Fractal Multiverses in VR

Johannes Saam
Framestore

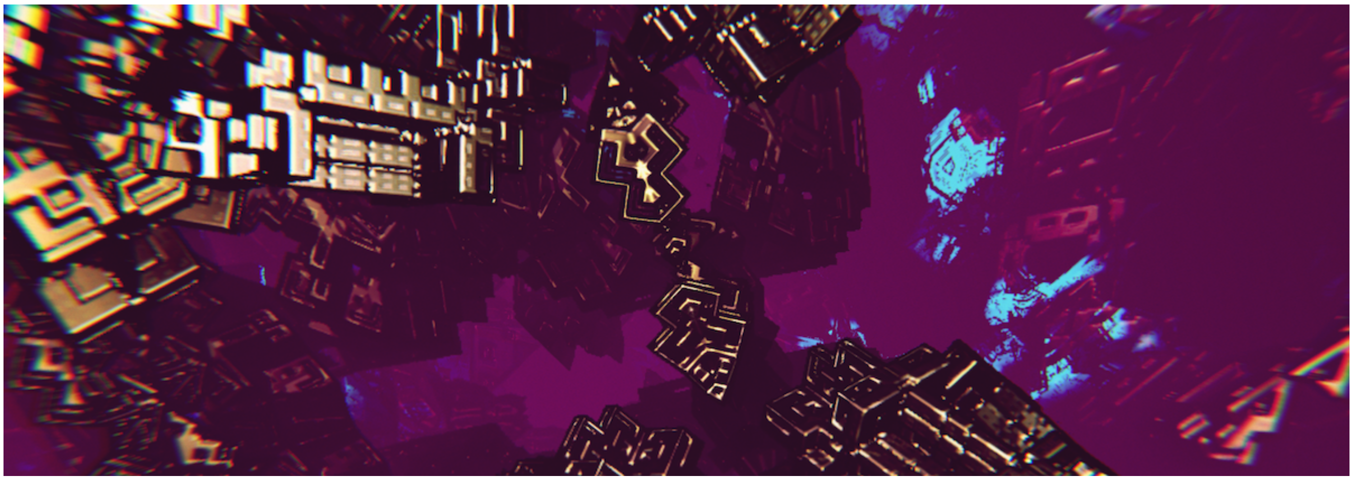
Mariano Merchante
Framestore

Patrick Beavers
Framestore

Rongxuan Jin
Framestore

Aron Hjartarson
Framestore

David Bees
Framestore



ABSTRACT

Fractals are complex mathematical structures that have interested the graphics community since their inception. We present our design decisions for an interactive fractal explorer and a novel approach for rendering fractals on VR headsets at high frame rates, through the use of stereo reprojection techniques and conemarching for distance estimation.

CCS CONCEPTS

• **Computing methodologies** → **Rendering**; **Virtual reality**; **Shape modeling**;

KEYWORDS

ray marching, fractals, signed distance functions, virtual reality, reprojection

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1 INTRODUCTION

Recently, there has been a resurgence of fractal renderings in popular media [Ebb et al. 2017; Hutchins et al. 2015]. Their deceptively simple nature of self repeating rules creates a nearly infinite amount of visual complexity and inspires many to enter into fields of graphics and rendering. As a representation of natural and growth phenomena, fractals are ideal due to their emerging features and similarity to our perceived nature. We present our approach to visualizing fractal environments as a six degrees of freedom virtual reality experience. This approach is also applicable to any scene defined by signed distance fields and can potentially accelerate fractal rendering in virtual reality applications.

2 DESIGN CONSIDERATIONS

Due to the abstract and chaotic nature of fractals, the main design challenges when developing an interactive VR explorer consist of the development of a suitable locomotion model and the discernment of how to navigate repeating patterns at vastly different scales.

We approached locomotion by restricting the navigation to a gaze-based, trigger-throttled mechanic. This aligns the view direction with the travel direction. Acceleration is paired with a linear and angular velocity-based foveated vignette [Fernandes and Feiner 2016] to minimize motion sickness. Several experiments with different input mechanics had caused nausea during testing and were discarded.

