Real-time Rendering of 3D “Fractal-like” Geometry

Deliverable 1: Final Year Dissertation

Solomon Baarda
SOLOMON BAARDA [Company address]

Abstract

Ray tracing getting popular, ray marching

I, Solomon Baarda confirm that this work submitted for assessment is my own and is expressed in my own words. Any uses made within it of the works of other authors in any form (e.g., ideas, equations, figures, text, tables, programs) are properly acknowledged at any point of their use. A list of the references employed is included.

Signed:

Date:

Table of Contents

Table of Figures

Table of Tables

Common Definitions

Table 1 – Common Definitions

Word	Definition
Frame	
Geometry	
Ray	
Render	

Common Abbreviations

Table 2 – Common Abbreviations

Word	Abbreviation
FPS	Frames per second
PC	Personal computer
SDF	Signed distance function

1 INTRODUCTION

https://github.com/SolomonBaarda/dissertation

1.1 AIMS & OBJECTIVES

The aim of this project is to develop a prototype real-time rendering engine, capable of displaying complex 3D “fractal-like” geometry. The performance of the engine will be benchmarked across various systems to determine whether the “real-time” aspect of the project has been achieved.

Want to create a rendering engine capable of rendering non-euclidian geometry

For which a ray-surface intersection function does not exist

There are lots of shader code to do this

Not many compiled applications though

Needs to be easily extendable to allow for custom scenes

Must have good performance to be realtime

Find a good balance between looking good and performance

Need approximations

1.2 PROJECT DESCRIPTION

The application will be benchmarked across several computers of varying spec to determine if the real-time requirement of the application has been achieved. For the scope of this project, real-time has been defined as a minimum of 60 frames per second (fps), as this is the industry standard for PC applications.

The benchmark scene has yet to be fully defined, but it must be non-trivial to render. This means it should contain multiple geometries (both fractal and primitive) and multiple lights while also making use of advanced rendering features like ambient occlusion, soft shadows, and reflections. The camera should move through the scene on a fixed path to view the geometries.

The benchmark scene should run for a fixed duration (so it takes the same amount of time on all machines), and the total frame count can be recorded and compared between systems. In addition, the minimum fps and maximum fps achieved should also be recorded and compared.

1.3 Scope

The scope of the project has been carefully considered, and several stretch goals have been included in the requirements specification if good progress is made. Some initial experiments with a prototype have been made (renders can be viewed on the GitHub repository) and good progress has been made.

A basic Mandel bulb

2 Literature Review

2.1 Realtime Rendering Methods

2.2 Ray Tracing

In computer graphics, ray tracing is a method of rendering an image of a scene, often with photorealistic detail. Rays of light are

by tracing the path of light and simulating the effects of its its effects on geometry [1].

method of rendering 3D environments and is often used for rendering scenes with photorealistic detail

In ray racing, a ray (simply a line in 3D space) is extended or traced forwards from the camera position until it collides with the surface of an object. From there, the ray can be absorbed or reflected by the surface, taking into consideration light absorption, reflection, refraction, and fluorescence.

n computer graphics, ray tracing is a rendering technique for generating an image by tracing the path of light as pixels in an image plane and simulating the effects of its encounters with virtual objects. The technique can produce a very high degree of visual realism, usually higher than that of typical scanline rendering methods, but at a higher computational cost.

Ray tracing is ideal for photorealistic graphics, as it takes into consideration many of the properties of light, but because of this it is computationally very expensive. Often, true ray tracers are not real-time, and they can take up to hours to render a single frame of video. To make a ray tracer capable of rendering in real-time, many approximations must be made when calculating the image. Hybrid approaches are often used.

One of the strengths (but also limitations) of ray tracing is that an accurate ray-surface intersection function must exist for every object in the scene. This is well suited for any Euclidian surfaces, such as primitives and meshes, which are made up of vertices, faces and edges, as points of intersection can be calculated relatively easily on these shapes.

This approach, however, is not suitable for any geometries for which a ray-surface intersection function does not exist [2], such as fractal geometries.

