REAL-TIME RENDERING OF HIGH QUALITY GLARE IMAGES USING VERTEX TEXTURE FETCH ON GPU

Hidetoshi Ando, Nobutaka Torigoe
Department of Computer and Media, Graduate School of University of Yamanashi, Takeda 4-3-11, Kofu, Yamanashi, JAPAN

Koji Toriyama, Koichi Ichimiya
Department of Mechanical Engineering, Graduate School of University of Yamanashi, Takeda 4-3-11, Kofu, Yamanashi, JAPAN

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Abstract: Using recent graphics hardware called GPU (Graphics Processing Unit), we can render high quality photorealistic images in real-time today. When rendering the scene, it is important to take into account how human eyes percept the whole scene. Glare is a phenomenon whereby bright light source cause spreading of light, and this effect is widely used in computer graphics to enhance reality of brightness of the scene. Real-time rendering of glare images is very important for recent computer games and virtual reality environment. Current technology for high quality glare rendering is too slow to be used for interactive applications, and fast rendering technology is limited to generate only blurry glare images. In this paper we introduce new technique for rendering high quality glare images in real-time using the latest technology called vertex texture fetch. The basic idea is to put what we call degenerate polygons on the screen as sensors to detect bright pixels and expand those polygons to form glare polygons where glare images are put. Combined with some performance enhancement techniques, our method can render very high quality glare images as fast as 60fps using modern GPUs.

1 INTRODUCTION

Computer graphics technologies are evolving very rapidly and images rendered using techniques like photon mapping or path tracing look much more photorealistic than using legacy ray tracing. In rendering of photorealistic scenes, it is not enough to create images based on physically based methods, but it is also important to take into consideration how the scene is perceived by human eyes. The most notable characteristics of human eyes are the glare effect when we see dazzling bright lights in the scene.

Glare is a phenomenon whereby bright light source causes spreading of light. It is perceived as blurry circle or a set of radial streaks around the light source. As current computer displays are physically limited by the maximum brightness, rendering of bright scenes needs extra work for human to perceive the scene really bright. Recently glare image generation is considered very common and effective technique to enhance visual reality of brightness in computer-generated images.

It is well know that glare is caused by scattering and diffraction of lights at obstacles close to or inside our eyes. Many research works have been done on generation of glare images based on physical models of our eyes. Those high quality glare images are widely used in recent CG movies which were rendered off-line.

Real-time rendering of glare images are also becoming very important to enhance visual reality of recent computer games and virtual reality applications. As recent GPUs support 16bit/32bit texture format, real-time rendering of HDR (High Dynamic Range) scenes became possible and combination of HDR rendering with glare effect will be crucial to next generation game consoles with latest GPUs. However current techniques for real-time rendering of HDR scene with glare images are

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quite limited either by image qualities or rendering speeds. This means practically fast rendering techniques are limited by image qualities and rendering techniques for high quality images have poor performance for real-time applications like computer games. In this paper, we describe our new techniques for high speed, real-time rendering of high quality glare images using the latest technologies on GPU and we hope to set the new level of standard for next generation computer games and interactive virtual environments.

2 RELATED WORKS

In this section we briefly overview some of the important results from previous works on generation of glare images and rendering techniques.

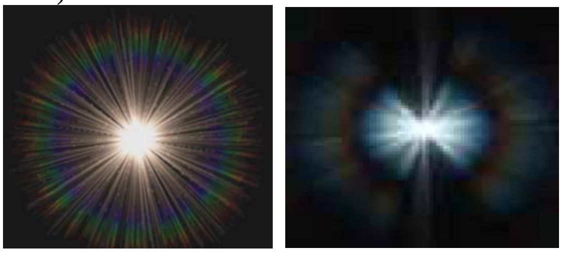
2.1 Generation of Glare Images

Many research works have been done on generating glare images based on our visual experiences or physical models of our eyes. Spencer et al. developed a method based on physical structure of human eyes to create glare images with sharp radial streaks (Spencer et al., 1995) (see Figure 1(a)). They took into consideration refraction and scattering of light at various places in our eyes and produced high quality glare images based on physical and perceptual model. By placing those glare images on bright light sources in the original scene, they confirmed the human viewers perceived the feeling of brightness although the computer display was not bright enough.

