# Foveated Rendering Techniques

Kyle Tuckey

University Of Brighton

**Abstract.** Foveated Rendering is the process of rendering imagery based on the users gaze. The eye fixation region is rendered in a higher level of detail while the region outside it is rendered in less detail, this method of rendering can lead to significant performance increases in wide field of view displays such as VR headsets. This paper looks at how the techniques used to achieve foveated rendering have developed overtime and what the future of this technology is likely to hold.

**Keywords:** Eccentricity, Fovea, Periphery, Gaze-Tracking, Virtual Reality

## 1 Introduction

Modern computer systems and devices are capable of rendering photo-realistic imagery at resolutions as high as 4K, the computational cost to render these images is huge. The human eye is only capable of sensing fine detail within a 5°central circle, this visual field is called the fovea, the angular distance away from the fovea is called eccentricity, as eccentricity increases the fine detail we see in the fovea rapidly decreasses, we call this area the periphery. Foveated rendering takes into account the users gaze and renders the graphics based on this, reducing the level of detail in the periphery and rendering the finer detail within the field of the fovea, this results in dramatically reduced computational cost when rendering. In this report we will look at previous implementations of foveated rendering systems and how they have developed overtime.

## 2 Early Foveated Rendering Techniques

Making use of foveation in Computer Graphics is not a new idea. This section look's at a papers using these techniques and gives a summary of their findings.

### 2.1 Gaze-Directed Volume Rendering

Levoy & Whitaker (1990) proposed integrating gaze direction into rendering algorithms. The algorithm that the paper describes ray traces a volume dataset over three images sampled at distances with the values of 1, 1/2, 1/4 of native resolution. It made use of a 3D MIPMAP to filter 3D volume taking fewer volume samples along the peripheral rays.

They performed an experiment that made use of an eye tracker that had two infrared light emitting diodes mounted onto it. The reflections of these infrared spots from the iris of each eye was then tracked by cameras mounted on the side of the helmet. the users were evaluated in two modes of the experiment, tracking mode where the user had to follow the motion of a cursor superimposed on the image and saccading mode. The users reported that the high resolution sweet spot followed their gaze perfectly in tracking mode, and adequately enough in saccading mode, the users were also aware of the variable resolution structure of the image.

In the conclusion of the experiment they noted how their approach would be suited for personal head-mounted displays, however at the time the resolution and angle of the displays were not good enough for this implementation to work. They also identified how their approach could benefit non-gaze environments by having the user attach a 3D cursor to areas of interest on objects within the scene, which would reduce image generation costs.

### 2.2 Gaze-Directed Adaptive Rendering

This technique was published in a paper by T. Ohshima (1996). The technique uses a level of detail selection algorithm based on the size of an object in the scene and how far away that object was from the viewpoint. For example any geometry that is close to or within the foveal view is rendered with a higher level of detail wheras anything further away is rendered with less detail, so only the basic shape of the geometry is rendered in the periphery and the more finite details are rendered in the foveal view. This differs from the other techniques in that it does not render at a lower resolution in the periphery instead choosing to eimply render geometry in a lower level of detail.

The way this sytem was tested is exactly the same as the paper by Levoy & Whitaker (1990), both papers ran very similar equipment setups. This paper also had the same two test modes, where the user followed a cursor on the screen and a saccading mode.

The results of the experiment show that through the method that they implemented they were able to reduce the burden of the rendering process and maintain the quality of generated images.

Guenter et al. (2012) identify an issue with this implementation; although the method successfully adapts geometric level of detail to eccentricity it does not do it for rendering resolution. This means that it cannot accelerate applications that are bottlenecked by per-pixel shading cost.

## 3 Modern Foveated Rendering Techniques

This section details two modern foveation techniques. The first was proposed by Guenter et al. (2012) and the second was proposed by Vaidyanathan et al. (2014).

### 3.1 MULTIRES

The system that would later be called MULTIRES was proposed by Guenter et al. (2012). The strategy in this paper resembles the one implemented by Levoy & Whitaker (1990). This system renders three overlapping layers centred around the central gaze, which they call eccentricity layers. the inner layer is the smallest and rendered at the highest resolution and finest level of detail, the two peripheral layers are rendered at a lower resolution and coarser level of detail, they are then updated at half the temporal rate as the inner layer and are interpolated up to native display resolution and smoothly blended between them.

In this paper three different user studies were carried out, the first test presented the users with pairs of short animated sequences one of these shorts used non-foveated rendering and the other used foveated rendering at varying quality levels, they then asked the users which of the shorts were of a better quality. This experiment was designed to deduce what foveation quality level was comparable to non-foveated rendering.

The second test presented users with a set of short sequences where the foveation quality would incrementally ramp up or down, users were then asked if the quality increased, decreased or remained the same over the sequence. the goal with this test was to find the lowest foveation quality perceived to be equivalent to a high quality setting.

The final test let the user explore the foveation space themselves they were first presented with a non foveated animation as a reference. The users started at a low level of foveation quality and could do a set of functions, they could increase the quality level, show the non foveated reference again or decrease the quality level, and they then recorded the first quality level index at which users stopped increasing the level and instead compared it to the reference. the test also explored how animation speed effected the demand for foveation quality, they did this by running the test across six different speeds of the moving camera, a panning camera that didnt move, and a static camera. Each test was presented to the subject twice resulting in 16 different tests.