2.3 Ray Marching

Ray marching is a variation of ray tracing, which differs in the method of detecting collisions between the ray and objects. Instead of a using a ray-surface intersection function, ray marching uses an iterative approach, where the current point is moved/marched along the ray in small increments until it lands on the surface of an object. For each point on the ray that is sampled, a distance function is called which returns the distance to the closest object. The ray is then marched forward by that distance, and the process repeated. If the distance function returns 0 at any point, then then the ray has collided with the surface of the geometry.

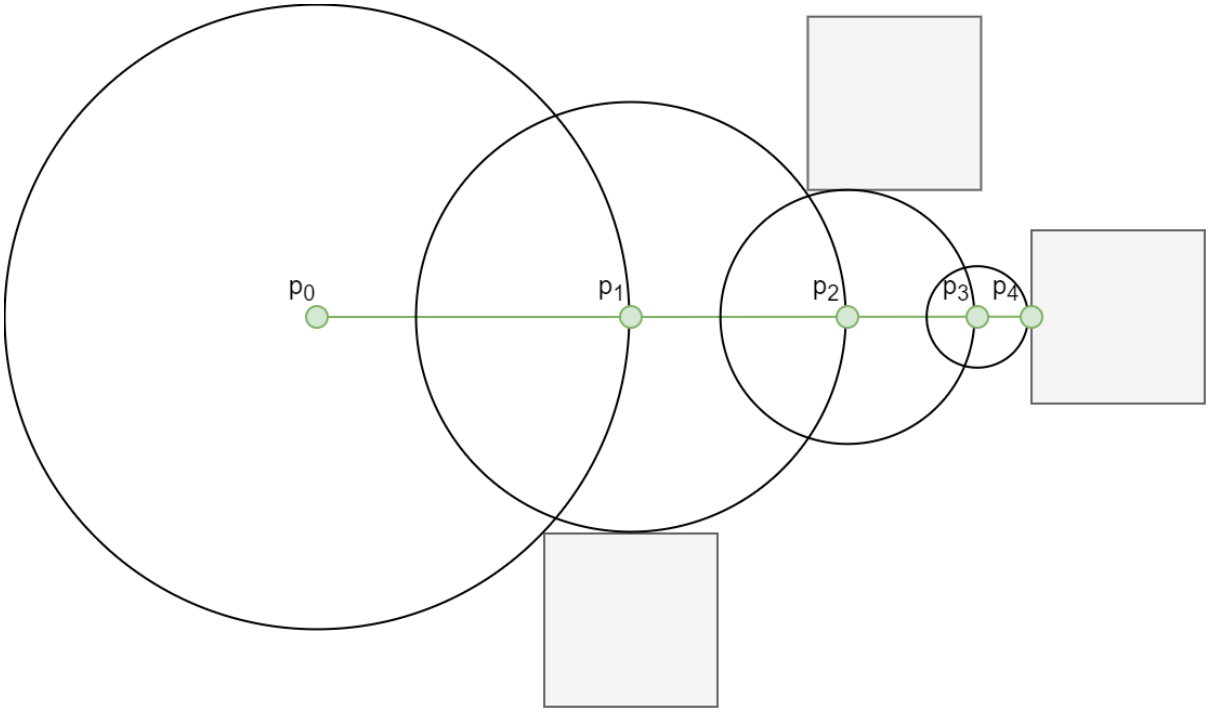


Figure 1 - Ray Marching

This approach may sound more computationally complex than tracing, however, it does provide several benefits. Most notably, ray marching does not require a surface collision function like ray tracing does, so it can be used to render geometry for which these functions do not exist. This allows more complex shapes to be rendered.

Ray marching also has infinite precision when zooming in, as no polygons are used.

2.3.1 Signed Distance Function

A distance function is a function which given any point in 3D space, will return the distance to the surface of the closest object. A signed distance function (SDF) is simply a distance function which contains a positive sign if the point is outside of the object, and a negative sign if the point is inside of the object. If a distance function returns 0 for any point, then the point must be exactly on the surface of an object.

DIAGRAM TODO

[3]

The sign returned by the distance function is very useful as it allows the ray marcher to determine if a camera ray is inside of an object or not, and from there it can use that information to render the objects differently.