Kakimoto et al. created glare images based on wave optics (Kakimoto et al., 2005) (see Figure 1(b)). They developed a method to simulate diffraction of light at human eyelash and pupil to generate physically based glare images. By changing the shapes of eyelash and pupil, various kinds of glare images were generated automatically. Glare images can be computed and generated off-line and can be used later for real-time rendering using graphics hardware.

2.2 Real-time Rendering of Scenes with Glare Images

Recent advances in GPUs made it possible to render HDR scenes with glare images in real-time. Mitchell et al. used pixel shaders of ATI GPUs to extract and blur bright pixels in the original HDR scene to produce blurry glare images (Mitchell, 2002).



(a) (b)

Figure 1: Computer generated glare images (a) by (Spencer, 1995) and (b) by (Kakimoto et al., 2005).

They developed an efficient implementation of 2D Gaussian blur kernel to be performed on GPUs. Using multiple pass rendering on GPUs to create glare images and synthesize them with the original scene, they could render the whole scene in real-time.

Kawase et al. developed efficient and practical techniques for generating blurry glare images to be used for computer games (Kawase and Nagatani, 2002). Their approach is similar to (Mitchell, 2002) in that they implemented multiple pass blur filters using pixel shaders on GPUs, but they also developed blur filters for cross glares and pseudo lens flares which produce rather artistic visual effects. (see Figure 2) Their techniques are widely acknowledged by game developers, and are used in recent popular game titles. The biggest problem with the above two techniques are that they apply blur filter using pixel shaders and thus can only produce blurry glare images. High quality glare images with sharp streaks produced by (Spencer et al., 1995) or (Kakimoto et al., 2005) can not be used with these techniques. Another problem is that as multiple blur filters using pixel shaders put heavy load on texture memory access, they have to down size the original image to 1/16 or even less. During the process of down sizing, very bright pixels surrounded by dark pixels disappear because of smoothing effect, which lead to failure of creating proper glare images around such points. When bright pixels move around in the scene, we often see flickering or popping up of glare images due to the above mentioned problem.

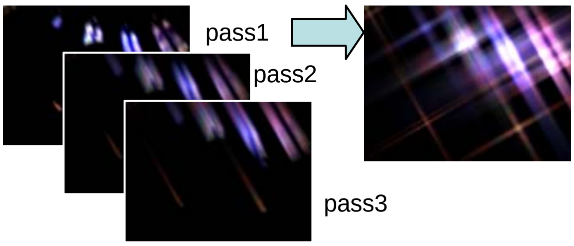


Figure 2: Multiple passes of blur filters for cross glare images (Kawase, 2003).

Kakimoto et al. not only showed how to generate glare images based on wave optics, but showed a way to render the whole scene in real-time (Kakimoto et al., 2005). They used their graphics hardware (SGI InfiniteReality4 with 1GB texture memory) to detect bright pixels in the scene which may cause glare effects, sent back an image which shows where the bright pixels are to CPU, let CPU create polygons to put glare image on and locate those polygons on appropriate position on the screen and render those glare polygons using the graphics hardware. Their rendering method requires heavy communication traffic between GPU and CPU, calculation load on CPU to create and place many glare polygons, heavy load on GPU to render many overlapping translucent glare polygons. Rendering time depends heavily on the number of bright pixels in the scene. Their experiment shows rendering of glare polygons on scenes with many bright pixels slows the rendering time down to less than 1fps, which makes this technique not suitable for interactive applications even with expensive graphics hardware. On the other hand, rendering time using blur filters are independent of the scene and thus can achieve constant frame rates, which is preferred by game developers.

