Utilising ray marching and signed distance functions to render a scene of primitives

By Anthony Sturdy (18015368)

BSc (Hons) Computer Games Programming

Supervised by Dr. David White

May 2022

Table of Contents

[Glossary 1](#_Toc85636349)

[Key Words 1](#_Toc85636350)

[Abstract 2](#_Toc85636351)

[Introduction 2](#_Toc85636352)

[Aim 2](#_Toc85636353)

[Objectives 2](#_Toc85636354)

[Literature Review 3](#_Toc85636355)

[Research Methodology 3](#_Toc85636356)

[Project Plan 3](#_Toc85636357)

[Gantt Chart 3](#_Toc85636358)

[Scope 3](#_Toc85636359)

[Analysis 4](#_Toc85636360)

[Design 5](#_Toc85636361)

[Implementation 6](#_Toc85636362)

[Testing 7](#_Toc85636363)

[Results 7](#_Toc85636364)

[Critical Evaluation 8](#_Toc85636365)

[Bibliography 9](#_Toc85636366)

[Appendices 10](#_Toc85636367)

[Appendix 1: Gantt Chart 10](#_Toc85636368)

[Appendix 2: Title 10](#_Toc85636369)

# Glossary

* **SDF** – Signed Distance Function
* **CSG** – Constructive Solid Geometry
* **FOV** – Field of View

# Key Words

Real-time rendering, Visual effects, Graphics processing, Fractals, 3D, Lighting.

# Abstract

This research explores using ray marching as a method of rendering. Ray marching steps along a ray toward a specified direction, until an intersection is found. The distance of each step is determined by the shortest distance to any object in the scene. The signed distance function which each object uses, defines the shape of the object.

For each pixel on the screen, a direction can be determined by its position on the screen and the cameras FOV. Each object in the scene is sampled for its distance from the starting point and the shortest distance is used to determine how far the ray can be stepped without intersecting with any object. This step is repeated until the distance becomes less than a specified threshold, which is then considered to be an intersection.

This method of using a signed distance function to determine the shape of objects in the scene allows for many effects which are difficult to achieve using traditional rasterised rendering. For example, object smoothing/morphing, real-time CSG boolean operations, rendering fractals, and more. Ray marching is commonly used for rendering volumetric objects, such as clouds.

# Introduction

Recent advances in graphics processing hardware have brought ray tracing into the forefront of real-time rendering (Akenine-Möller et al., 2018). Ray tracing can be used to simulate how light travels which results in a higher fidelity render than traditional methods of rendering.

Whereas ray tracing tests for an intersection between a ray segment and objects in the scene in order to find the nearest intersection (Whitted & Foley, 1980), ray marching differs by stepping along a ray incrementally until an intersection is found.

A common ray marching technique is known as sphere tracing. Sphere tracing utilises signed distance functions (SDFs) to calculate the distance of each step along the ray. At each ray step, all objects are sampled for their distance to the current point, the ray can then be stepped forward by the shortest distance which ensures the ray will not travel inside, nor skip over, any object in the scene (Hart, 1996). Due to the type of SDF defining the shape of that object, it is possible to render fractals or modify the output distance to manipulate the shape or appearance of the object.

## Aim

This research aims to explore the areas needed to produce a game engine which utilises ray marching as a method of rendering a 3D scene, and to take advantage of the characteristics of ray marching to achieve various visual effects.

## Objectives

To achieve this aim, the research will enable the development of:

* A performant, real-time ray marching renderer.
* An engine framework surrounding the renderer, providing a platform to produce games/real-time applications.
* GUI controls to interact with the engine and scene at runtime.
* A 3D modelling tool which allows for primitives to be combined and visual effects to be applied in order to output a detailed model, which can then be imported to the engine.

# Literature Review

The definition of ray marching is to step along a ray in a specified direction until an intersection has been found. The naïve approach to implement this would be to step along the ray linearly using a fixed step size (Biagioli, 2016), this algorithm is simple but introduces potential problems. The accuracy of this algorithm is tied to the step size – a shorter step is more accurate, but computationally more expensive – which means a perfectly accurate step size is unachievable. See Appendices 1 and 1.5 for visual representations of the potential problems with a linear step size.

An improved algorithm is to ray march across distance fields, where the step size at each increment is determined by the shortest distance from the current position to any object in the scene. As the ray approaches a surface, the distance travelled becomes increasingly shorter (Hart et al., 1989), when the distance becomes lower than a specified threshold, the ray is considered to have intersected with the geometry. This method provides increased accuracy as it is impossible for the ray to pass inside, or through, any geometry. This method is referred to as sphere tracing. See appendix 2 for a visual representation of sphere tracing.