In the scene below

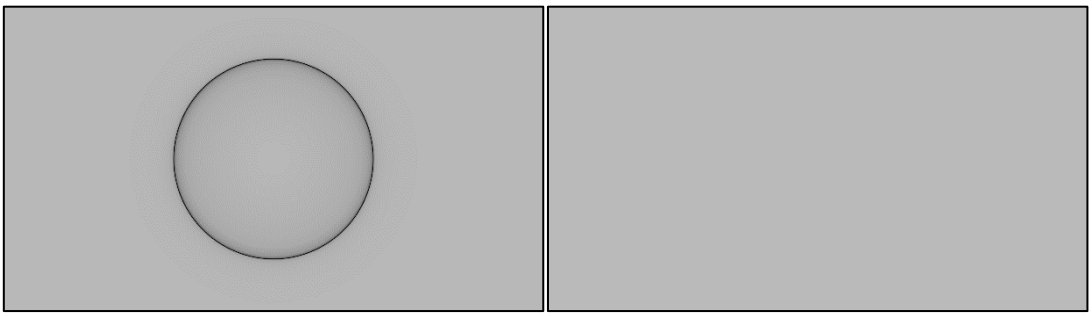


Figure 2 - DF and SDF

2.3.2 Primitives

Signed distance functions exist for most primitive 3D shapes, such as a sphere, box, plane etc.

For a sphere with radius R, positioned on the origin 0,0,0, the

$$sphereSDF(p) = |p| - R$$

$where\ p\ is\ a\ vector\ in\ the\ form\ \{x, y, z\}\ and\ R\ is\ the\ circle\ radius\ in\ world\ units$

Deriving an SDF

2.3.3 Alterations & Combinations

Signed distance functions can be translated, rotated, and scaled.

Signed distance functions can be combined using union, subtraction, and intersection operations.

