

Real-time depth of field with an octagonal bokeh shape

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Abstract

In order to achieve photorealism in computer graphics, depth of field (DOF) is an important effect. Realistic depth of field can be implemented using ray-tracing or accumulation buffer techniques. To create a depth of field effect in real time, post-processing effects can be used, such as the reverse-mapped z-buffer technique [Demers 2007]. It is difficult to achieve the same amount of realism as ray-tracing or accumulation buffering can achieve but post-processing can definitely create acceptable looking depth of field.

In our project, we decided to use a reverse-mapped z-buffer technique to create a depth of field effect. We also wanted to have a polygonal bokeh effect which is characteristic in out of focus regions of photographs. Our implementation creates a depth of field effect with an octagonal bokeh shape. It is possible to create a few other bokeh shapes, but this algorithm does not support arbitrary bokeh shapes.

1 Introduction

Depth of field is the effect where objects within a range appear in focus. Objects with a shorter or longer range i.e. objects in the background and foreground will be out of focus and appear blurry. An object will become more blurry as its distance from the focal point increases.

In a real camera and in our eyes a lens and the lens properties will decide what is in focus and what is out of focus. This is an important tool for filmmakers and photographers to help them direct the viewer's attention and to give a better sense of depth. A computer generated image is not rendered with a lens and will render everything in focus and lack a sense of depth.

2 Algorithms

A virtual lens was created to calculate the circle of confusion for every pixel.

2.1 Circle of confusion

The circle of confusion decides how blurry a pixel should be. [Demers 2007]

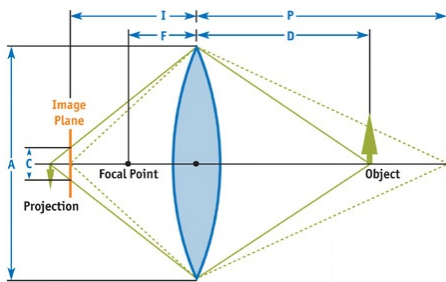


Figure 1: The circle of confusion

$$C = A \frac{F(P - D)}{D(P - F)}, \quad \frac{1}{P} + \frac{1}{I} = \frac{1}{F}$$

C = Circle of confusion.

A = Aperture.

F = Focal length.

P = Plane in focus.

D = Object distance.

I = Image plane.

The Aperture and Image plane were chosen to make the depth of field effect look as realistic as possible. They were not based on reality but on what we found looked best. The plane in focus was variable in the program. The circle of confusion is stored in the alpha channel for every pixel.

2.2 Bokeh

For every pixel 12 samples including the center pixel were blended to give the pixel its new color. The circle of confusion decides the length between the samples, for example if the circle of confusion is equal to zero, 12 samples are taken from the center pixel which will then keep its original color i.e. stay in focus. To get the bokeh effect samples are first taken horizontally and then vertically to cover a square and then the same thing is done where the horizontal and vertical samples are tilted 45 degrees which will cover a diamond. The min function is taken over the two resulting images and the result will be a octagon. [L.McIntosh and S.DiPaola 2012]

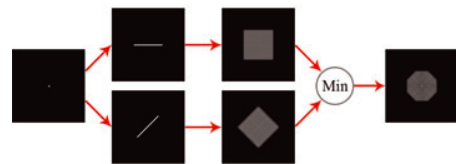


Figure 2: How to get the bokeh shaped filter

2.3 Bleeding pixels

Pixels in the background are going to take samples from pixels in focus. This will create a glow around objects in focus, pixels in focus are bleeding out in the background. To remove the bleeding pixels, a depth test was implemented. The pixel being blurred won't use the sample if the center pixel has a larger depth than the pixel we want to sample from. [Nischwitz 2013]

3 Results

The results of this project are presented in the following pictures.

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Figure 3: The flower pot is in focus and the lion is out of focus.



Figure 4: The lion is in focus and the flower pot is out of focus.



Figure 5: The lion is in focus and the wall is out of focus.



Figure 6: The wall is in focus and the lion is out of focus.



Figure 7: Pixel bleeding can be seen around the nose of the lion.

The performance of the implementation is good enough to make it possible to use in real-time applications. It is also easy to implement it into existing projects since it is only a post-processing effect.

4 Discussion

This implementation is an efficient way of creating a fairly realistic looking depth of field effect. However, it does have a few artifacts that a physically accurate depth of field effect dose not have.

4.1 Pixel Bleeding

Pixel bleeding can occur at the edge of an object that is in focus in front of a blurry background. This effect can be seen in figure 7. The reason pixel bleeding occurs and how to remove the artifact is explained in section 2.3. In our implementation we have used this method to remove the artifact.

4.2 Partial occlusion

Partial occlusion is an effect that occurs when the background is in focus and there is an out of focus object in the foreground. The edges of the foreground object should be blurred over the background in a physically accurate depth of field effect. This does not happen when blurring the image as a post-process since the circle of confusion at the in focus background is less than one and will not sample from the blurred foreground. This causes the edge of the foreground object to be sharp, as can be seen in figure 4 and 6. [Earl Hammon 2007]

Our implementation does not completely solve this problem. However, we do blur the circle of confusion map stored in the alpha channel of the image at the same time as we blur the color channels. This makes the sharp edges slightly blurred in an attempt to hide this artifact from the user.

4.3 High-dynamic-range rendering

In order to get more out of the bokeh effect, HDR rendering could be used. The bokeh effect is most noticeable wherever there is a brighter point surrounded by darker pixels. By using HDR rendering this might be achieved at certain areas of the image.

4.4 Bokeh effect

The bokeh effect is achieved because the filter kernel has the shape of an octagon, it can be seen in figure 6 around the eyes and the ears of the lion. Other shapes can also be achieved using the method described in section 2.2 by changing the angles that you blur in. A circular bokeh shape, which is another common shape, cannot be created using this method.

There are methods for creating arbitrary bokeh shapes. These methods tend to rely on calculating where the bokeh shapes are supposed to appear and then render quads at these locations with the texture of the bokeh shape. This can also be done as a post-processing effect and is an alternative to the method we chose to implement.

References

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