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GPU rendering for autostereoscopic displays

Francois de Sorbier  
LABINFO-IGM  
UMR CNRS 8049  
Université Paris-Est, France  
fdesorbi@univ-mlv.fr

Vincent Nozick  
Graduate School of Science and Technology  
Keio University, Japan  
nozick@ozawa.ics.keio.ac.jp

Venceslas Biri  
LABINFO-IGM  
UMR CNRS 8049  
Université Paris-Est, France  
biri@univ-mlv.fr

Abstract

In recent years, stereoscopic technology has advanced from stereoscopic to autostereoscopic displays. These latter family involves to display several views of a scene. In the case of real-time computer graphics images, the standard approach consists in rendering every view independently. This paper presents an alternative method to generate multiple views for autostereoscopic displays in a single rendering pass. Our algorithm is based on the fact that vertices properties remain the same from different viewpoints. Taking advantage of the latest generation of GPUs including geometry shaders, we propose a method that significantly speeds up the rendering process by duplicating and transforming incoming primitives for a defined set of views. Our method involves very few modifications to be used with a standard stereo device.

1. Introduction

Stereovision is a well known technique to enhance virtual reality devices involved in human immersion. In comparison to standard display, stereoscopic devices increase the visual immersion feeling. In recent years, stereoscopic technology has advanced from stereoscopic to autostereoscopic displays. The latter family does not require to wear any glasses or specific device for the user. Moreover, current autostereoscopic screens can display much more than two images to provide an adequate rendering in several directions and to be adapted for multi-user purposes. This new technology introduces new challenges like data acquisition, rendering and data transfer. Concerning the data acquisition, two cases should be considered: the input images are captured from video cameras or generated by computer graphics methods. We will focus on the second case where the scene should be rendered several times. This multiple rendering usually implies redundancies and can sometimes prevents rendering in real-time.

2. Autostereoscopic rendering

This article presents a new method for generating computer graphics that renders the scene from multiple viewpoints through geometry shaders. The only difference between the rendered images from a same scene being the viewpoints, the following properties are preserved: geometry, object colour computations, and part of the illumination computations. Thereby we take advantage of GPU capabilities to compute vertex attributes only once and then clones the result to render the multiple views dedicated to the autostereoscopic display. The goal of our method is to significantly enhance the rendering frame rate with few additional operations by generating multiple views of a scene in a single rendering pass.

2.1. Multi-view generation methods

The goal of a stereovision system is to produce two images of a same scene from two slightly different viewpoints and to associate them to the right and left eyes. Anaglyph, polarisation or shutter [10] are popular methods used to achieve stereovision but involve using glasses that impairs the feeling of immersion. Nevertheless, recent research works on autostereoscopy added the following benefits to the former stereoscopy idea:

- stereo displays allow multi-user applications;
- users do not have to wear glasses;
- users receive adequate stereo images according to their position.

Dodgson [2] presents a variety of autostereoscopic displays. But among them only two major techniques pro-
viding multiple view displays are available from several famous companies such as Philips [12] or Sharp [1].

The technique proposed by [5] uses the parallax barrier to feed both eyes strips of images lighted according to a barrier mask. The second technique presented by [14] relies on lenticular sheets. Vertical lenses are set over a group of pixels and emit light from each "sub-pixel" in different directions (up to 64 as presented by Takaki [15]). Unlike the parallax barrier technology which induces a luminosity loss because of opaque areas, lenticular sheets preserve the wholeness of luminosity.

2.2. Multi-view generation methods

As mentioned above, the 3D data can come from video camera acquisition or computer graphics rendering, but in both cases, the data generation can become a problem. In the case of video camera acquisition, plugging several cameras on a computer leads to video-stream saturation. This problem can be solved using online video-based rendering method as proposed by Nozick and Saito [9].

In the computer graphics case, the scene should be rendered for every different viewpoint which dramatically decreases the rendering frame rate and may prevent rendering in real-time. Several methods have been proposed to overcome the multi-pass rendering limitation for multi-view rendering of 3D information. A point-based rendering solution was proposed by Hübnner et al. [4] using GPU to compute multi-view splatting, parametrised splat intersections and per-pixel ray-disk intersections in a single-pass. This method reaches 10 fps for 137k points in a 8-view configuration. To increase multi-view rendering performance, Hübnner and Pajarola [3] present a direct volume rendering method based on 3D textures with GPU computations to generate multiple views in a single pass. These two solutions significantly decrease the computation time but are not suited for polygon based graphics.