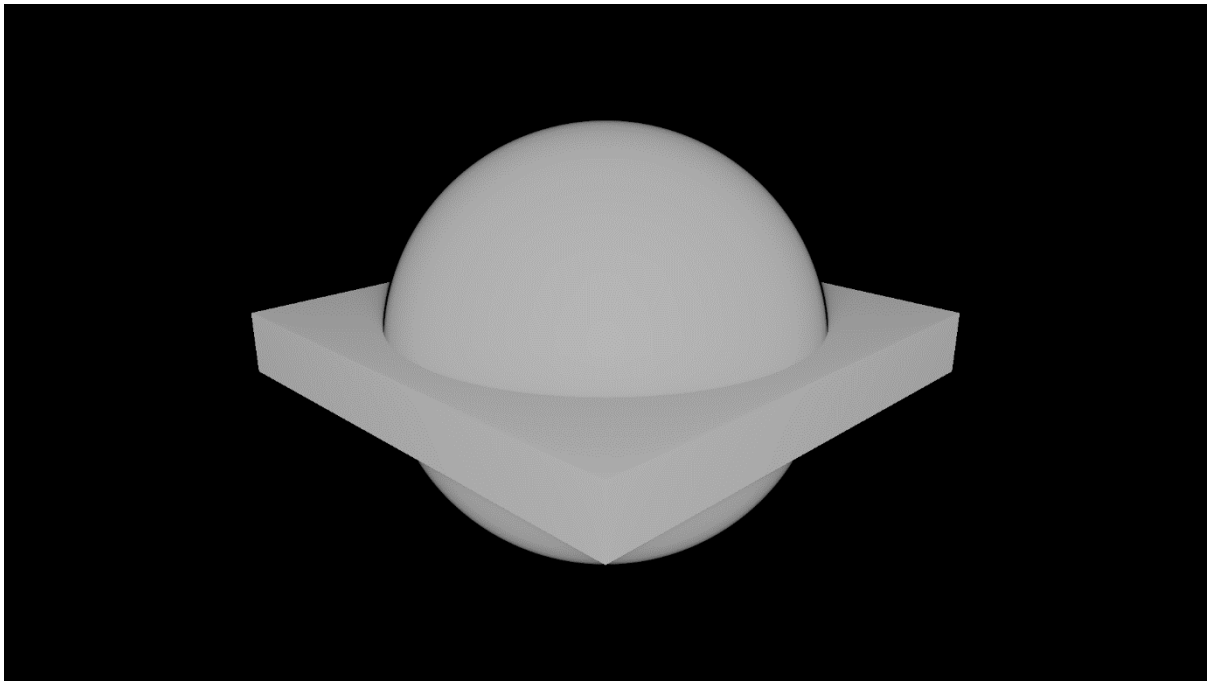


Figure 3 - Union of Sphere and Box

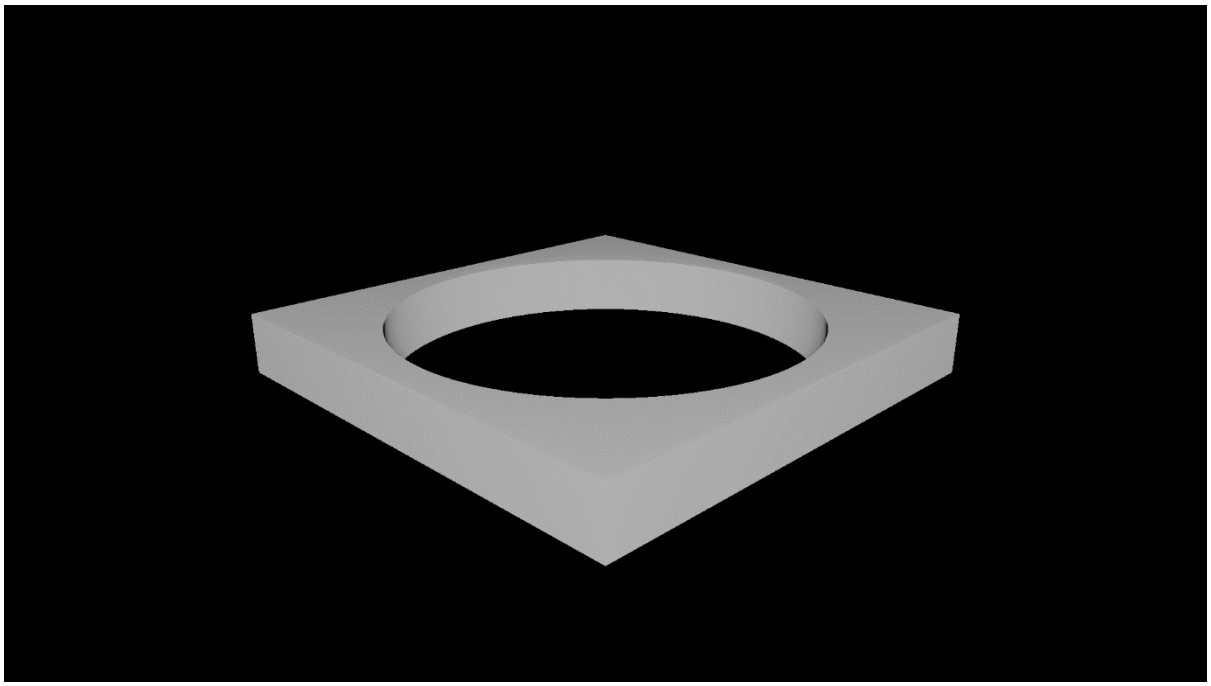


Figure 4 – Intersection of Sphere and Box

Signed distance functions can also be combined using a version that uses smoothing.