To summarize the problems of current techniques for real-time rendering of glare images, techniques using blur filters by pixel shaders are only limited to produce blurry glare images, and although using glare polygons can generate high quality glare images current implementation using combination of CPU and GPU are too slow to be used for interactive applications. In the next section we describe the basic algorithm of our new method for rendering high quality glare images in real-time.

3 THE BASIC ALGORITHM

From the above discussion on the problems of current techniques for real-time rendering of glare images, we can conclude that using blur filters can not generate high quality glare images in spite of stable frame rate. To render high quality glare images it is therefore necessary to use glare polygons and put high quality glare images prepared off-line. By choosing this approach, we can use any type of glare images including blurry circles, sharp radial streaks, cross glares, and so on. The question now is how we can generate and render glare polygons at an interactive frame rate.

Our basic idea is to put glare sensors all over the screen, one sensor for one pixel. When a glare sensor detects that the pixel is bright enough to generate glare to human eyes, we put glare polygons at the location of the pixel with proper luminance value of the pixel. The above idea is realized by using 'degenerate polygons' and VTF (Vertex Texture Fetch) techniques available on recent GPUs. Our algorithm is totally implemented on GPU and thus needs no read back of images to CPU.

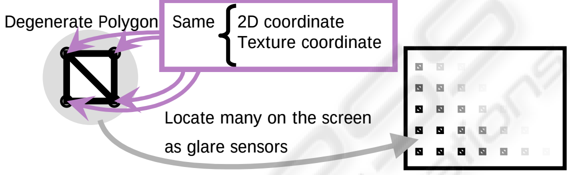


Figure 3: Degenerate polygons as glare sensors.

3.1 Degenerate Polygons as Glare Sensors

Figure 3 illustrates how we use degenerate polygons as glare sensors and create glare polygons. Conceptually a degenerate polygon is a quad with no size and it consists of 4 vertices. Each vertex has the same screen coordinate values, the same texture coordinate values for detecting bright pixel on the screen. Each vertex also has different texture coordinate values for glare images and different 2D directional vector for expanding the polygon. Each vertex of a degenerate polygon checks the luminance value of the pixel of the scene using VTF functionality.

VTF is a functionality to access texture memories from vertex shaders which was introduced as part of shader model 3.0 of Direct3D, and is currently supported by NVIDIA GeForce 6 and later GPUs. One examples of VTF functionality is what is called displacement mapping where each vertex is displaced according to some values stored in texture memory. There are not yet many examples to show the potential of VTF, and we expect our method to be one of the very few. Care must be taken when using VTF because it is much slower than texture fetching by pixel shaders. Also, current implementation of VTF by NVIDIA has the limitation that vertex shaders can only read textures with 32bit floating point format.

As a glare sensor, one degenerate polygon checks the assigned pixel in the rendered scene and decides if the luminance value of the pixel is above the threshold. If the pixel is considered bright enough, each vertex of the degenerate polygon moves itself away from its original position to expand the quad to form a square to be used a glare polygon where the glare image is put on. If the assigned pixel is not bright enough, the degenerate polygon will be ignored at the rasterizing stage.

3.2 Rendering of Glare Polygons

Once a degenerate polygon expands itself and becomes a glare polygon, pixel shaders put a translucent glare texture on the square polygon to generate a glare image. Each vertex of the glare polygon has unique texture coordinate values for glare texture, i.e. (0, 0), (1, 0), (0, 1) and (1, 1) so that the glare texture image will fit into the square glare polygon.

Glare polygons are then rendered to a target texture which will be later synthesized with the original scene. When there are many bright pixels in the original scene, rendering of many overlapping translucent glare textures pushes the memory bandwidth to the limit and this rendering stage becomes the performance bottleneck.