The core visual feature of fractals consists of similar patterns at different scales. As we are using stereo output, scale cannot be decoupled from the actual scale of the virtual camera. Accurate depth cues are essential for a relaxed and lengthy experience. Depending on the distance between the camera and the closest point on the distance field, the interocular distance is shifted, modifying the perceived scale. The scales range from human scale to microscopic, modifying the maximum thrust of the player to ensure a smooth transition between scales, which has proven essential for comfort. These elements ensure a calm and comfortable experience and allow the user to focus solely on the exploration of fractal surfaces.

3 CONEMARCHING

The core rendering technique is based on sphere tracing. More specifically, we implemented a hierarchical acceleration structure that takes advantage of the spatial coherence of scenes and is usually referred to as conemarching. Fractals are defined as distance functions, which are used to estimate the distance that each ray (or cone) must march along a specified distance until a predefined threshold is crossed and an intersection with the implicit function happens.

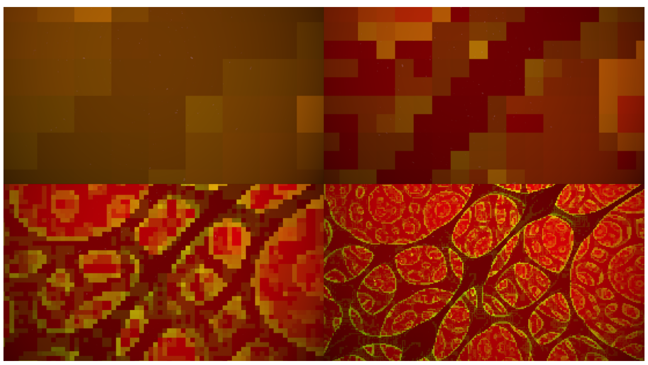

Figure 1: Iterative refinement of fractal shapes

A series of passes with increasing resolution are dispatched, where each pixel is assumed to be a cone and each ray marches until there isn't a guarantee that the cone won't collide with the surface. An example of this approach with 4 passes can be seen in figure 1. The result of this ray distance is then shared to the next pass, which doubles resolution but reuses most of the effort in finding intersections with the geometry.

4 STEREO REPROJECTION

Although conemarching accelerates the surface estimation dramatically, it is still expensive to calculate for both eyes. The key rendering optimization in this application is the stereo reprojection of intermediate depth results to each eye. Our approach is inspired by [van de Hoef et al. 2011]. We estimate the surface intersection for the center eye and then reproject the results for both left and right eyes. The main contribution to our technique resides in the fact that reprojection artifacts can be fixed by approximating depth based on outlines. Additional sphere tracing will fix any kind of stereo artifact that may arise. This results in stability and essentially removes the need to conemarch twice. This method is also independent of the surface definition and should work with any scene defined with a distance signed function – in fact, a fractal SDF is usually the worst case due to its high frequency details.

5 SHADING

Most of our acceleration techniques focus on depth estimation. However, shading each fractal is prohibitively expensive in some cases due to the iterative nature of fractal distance estimation. The main constraint that most of our implemented fractals have is the lack of a surface normal, as estimating this requires finite differences and multiple samples of the distance function. Because of this, we approached rendering in a non-photorealistic way through the use of approximations of shading related signals at the cost of quality and precision. This approach is then used to simulate fake subsurface scattering, rim lighting, or diffuse depending on the direction chosen (either towards a light or the camera). Additional implemented optimizations include fixed foveated rendering and vignetting.

6 CONCLUSIONS AND FUTURE WORK

Reprojection techniques are promising in the context of raymarched scenes with well-defined distance functions, particularly in virtual reality. Low frequency signals, such as ambient occlusion or post processes like bloom or volumetric scattering might be suitable for stereo reprojection with a small quality loss. In addition, current temporal reprojection techniques are generally used for anti-aliasing and sample gathering [Fuglsang and Pedersen 2016], but in the context of depth estimation with conemarching, these can give a lower bound on the intersection distance, thus accelerating the rendering. Hybrid approaches based on point clouds or uniform grids can also help prune long rays or edge cases.

We expect more SDF-based rendering approaches in VR applications in the near future. Creating virtual worlds based on mathematical formulas rather than hand-crafted content creates a truly endless open world to explore. Probing this multi-dimensional space for certain specific structures could be used as a source for procedural content creation, through fractal explorers like our application or even machine-learning sentinel entities designed to find interesting shapes and compositions.

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