximately rendered by radiance determined by global photon map, which is defined by tracing and storing photons toward all objects. Consequently, two types of photon map are necessary for getting images with caustics and global illumination.

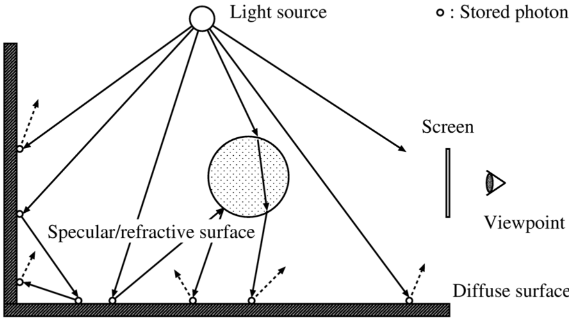

Figure 1: Photon tracing

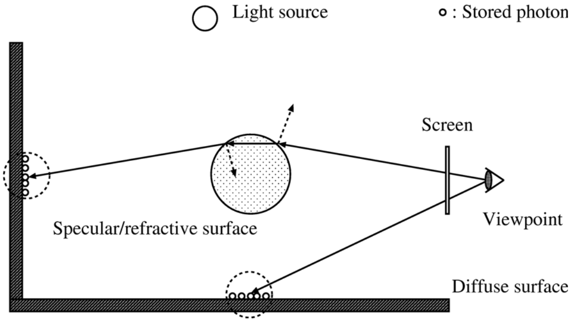

Figure 2: Rendering using photon map

3 Adaptive Photon Mapping in the Use of Automatic Differentiation

Although it is a great advantage for the photon mapping to be very versatile and fast, too small or too many photons may cause low quality of images or redundantly long computation time, respectively. In this section, an adaptive photon mapping is proposed in the use of the automatic differentiation. First, we show an outline of the conventional rendering technique by the photon mapping:

1. Execute the photon tracing and construct the photon map.
   - (a) Generate a photon map for a scene by emitting and tracing photons from sampling points of light sources.
   - (b) From the result of tracing of many photons, obtain information whether there are any edges in neighbor area of each photon. If so, revise the photon map by emitting and tracing additional photons around there.
2. Execute an adaptive distributed ray tracing with the photon map.
   - (a) Trace a ray and obtain an intersection with an object for each pixel on a given screen.
   - (b) From the result of the tracing, obtain information whether there are any edges of the object in the neighbor area. If so, distribute and trace the ray.
   - (c) Calculate intensity at each intersection by tracing rays to light sources.
   - (d) From the reult of the above tracing to the light sources, obtain information on direct illumination, i.e., whether each intersection exists in area of half shadow, half shade, or half highlight. If so, execute oversampling for the light source and get revised intensity.
   - (e) Calculate caustics and indirect illumination at each intersection by the obtained photon map.

It is noted that in each step we need many photons/rays to determine whether we should define additional photons/rays to improve quality of images. Here we introduce automatic differentiation to the whole of the above algorithm to detect automatically whether more photons/rays are necessary. An outline of the proposed method is as follows:

1. Execute the photon tracing using the automatic differentiation and construct the photon map.
   - (a) Generate a photon map for a scene by emitting and tracing photons from sampling points of light sources.
   - (b) Applied the automatic differentiation to the above photon tracing, obtain information whether there are any edges in neighbor area of each photon. If so, revise the photon map by emitting and tracing additional photons around there (see Figure 3).
2. Execute an adaptive distributed ray tracing with the photon map.
   - (a) Trace a ray and obtain an intersection with an object for each pixel on a given screen.
   - (b) Applied the automatic differentiation to the above ray tracing, obtain information whether there are any edges of the object in the neighbor area. If so, distribute and trace the ray.
   - (c) Calculate intensity at each intersection by tracing rays to light sources.
   - (d) Applied the automatic differentiation to the above tracing to the light sources, obtain information on direct illumination, i.e., whether each intersection exists in area of half shadow, half shade, or half highlight. If so, execute oversampling for the light source and get revised intensity.

(e) Calculate caustics and indirect illumination at each intersection by the obtained photon map (see Figure 4).

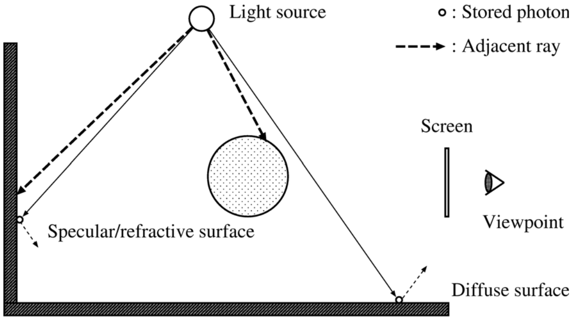

Figure 3: Adaptive photon tracing with automatic differentiation. An adjacent ray to the left is determined to be unnecessary by the proposed method because it can be represented by the original ray arriving at the same surface. On the other hand, an adjacent ray to the right is determined to be necessary because the original ray goes to different surface.