Following the above idea, we can generate very high quality glare images. But straight forward implementation of the described method is not practical for current GPUs. As described above, when there are so many bright pixels in the original scene, there will be so many overlapping translucent glare polygons and rendering the whole scene is sometimes as slow as a few fps. In the next section, we will describe some performance enhancement techniques of our method without sacrificing the final glare image quality.

4 PERFORMANCE ENHANCEMENT TECHNIQUES

In this section we describe some important techniques to improve performance of our basic method. The basic strategy is to reduce the number of translucent glare polygons as many as possible without sacrificing the final image quality. The technique to reduce the number of redundant VTF is also described.

4.1 Grouping Glare Polygons

The first step to reduce the number of glare polygons is to group some neighbouring glare polygons and replace them with one new glare polygon where possible. Assume we are going to group NxN neighbouring pixels. (see Figure 4) To maintain consistency, we set the luminance value of the new glare polygon to be the sum of all luminance values of the neighbouring pixels. We also adjust the center position of the new glare polygon taking in to consideration the distribution of luminance value over the neighbouring pixels. The new luminance value L_0 and the new center position P_0 of the new glare polygon is defined by the following equation.

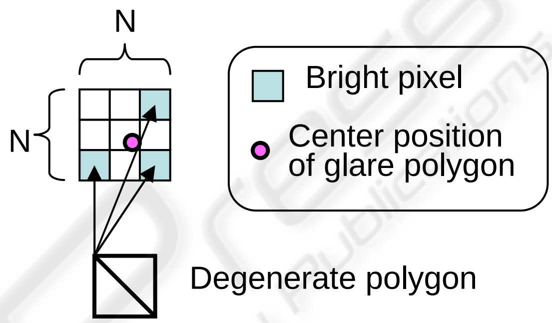


Figure 4: Grouping NxN Pixels for one glare polygon.

$$\left.\begin{aligned} L_0 &= \sum_{i=1}^{N\times N} L_i \\ P_0 &= \frac{1}{L_0}\sum_{i=1}^{N\times N} L_i \cdot P_i \end{aligned}\right\} \text{...............(1)}$$

If we are to group 2x2 neighbouring pixels and create one glare polygon for these pixels, we can reduce the number of glare polygons to 1/4 compared to the number of polygons before grouping. This reduction result in big performance gain because we are limited by pixel fill rate of GPU. Adjustment of new glare position works great for chasing a small moving pixel. From visual tests by many users, we can safely group 4x4 pixels using this technique and still maintain high quality of the final glare images.

Notice that the number of vertices was reduced to 1/NxN, but each vertex now has to check for NxN pixels for the calculation of L_0 and P_0, and the total number of VTF in the scene remains the same. To reduce the cost of 4 vertices of one degenerate polygon accessing the same group of NxN pixels using costly VTF, we now replace this process by a pixel shader program which can read textures much faster than using VTF. We first run a pre-processing by a pixel shader program to read all NxN pixels, calculate L_0 and P_0 values and store them in the new render target texture. Now each vertex of degenerate polygons has to read only one texel from the texture just created to get L_0 and P_0 values. This reduces the number of costly VTF down to 4/(NxN).

4.2 Clustering of Bright Pixel Areas

The above technique to reduce the number of glare polygons works great to achieve significant speed gain. We can stably achieve enough frame rates in most cases, but in some very extreme situation where the scene is mostly covered by bright areas, there will be too many overlapping translucent polygons to slow down the rendering speed. One example of this is rendering of very bright sky covering wide area of the scene.

To maintain decent frame rate even in such extreme situation, we further group glare polygons to cover fairy wide area of bright pixels. Figure 5 illustrates the basic idea of this approach. If more than 90% of the pixels in 8x8 pixel area are bright enough to cause glare effect, we put one glare polygon for this area and prohibit expansion of other degenerate polygons in the same area. Luminance value and center position of the glare polygon can be calculated by the equation (1) presented before. If the above 8x8 area was not filled with enough number of bright pixels, we do not create a glare polygon for the area and let other 4 degenerate polygons in the area do the job. This hierarchical organization of glare polygons works great to reduce the number of polygons and to maintain good frame rate.