An alternative solution has been proposed by Morvan et al. [8]: a single 2D image plus a depth map which are interrelated to display multiple views. Although the algorithm saves the bandwidth of data emitted to the system, it does an assessment over available data to fill the area’s missing information of the new views and then reduces the content’s truthfulness.

3. Algorithm outline

This section presents the geometry shader and shows how these new capabilities can be used to speed up stereoscopic rendering. We also explain how this method can be inserted in a classic rendering pipeline.

3.1. Geometry shaders

In recent years, vertex and pixel shaders have been widely used to speed up or improve rendering quality compared to CPU or older GPU.

![OpenGL pipeline with the fourth version of shader model.](image)

The fourth version of shader model introduces a new kind of shader called geometry shaders [7]. The geometry shader stage is inserted in OpenGL pipeline just after the vertex shader stage and before the clipping transformations as depicted in Fig. 1. The main purpose of geometry shaders is to manipulate incoming single fixed primitives like points, lines or triangles. Thus operations on geometry such as duplication, transformations or adding vertices are now available on GPU.

A vertex belonging to a new primitive is generated using EmitVertex function and finally emitted with the EndPrimitive function.

3.2. Our algorithm

The main purpose of our method is to speed up the multiple view rendering of a scene considering that vertex properties remain the same from a viewpoint to another. The new geometry shader stage takes place between the vertex
shader and fragment shader stages. An incoming primitive in the geometry shader stage can be manipulated and used to produce new primitives, thus saving extra-time required for vertex attribute computation in a basic multi-view process.

Our algorithm duplicates and transforms every rendered triangle according to the corresponding viewpoint. The resulting primitives are rasterized and transmitted to the fragment shader. Given \( N \) render-buffers associated to each of the \( N \) views, every received fragment is rendered into the correct buffer.

Rendering is performed into several textures to allow for the correct textures’ combining according to the autostereoscopic screen used. FrameBuffer Object (FBO) and Multiple Render Target (MRT) extensions are used to achieve this process. However since OpenGL implementation of FBO and MRT share a single depth buffer tied to the first draw buffer, it is not possible to use the common depth test to perform hidden-surface removal. So we need to apply our own depth test in fragment shader to discard undesirable fragments.

Our algorithm (Fig. 2) can be described as follows:

- compute modelview and projection matrices related to the \( N \) viewpoints
- set the middle viewpoint as the default viewpoint
- render the scene
  - process vertices
  - for each received primitive in the geometry shader
    - clone the primitive
    - perform modelview and projection transformations for the \( N-1 \) extra viewpoints
    - emit new primitives to fragment shader
  - according to the viewpoint, render results into \( N \) separate textures using MRT
- compose the \( N \) textures according to the multi-view autostereoscopic display

Currently the painter’s algorithm is used to perform the depth test even if results are well known to be not optimal. It exists two others solutions that could be applied to perform an efficient depth test.

The first one is to use one single texture that is shared between the multiple viewpoints that allow to use a single depth buffer. It takes advantage of the geometry shader to clip the triangles to the bounds of the area defined for a viewpoint and such a way there is no overlapping between the different renderings. However, using a single texture for every view strongly limits the number of generated images and their resolution. Moreover, this method may cause triangles to pop in and out because of the clipping.

The second solution will be available with next generation of graphic cards. The incoming specifications will allow to read and write into an active texture. The alpha value can be used in such a way as to store and read back depth values to perform our own depth test.

4. Implementation

This section describes the three main stages implementing our method.

4.1. Geometry duplication

As mentioned above, the duplication stage performed by the geometry shader is the key point of our method. \( N \) new primitives are generated according to the incoming primitive and the corresponding transformation matrices.

The following GLSL [13] code describes this process:
The matrix array transmitted from the main program to the geometry shader contains for each viewpoint the pre-computed projection matrix multiplied by this viewpoint’s modelview matrix. The variable \texttt{flag} is set with a different fixed value for each primitive. Then, in the next stage, fragments are rendered in the correct draw buffer according to this value.

### 4.2. Multi-view rendering

According to the value of the received variable \texttt{flag}, the fragment is rendered into the corresponding draw buffer. MRT constrains to render the fragment into each defined render buffer otherwise the result could be undefined. Thus if a fragment have to be written into a wrong buffer, its alpha value is set to zero and an alpha test is applied to discard these undesirable fragments.