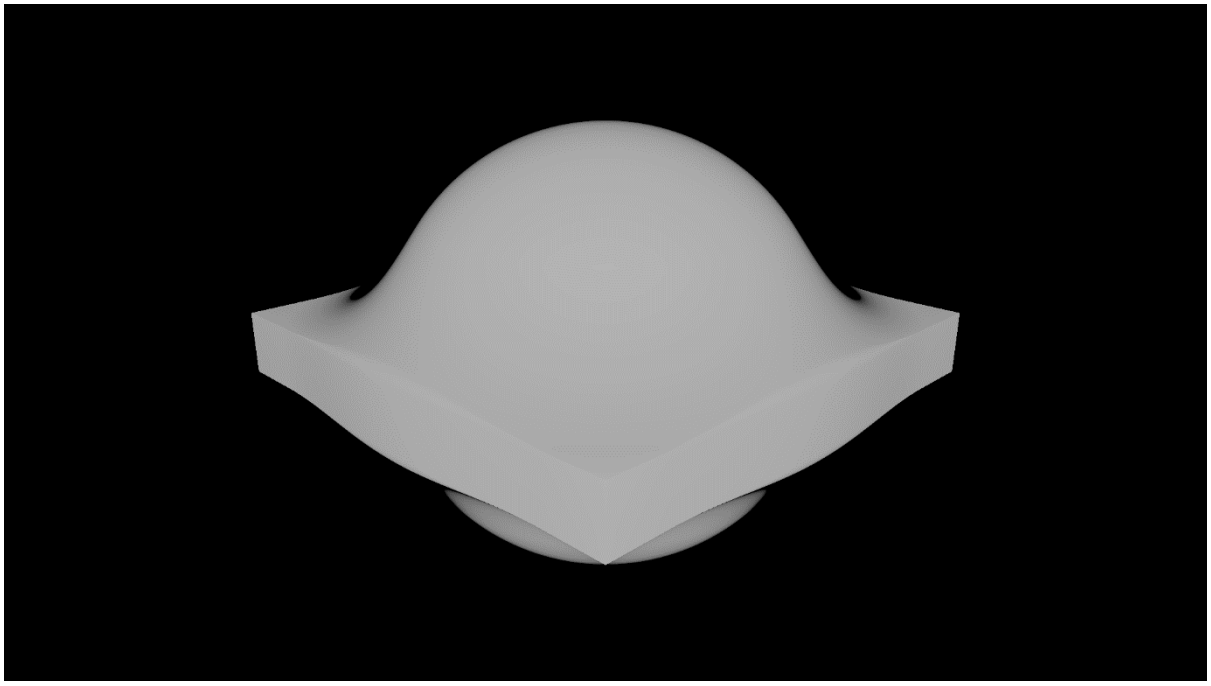


Figure 5 - Smooth Union of Sphere and Box

There are several alterations that can be applied to primitives once we have their signed distance function. A primitive can be elongated along any axis, its edges can be rounded, it can be extruded, and it can be "onioned" – a process of adding concentric layers to a shape. All these operations are very cheap.

Signed distance functions can also be repeated, twisted, bent, and surfaces displaced using an equation e.g., a noise function or sin wave.

2.3.4 Surface Normal

The surface normal of any point on the surface of an SDF can be determined by probing the SDF on each axis, using an arbitrary epsilon value.

$$\begin{aligned} normal = normalise(\{\, & SDF(p + \{e, 0,0\}) - SDF(p - \{e, 0,0\}), \\ & SDF(p + \{0, e, 0\}) - SDF(p - \{0, e, 0\}), \\ & SDF(p + \{0,0, e\}) - SDF(p - \{0,0, e\})\ \}) \end{aligned}$$