Ray marching is commonly used for rendering volumetric objects, such as clouds.

# Research Methodology

A description of the choice of investigation method and review of the available literature. This will be waterfall, agile, hybrid, etc.

# Project Plan

The project planning process (actual plan should be placed in an appendix), scope with a statement of the evaluation criteria and how the project will proceed. Reflect upon your Aim and Objectives.

## Gantt Chart

See appendix 1: Gantt Chart *(for example)*

## Scope

Is the project achievable?

# Analysis

A description of the choice of an analysis or problem-solving method. It is important to describe the process by which the method is chosen to show that it is appropriate for the problem situation.

A narrative description of the application of the analysis method, indicating the problems which arose during this process and how they were identified and overcome. Obviously, most projects will include models, charts, or diagrams at this stage. These may be included in the chapter or in an appendix.

In short, investigate all possible options available to you in order to successfully achieve the scope of the project in the time given.

# Design

Here you will justify your chosen tools and processes from your previous research into the background of the project and the options available to you in the analysis.

Identify and justify:

* The choice of an appropriate method.
* Your experience of its application.

# Implementation

The Implementation chapter should show clearly how the solution to the problem is realised. As with the other parts of the project, the selection of the implementation method should be described and justified. Also, the nature of the solution will depend on the nature of the project and the course.

# Testing

This chapter should address the evaluation of the solution against its objectives and success criteria.

Consider:

* A description of the testing strategy and the choice of testing method.
* The planning and application of the tests. How have you concluded this is the correct type of test to run?

# Results

The conclusions that may be drawn from the results of the tests and any modifications to the design and implementation that could be recommended.

What are you results?

What analysis can you identify from them?

Did you find something you did not expect?

Or was it exactly what you expected?

# Critical Evaluation

This chapter is of **crucial importance** to the whole work. It deals with the success of the project in academic terms, rather than the success criteria for the solution. Even the best analysis, design and implementation will be let down by an inadequate critical evaluation. The examiners will look at this chapter most carefully when determining the success (or otherwise) of the project. Although the exact nature of the evaluation will vary between projects, it is possible to identify certain issues which should be addressed:

* Your evaluation of the degree of success in carrying out the project
* What you have learned by doing the project
* What you would do differently if the project were to be repeated
* Any extra features you would recommend if the project could be extended
* The value to you of the learning process and the extent to which the project has added to your professional and academic expertise
* What future projects open the next chapter, should this projects research be continued further into Master Degree for example?

# Bibliography

Akenine-Möller, T., Haines, E., Hoffman, N., Pesce, A., Hillaire, S. & Iwanicki, M. (2018). *Real-Time Rendering*. 4th Ed. [Online]. A K Peters/CRC Press. Available from: https://www.realtimerendering.com/Real-Time\_Rendering\_4th-Real-Time\_Ray\_Tracing.pdf. [Accessed: 25 October 2021].

Biagioli, A. (2016). *Raymarching Distance Fields: Concepts and Implementation in Unity*. [Online]. 1 October 2016. Available from: https://adrianb.io/2016/10/01/raymarching.html. [Accessed: 30 October 2021].

Hart, J.C. (1996). Sphere tracing: a geometric method for the antialiased ray tracing of implicit surfaces. *The Visual Computer*. [Online]. 12 (10). Available from: https://www.researchgate.net/publication/2792108\_Sphere\_Tracing\_A\_Geometric\_Method\_for\_the\_Antialiased\_Ray\_Tracing\_of\_Implicit\_Surfaces. [Accessed: 26 October 2021].

Hart, J.C., Sandin, D.J. & Kauffman, L.H. (1989). Ray tracing deterministic 3-D fractals. *ACM SIGGRAPH Computer Graphics*. [Online]. 23 (3). Available from: https://www.cs.drexel.edu/~david/Classes/Papers/rtqjs.pdf. [Accessed: 30 October 2021].

Whitted, T. & Foley, J.D. (1980). An Improved Illumination Model for Shaded Display. *Graphics and Image Processing*. [Online]. 23. p.pp. 343–349. Available from: https://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.156.1534. [Accessed: 26 October 2021].

# Appendices

## Appendix 1: Ray marching linear step size, problem one

Intersection is found inside the geometry.

## Appendix 1.5: Ray marching linear step size, problem two

Ray misses narrow geometry.

## Appendix 2: Sphere tracing algorithm visualised

­