The results of these tests provided thresholds which were the lowest quality level each subject identified as either equal to or better quality than the non-foveated reference. The threshold for the first test had a mean of 14.9, the second test the mean was 11.9 and for the final test the mean was 14.5. From these values they were able to derive 2 estimates which could be used to predict foveation savings with larger displays. In the conclusion the experiments showed that foveated rendering improves graphics performance by a factor of 5-6 on current desktop displays at HD resolution.

### 3.2 Coarse Pixel Shading

The focus of the paper by Vaidyanathan et al. (2014) is not solely on foveated rendering, however it does implement its own algorithm to achieve foveation in rendering. In their implementation several layers are rendered to the screen with decreasing resolution around the viewers gaze, these layers are then composited to produce the final image. In order to understand how foveated rendering can be achieved through this algorithm you need to first understand how their algorithm for Coarse pixel shading works.

The idea behind Coarse Pixel Shading is that in order to shade at a lower rate than once per pixel you need a pixel to represent a group of pixels; this is called a Coarse Pixel. This group of pixels will share the result of a single coarse pixel shader evaluation. Using this method of shading they are also able to vary shading rates across different regions of the screen, in order to achieve this they divide the screen into tiles and allow a different value of Coarse Pixel size per tile, each tile maps to a shading grid with the selected Coarse Pixel size.

With Coarse Pixel Shading you can shade efficiently with foveated rendering, because you can avoid resending geometry over multiple rendering passes. They are able to control the shading rate with a few parameters such as the point that represents the centre of the gaze, aspect ratio, inner and outer minor radii, and inner and outer Coarse Pixel parameters.

Because the focus of the paper was not foveated rendering there are no user tests performed with it in mind.

### 3.3 limitations

The paper by Patney et al. (2016) highlights an issue with both the above renderers, both renderers focus on reducing the performance costs of rendering, however neither of them minimize perceptible artefacts introduced in the foveation process. This in turn causes temporal aliasing, which distracts users and break's immersion.

## 4 Emerging Foveated Rendering Techniques

The most recent paper on foveated rendering is by Patney et al. (2016) the paper detailed how they applied a gaze tracking device to a virtual reality headset, for the purpose of developing a new foveated rendering system. The authors discuss in the conclusion of this paper that the reason they set out to create a new rendering technique was because they found that their implementations of both the MULTIRES system by Guenter et al. (2012) and the Coarse pixel shading system by Vaidyanathan et al. (2014) introduced artifacts and then realised that they did not have a way of reducing the artifacts. The paper gives an overview on human peripheral vision talking about the various tasks that are at play in our peripheral vision and how these contribute to the effectiveness of foveated renderers. They discuss how recent foveated renderers build on the cortical magnification theory decreasing various visual factors such as resolution, shading rate and screen-space ambient occlusion with increasing eccentricity, and say how this alone fails to describe all aspects of peripheral vision.

They created a "emulated foveated renderer" which was a perceptual sandbox where they performed foveation as a post process, this was so that they could figure out what their perceptual visual target was, which would then be used in their design decision for the final foveated renderer. The way this was evaluated was through a user study. Through the sandbox they were able to emulate three different foveation techniques the first was 'Aliased Foveation', they then emulated 'Stable Foveation', and the final foveation strategy they emulated was the foveation technique they had developed.

They compared each strategy in a user study. The procedure of the study was to show the users various scenes rendered with and without foveation and to pick which looked better, in each trial they sequentially presented a foveated and non-foveated version of the scene in a random order. The results of the user study showed that the threshold for their strategy was significantly higher than the other two being 3x better than aliased foveation and 2x better than temporally stable foveation, therefore they were able to confirm that temporally stable and contrast preserving peripheral images are superior to temporally unstable and non-contrast preserving strategy's.

Following the results they then produced a foveated renderer for VR that achieves variable-rate sampling without temporal aliasing, preserves contrast and improves performance from reduced sampling rates in the periphery. Following this they performed a second user study to see if the rendering system they had created did in fact achieve superior image quality. They compare the rendering system against the MULTIRES foveated rendering system. they found that their rendering system was capable of generating images of a higher quality than the MULTIRES system, which verified their hypothesis. They also found that their system achieved a 50% reduction in pixel writes than the MULTIRES system and was 50% more effective at lowering the shading cost

Despite the results of the user study being exceptionally positive, there are still limitations in fully realising the potential of foveated rendering in VR. For example the blink detection in the gaze tracker was poor, which then introduced artefacts when blinking due to brief loss of gaze tracking. Although they developed a perceptual target they dont claim it to be an ideal target and state that future improvements to the perceptual target could provide additional insights into a reduction in shading work.

In the conclusion the authors talk about how they implemented both the MULTIRES system by Guenter et al. (2012) and the coarse pixel shading system by Vaidyanathan et al. (2014) and found that both introduced objectionable artifacts that were gaze and head motion dependent

## 5 Conclusion

Since the 1990's foveated rendering has been pointed to as an area of great potential when it comes to reducing the computational cost of rendering. All the example's that have been shown in this paper all focused on tracking the user's gaze and using that information to dramatically reduce computational cost. The paper reveals that over a period of 26 years foveated rendering techniques have been continually developed and improved to the point where soon it will be applicable in modern VR headsets. There is still much that can be done to further develop upon current system's but the development's since the paper by Levoy & Whitaker (1990) and the paper by Patney et al. (2016) have been enough for the industry to comfortably make a push for this technology to be released.

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