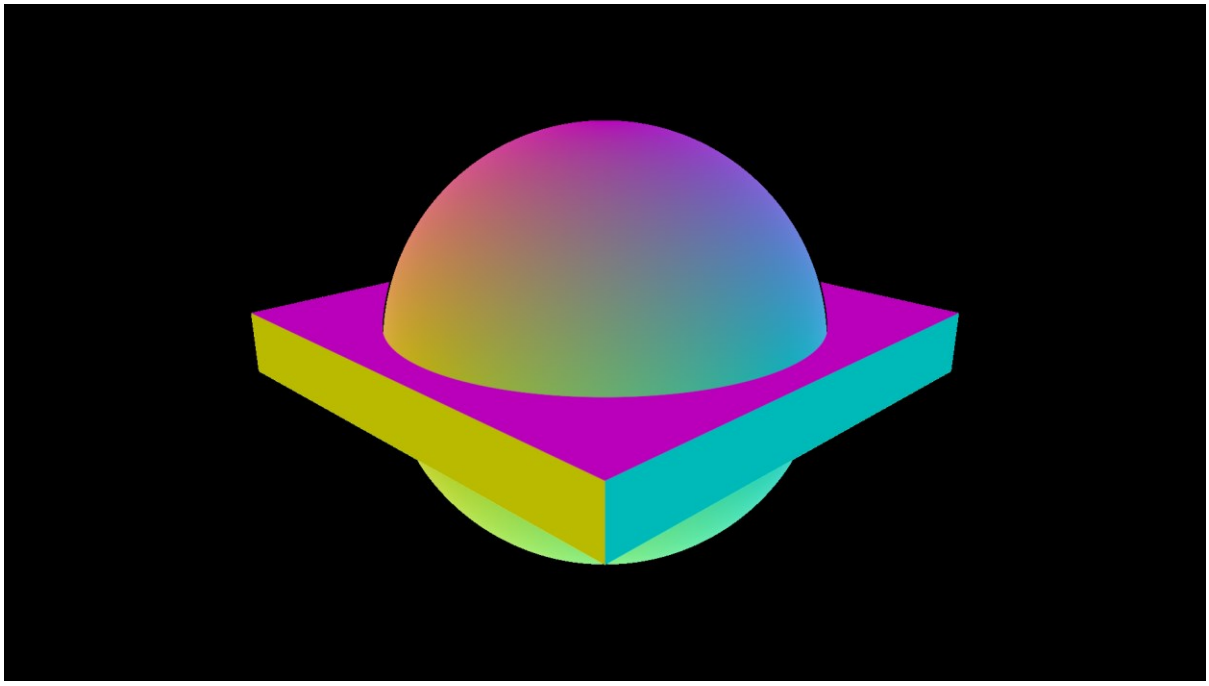


Figure 6 - Surface Normal of Sphere and Box Scene

2.3.5 Fractals

In mathematics, a fractal is a complicated pattern built from simple repeated shapes, which are reduced in size every time they are repeated [4]. These shapes are self-similar, though not often symmetrical.

The idea of fractal geometry appeared in the late 1970s, inspired through the work of Benua Mandelbrot and his book “Fractals: form, chance and dimension”, released 1977. This book introduced the concept of a “fractal dimension”, a measure of the complexity of how the detail in a pattern will change in respect to the scale at which it is measured [5].

How they are calculated – running sum etc

3D fractals

2.3.6 Collision detection

Collision detection is possible

Marble marcher

2.4 Existing Projects

2.4.1 Fragmentarium

https://github.com/Syntopia/Fragmentarium

https://github.com/3Dickulus/FragM

2.4.2 Smallpt

https://www.kevinbeason.com/smallpt/

2.4.3 Ray Tracing in One Weekend

https://github.com/RayTracing/raytracing.github.io

3 Requirements Analysis

3.1 Use Cases

3.2 Requirements Specification

Table 3 - Functional Requirement Specification

ID	Name	Description	Priority	Testing strategy
F-1	Real-time	The application must be capable of rendering scenes in real time	MUST	
F-2		The application must		
F-3				
F-4				
F-5				

Table 4 - Non-functional Requirement Specification

ID	Name	Description	Priority	Testing strategy
NF-1	Executable	The application must run from a compiled executable	MUST	
NF-2	Display resolutions	The application must support the following common display resolutions: 1366x768, 1920x1080, 2560x1440 and 3840x2160		
NF-3				
NF-4				
NF-5				
NF-6				