4.3 Shrinkage of Glare Polygons

To be physically correct, glare image keeps its size on the screen independent of the luminance value. The image just gets dimmer when the luminance gets lower, but never gets smaller. Glare images often have brightest pixels at their center where the light source is, and get dimmer towards the outer edge. When the luminance value of the glare image gets dim enough, image around the edge gets imperceptive to human eyes, and we can safely discard these dark areas by shrinking glare polygons.

When shrinking a glare polygon, care must be taken not to scale down the glare image drawn on the screen. Shrinking a glare polygon without scaling down the glare image requires linear adjustment of texture coordinate values at each vertex of the glare polygon according to the size of the shrunk polygon. When to start shrinking and how much we can safely shrink for certain luminance value depends totally on luminance distribution of the glare image, but this can be precomputed. Shrinking glare polygons where possible reduces unnecessary overlapping of too dark glare images and we can gain some speed in some cases.

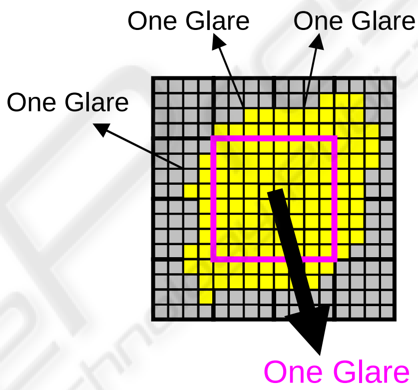


Figure 5: Clustering of bright pixel areas.

4.4 Performance Evaluation

By combining all these techniques, we achieved drastic performance improvement over straight forward implementation of our basic method. We used NVIDIA GeForce 7800 GTX GPU with HLSL of DirectX9 to render 1024x786 size scenes with glares. The size of glare images used was 512x512. Some of the images are shown in Figure 6. The images at the top are the original scenes without glare images, those in the middle are with glare images and those on the bottom show the edges of glare polygons. It can be seen that degenerate polygons with VTF works great to create high quality glare images at proper locations. Rendering speed was above 60 fps in average, over 120 fps in the best case, and 40 fps in the worst case. This depends mostly on how many glare polygons were drawn on the screen.

5 CONCLUSIONS

We have presented a new method for real-time rendering of high quality glare images using the latest vertex texture fetch technique. The basic idea is to put degenerate polygons on the screen as sensors to detect bright pixels and make them expand to form glare polygons where glare images are put. We have also presented some techniques to improve rendering performance without sacrificing image quality. It is fast enough for truly interactive applications like computer games and virtual environment. Combined with proper tone mapping at the last rendering stage, the generated scene looks pretty realistic. We will be using this technique for such applications to enhance visual quality and visual experience of the users.

You can replace degenerate polygons with point sprites to reduce the number of VTF and save video memory space. As VTF is not the performance bottleneck, rendering speed gain is negligible. Using our degenerate polygons, rotation of glare images can be done by vertex shaders at almost no cost. Rotation of glare images needs to be done by costly pixel shaders when using point sprites. We recommend to use point sprites only if the GPU memory is limited, i.e. GPUs in game consoles, and rotation of glare image is not necessary. There are many tuneable parameters to gain rendering performance and we do not have enough space to describe this in detail, such as usage of texture channels.

In this paper we described our method for glare image rendering, and we are currently working on generating so called “Lens Flare” effects. We can use the same VTF technique with degenerate polygons, but we need many polygons for a set of lens flare images. Our technique works for any type of glare images including sharp radial streaks and blurry circles. Although creation of glare images is not the main theme of this paper, we need a good tool to create high quality glare images for high quality rendering.