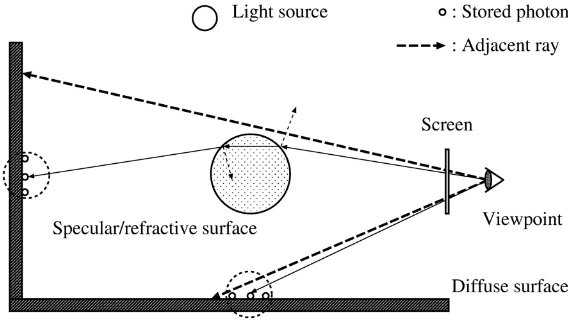

Figure 4: Adaptive distributed ray tracing with automatic differentiation. An adjacent ray to the below is determined to be unnecessary by the proposed method because it can be represented by the original ray arriving at the same surface. On the other hand, an adjacent ray to the above is determined to be necessary because the original ray from the viewpoint intersects a ball before arriving at the left wall.

Although it takes computational cost for the automatic differentiation, we can decrease the number of photons that stored in the photon map and most of the scene can use an interpolated irradiance value in rendering. Therefore, the proposed method makes the photon mapping adaptive so that the computational cost becomes low.

Furthermore, since the integrated application of the differentiation to each step is independent, even partial use of the proposed method is available. For example, the application to detection of edges of objects is proposed in Ref.[4].

4 Experiments

In this section, we consider a scene with three balls (diffuse, mirrored and transparent balls from the left to the right) in a room illuminated by a planar light. The scene is rendered by both of the conventional method and the proposed method, respectively. Table 1 shows common settings. Futhermore, the proposed method is examined by applications to a part of effects of global illumination.

Table 1: Common settings

resolution of image	300 × 450
number of distribution for a pixel	16
number of sampling points for the planar light	300

Fig.5 shows an image generated by the conventional method with 25,000 initially emitted photons for caustics and 500,000 initially emitted photons for global illumination. Fig.6 shows an image generated by the proposed method with 5,000 initially emitted photons for caustics and 100,000 initially emitted photons for global illumination. Table 2 shows number of pixels to be distributed and added photons to improve.

From the images, Fig.6 seems to have the same quality even the less initial photons are defined. Since the proposed method can determine necessaries of additional photons for improving quality of images, less initial photons than the conventional one achieves the similar quality.

Table 2: Pixels to be distributed and number of added photons

distributed pixels for anti-aliasing (among 135,000)	3,386
distributed pixels for a planar light (among 135,000)	10,384
number of added photons for caustics	2,216
number of added photons for global illumination	16,043

Table 3 shows computational time of the proposed method with respect to computation time under Red Hat Linux with Pentium4(2.0GHz). Althoguh the automatic differentiation needs more computational time than computation without it, the proposed method is much faster than the conventional method (see Table 3). It is also noted that the proposed method achieves the best performance among the whole/partial adaptive applications. This concludes that necessary photons for representing a scene locate ununiformly in the given space, and that the adaptive definition of photons by the proposed method can obtain such photons efficiently.

Table 3: Comparison of computation time

technique	time[s]
conventional (Fig.5)	14,210
proposal for photon tracing	11,056
proposal for a planar light	2,159
proposal for photon tracing & a planar light	1,272
proposal for photon tracing & anti-aliasing	771
proposal for a planar light & anti-aliasing	204
proposal for the whole (Fig.6)	121

5 Conclusion

In this paper, an adaptive photon mapping in the use of automatic differentiation is proposed. Since the automatic differentiation is used when photons emit from light sources through the scene, we can check the variation of surrounding shape and lighting. Therefore, we can decrease the number of photons and make images in lower computational cost.

Acknowledgement

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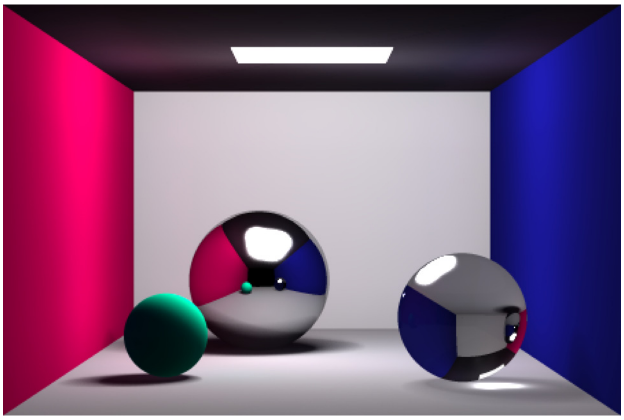

Figure 5: an image by the conventional method

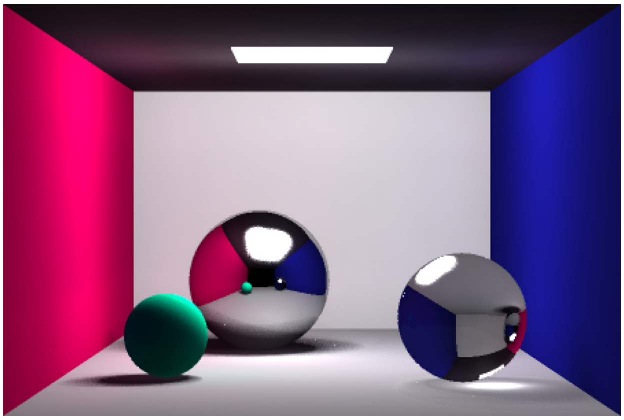

Figure 6: an image by the proposed method