3.3 Testing Strategy

3.4 Evaluation Strategy

4 Software Design

4.1 Structure

4.2 Technologies

5 PROJECT PLAN

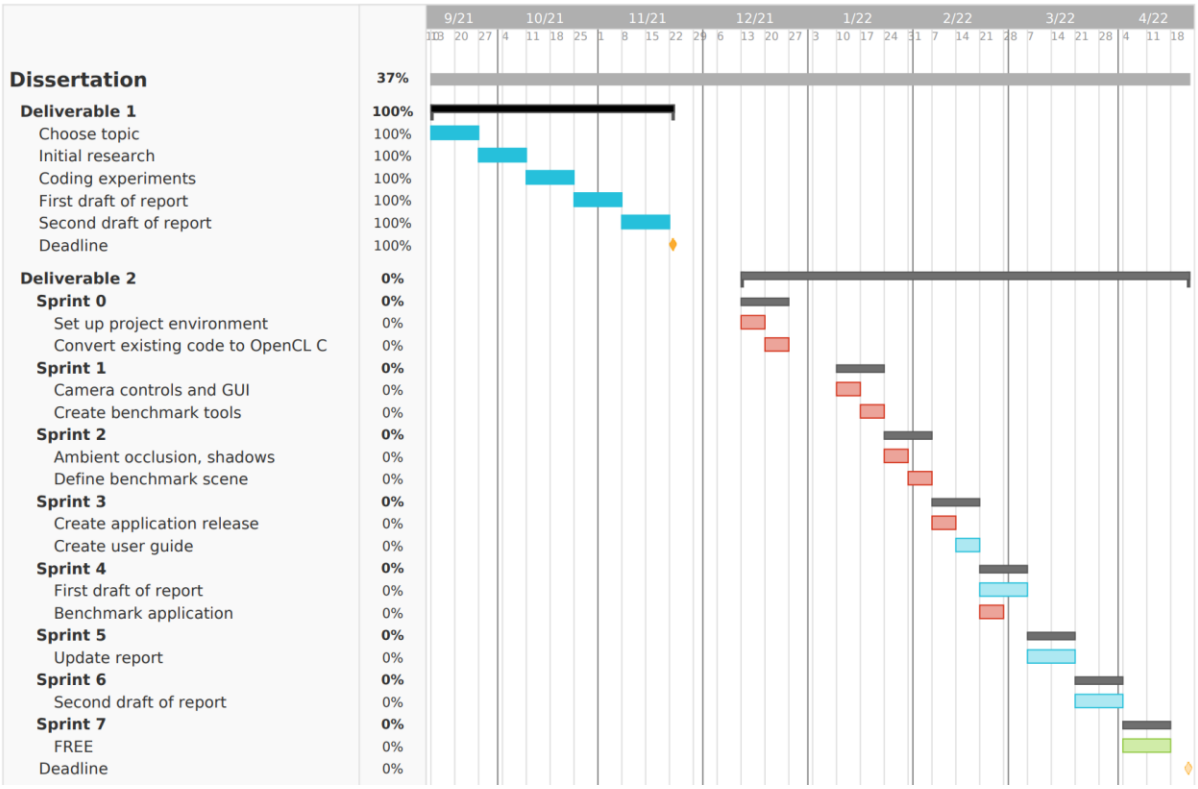
5.1 DESIGN METHODOLOGY

5.2 LEGAL, ETHICAL & SOCIAL ISSUES

A well-researched consideration of any Professional, Legal, Ethical, and Social Issues pertinent to the project. (e.g. codes of conduct (BCS), codes of practice, standards, computer law, ethical decision making, intellectual property, social aspects, copyright, data protection, and so on)

5.3 RISK ANALYSIS

5.4 TIMETABLE



6 REFERENCES

[1] J. Peddie, “Ray Tracing: A Tool for All,” 2019.

[2] V. da Silva, T. Novello, H. Lopes, and L. Velho, “Real-time rendering of complex fractals,” Feb. 2021, [Online]. Available: http://arxiv.org/abs/2102.01747

[3] Inigo Quilez, “distance functions,” 2013. https://www.iquilezles.org/www/articles/distfunctions/distfunctions.htm (accessed Oct. 28, 2021).

[4] Cambridge English Dictionary, “Cambridge English Dictionary.” https://dictionary.cambridge.org/dictionary/english/fractal (accessed Oct. 18, 2021).

[5] M. S. Longuet-Higgins, “Review of Fractals: Form, Chance and Dimension by Beniot B. Mandelbrot,” *Journal of Fluid Mechanics*, vol. 92, no. 1, pp. 206–208, May 1979, doi: 10.1017/s0022112079210586.

7 APPENDICES