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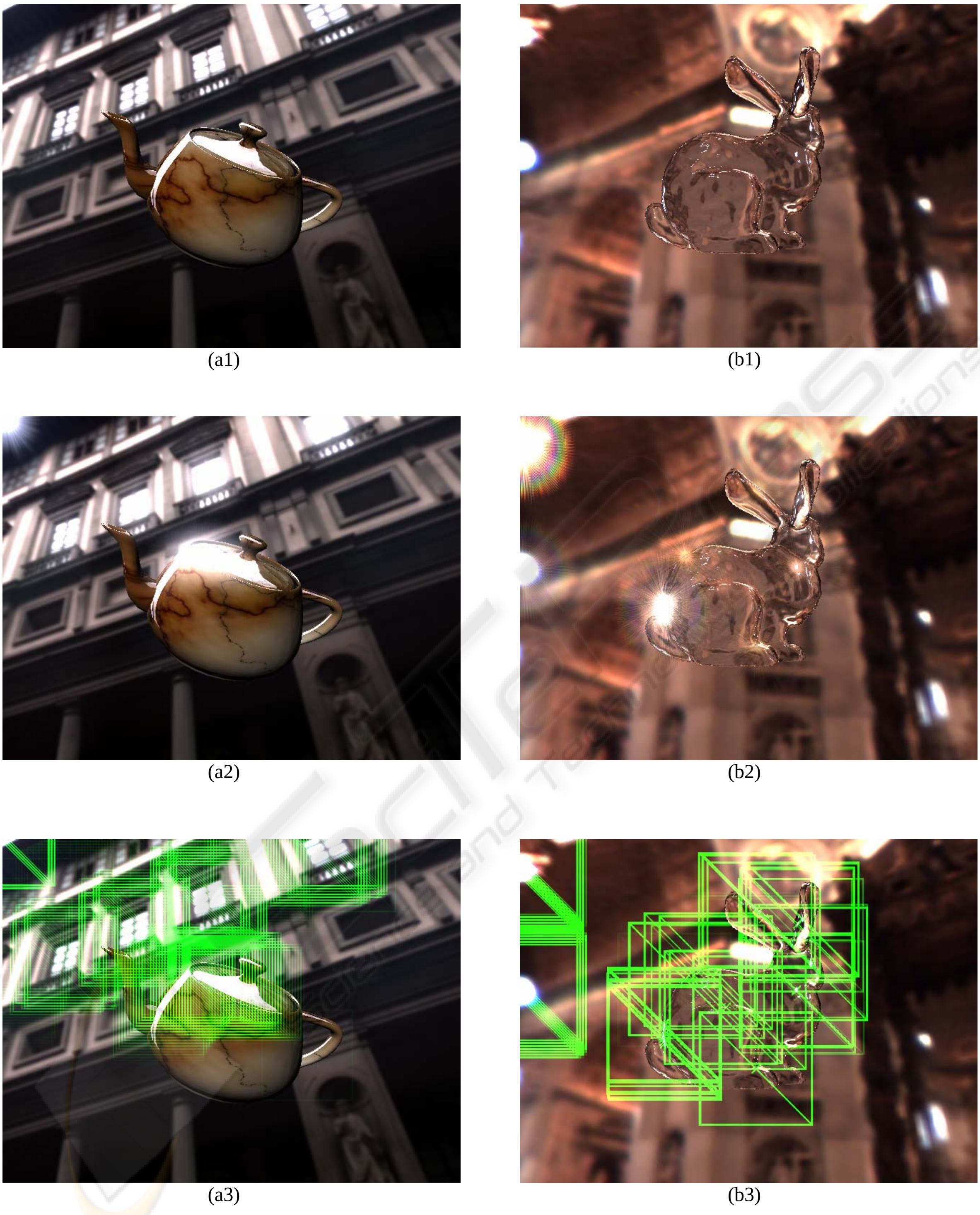

Figure 6: TOP (a1,b1) Original scenes without glare image, MIDDLE (a2, b2) Scenes with glare images generated with our method, BOTTOM (a3, b3) Glare polygons rendered as green squares to show their locations.