Of course, since this operation arise at the end of the fragment program, this method is absolutely compatible with a normal use of the transparency with the alpha channel.

### 4.3. Final image generation

The rendering process generates \( N \) textures tied to the \( N \) viewpoints. According to the stereoscopic device used, these textures have to be composed to produce the correct final image. Figure 4 depicts two existing pixel arrangements for lenticular sheet-based system. To speed up the computational time of this stage, the GPU is once again required. More information can be found in [6]. Figure 5 presents a ready-to-use image.

### 5. Results and discussions

We tested our method on PC Intel core2 duo 2,40GHz with a Nvidia GeForce 8800 GTS graphic card under Linux.
system. Usually autostereoscopic screens using lenticular sheets technology have a $1920 \times 1080$ resolution. For our tests we choose to use the maximum of available images in one single pass i.e. 8 images related to different viewpoints. Consequently the resolution of each generated image is $240 \times 180$ (keeping a 4:3 ratio). Of course, our method is also well suited for much higher resolution.

Table 1 presents our results obtained with our method and compares it to the traditional multi-pass process.

<table>
<thead>
<tr>
<th>Number of views</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-pass method (fps)</td>
<td>157</td>
<td>80</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td>Our method (fps)</td>
<td>157</td>
<td>141</td>
<td>70</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 1. Frame rates obtained while rendering a scene with about 80,000 triangles.

These results show that our method speeds up the rendering process especially for a small number of additional views. Since the geometry shader implementation is not effective yet, we notice that performance deviation result for higher number of images is not as high as expected. Indeed, we have observed that adding just one varying variable between the geometry and the fragment shader can induce a severe drop of performance (for instance, switching from 13 to 14 floats doubles the rendering time in the 4-view case). According to the opinion of the computer graphic community, bad performances of the first geometry shaders release with high amount of vertices seem to be well known [11]. However forthcoming generation of graphic cards will probably improve geometry shaders efficiency.

Our method was also tested with different kinds of rendering process to evaluate their impact on performances. Table 2 depicts the results.

<table>
<thead>
<tr>
<th>Number of views</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>No illumination (fps)</td>
<td>326</td>
<td>168</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Texture (fps)</td>
<td>326</td>
<td>167</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Per-vertex illumination (fps)</td>
<td>160</td>
<td>83</td>
<td>28</td>
<td>24</td>
</tr>
<tr>
<td>Per-pixel illumination (fps)</td>
<td>160</td>
<td>83</td>
<td>28</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 2. Results presenting our method with different kinds of rendering with 80,000 triangles.

We can notice that results of per-vertex illumination and per-pixel illumination are similar. This is due to the capability of latest GPU to distribute resources between the fragment shader and the vertex shader.
The goal of the last test was to increase the number of rendered views (more than 8) and to check results with varying number of passes including more or less views to render.

Table 3 shows that currently, a mix between multi-pass and geometry shader provides the best results, with a significant enhancement compared to the traditional multi-view generation method. We can especially notice good performance when rendering three views per pass. Indeed, the current version of geometry shader is efficient with a low number of primitives to generate and balance the passes needed to render the multiple views.

In addition to require only few changes according to a traditional rendering process, benefits of our method under 8 views can be summed up as follows:

- \( n \text{view} \times 1 \times \text{nb_primitives} \times \text{nb_vertex.shader_op} \) operations saved on vertex attribute computation;
- data are rendered only once;
- less data exchange between CPU and GPU;

Finally to resolve the single shared depth-buffer limitation, we expect that a separate depth-buffer for each rendering buffer of the MRT will be available on the next graphic cards generation or that reading and writing in an active texture bit allocation for multi-view video compression. In Picture Coding Symposium (PCS), to appear, 2007.


Table 3. Results outlined by our method for 12 views using varying number of passes. In this configuration, the traditional method reaches 14 fps.

<table>
<thead>
<tr>
<th>Number of passes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Views per pass</td>
<td>12</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Results (fps)</td>
<td>N/A</td>
<td>14</td>
<td>15</td>
<td>23</td>
<td>21</td>
</tr>
</tbody>
</table>

As a future work, we intend to merge multiple-view rendering with the composition process described on chapter 4.3.

7. Acknowledgement

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References
Figure 5. A 4-images composition for a lenticular sheet system with focus on the Stanford Bunny model.