**A Prehistoric Scene of Mars in WebGL**

Final Report for CS39440 Major Project

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**Declaration of originality**

I confirm that:

* This submission is my own work, except where clearly indicated.
* I understand that there are severe penalties for Unacceptable Academic Practice, which can lead to loss of marks or even the withholding of a degree.
* I have read the regulations on Unacceptable Academic Practice from the University’s Academic Quality and Records Office (AQRO) and the relevant sections of the current Student Handbook of the Department of Computer Science.
* In submitting this work I understand and agree to abide by the University’s regulations governing these issues.

Name: Samuel Snowball

Date: 19/04/2017

**Consent to share this work**

By including my name below, I hereby agree to this dissertation being made available to other students and academic staff of the Aberystwyth Computer Science Department.

Name: Samuel Snowball

Date: 19/04/2017

**Acknowledgements**

I am grateful to…

I’d like to thank…

The khronus group, Mozilla and chrome team for webgl,

Gregg Tavares - Gman on stackoverflow/github and for: <https://webglfundamentals.org/>

Also for: <https://github.com/greggman/webglfundamentals/blob/master/webgl/resources/m4.js>

My supervisor for q & a

**Abstract**

A prehistoric scene of Mars created in WebGL (Web Graphics Library), GLSL (OpenGL Shading Language) and JavaScript. The scene allows users to roam around and explore Mars as it existed in its Noachian period, around 4 billion years ago. The project uses some features of WebGL (2.0) which are only available in Chrome and Firefox. You can check if your browser can run the project here:

http://webglreport.com/?v=2

The original aim of this project was to create an interactive Mars mission control game, where the user would roam around Mars as a rover completing various tasks. The project direction changed after the mid project demonstration, it became clear I did not enjoy creating the game aspects, so decided to just focus on the graphics instead.

My motivation for the project was to learn how computer graphics work. At the start of this project I had next to no experience with GLSL and no experience with WebGL. Learning these new languages whilst going along was challenging, however my desire to learn outweighed the problems I encountered.

Programming in WebGL will help me gain an understanding of what’s actually going on at the low level, to get graphics to display on the screen. Learning WebGL is useful due to its flexibility running on various different operating systems, rather than an alternative like Direct3D, which only runs on Windows.

I haven’t been able to find a similar project built like this before. This is mainly due to it being in 3D and the low level languages used.

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# Background, Analysis & Process

## Background

3D graphics had always fascinated me, how could you display 3D objects on a 2D screen? I had some experience with game engines and libraries but I never found enjoyment in using them. These tools covered up the details of how the scene was actually being displayed, which was the main thing I always wanted to learn. I wanted to dive deeper than just dragging objects into a premade 3D scene, adding textures and then hitting play.

The original project involved making a game. Making games was something I had some experience in so I was immediately drawn to it. I had just finished the Advanced Computer Graphics module. This helped me gain knowledge which proved essential to complete the project.

In the mid project demonstration, I realized I did not enjoy creating the game aspects of the project. There were 2 different things I was working on: the game code written in JavaScript and the graphics code in WebGL. Since the graphics were what I was interested in, writing thousands of JavaScript lines to create a game was not interesting. The games aspects also took so long to write and because of this, the graphics of the game suffered. Mid-way through the project I decided to strip out all the game aspects and just focus on the graphics.

I was interested in low level graphics before the project came out and gained some experience in OpenGL (Open Graphics Library) over Christmas. I knew regardless of if I got this project, developing with low level graphics was a skill I wanted to have. Luckily I got assigned this project, and with my head start in graphics programming I was confident to begin.

The only project related to Mars I could find was from NASA, who had developed a Mars rover game. Unfortunately there wasn’t anything I could learn from this as it had obviously built in a rush, being 2D and lacking game playability.

I knew I had a variety of options to develop the scene. Game engines, libraries and raw graphics libraries where all available to me. I knew I wanted to develop the project in a low level library. I had used games before, but they covered the complex details of how the graphics actually get rendered

Using game engines like Unity or Unreal for the project would have created a very realistic looking scene. They were designed to make creating games as fast and as painless as possible. Most engines will handle: user input, sound, rendering, memory management and many more features for you. Most often, engines have sub-engines which will handle complex physics and collision detection. Having all of these pre-built features allows the user to simply focus on building their game, rather than the engine behind it.

Engines are powerful, if you know how to use them. They require lots of time to be able to use them effectively. It might take too long to complete the project after learning how to use an engine. They require lots of memory, long installation times and are very computationally expensive. As this was a relatively small project, rather than an AAA sized game, the overhead of using an engine was not worth it. With a game engine there is also less flexibility, you can’t fix bugs or render more efficiently (unless it’s open source).

Game engines have their place, and you would rarely write a game in the industry without one. However for learning purposes, developing at a lower level is the best way to go.

Realistically, I could have used a mid-weight game library like three.js. This is a 3D JavaScript library for rendering graphics within a browser, it uses WebGL at its back end. But with using this I would not have gained an understanding of how graphics work, as it’s done for you behind the scenes. Since I was already familiar with the library, I also would have not learnt much whilst building the project.

A lower level option was Direct3D, which is an API built to render graphics on Windows machines. If you want to create a game with Direct3D for multiple platforms, you can’t. Still, most games are written in Direct3D due to its solid Microsoft framework and developer toolsets. It can make use of the other DirectX libraries (DirectSound) for a more engine-like feel. Since I had no experience with Direct3D, and since there were more flexible options out there, I saw no reason to use it for this project.

Vulkan is another API for rendering graphics. It is new and much lower level than OpenGL, meaning it will run more efficiently on the hardware. It has a much cleaner API than OpenGL, which has had things thrown on top of it ever since its introduction in 1992.

Vulkan in general has a much cleaner, newer API than OpenGL, which is one of OpenGLs downfalls. The old legacy code can be a nightmare for some developers.

A flexible alternative is OpenGL, which is a C API for accessing the devices graphics hardware. Unlike Direct3D, OpenGL can run on various different operating systems such as: Windows, MacOSX, Linux and Unix. This means OpenGL applications are highly portable. This is the biggest reason why OpenGL is the most widely used and supported choice for graphical applications. Not only that but as OpenGL has been around for 20 or so years it has stable releases.

I had some experience using OpenGL, but if I chose this it would have meant I had to use a base language of C++. I had heard of an alternative called WebGL, but had no experience using it. After researching into WebGL more, I realized this would be a better fit. WebGL is a JavaScript API for rendering graphics within a browser. This means I would be programming the base code in JavaScript, which I was confident with, rather than the base code in C++ using OpenGL. I knew I would struggle with the graphics aspect alone and if I were to also struggle with the base language, then the project would be a disaster. The standard APIs like OpenGL and Direct3D would have been perfect if I was confident in C++ however in the end, the benefits of the APIs did not matter as I couldn’t use C++ efficiently.

Hence the final languages I decided to use where: WebGL, GLSL and JavaScript.

WebGL is based on OpenGL ES 2.0 (an old version of OpenGL for Embedded Systems). This means it lacks many features of the modern graphics libraries such as OpenGL or Direct3D. These other graphics APIs are much better documented and have more learning resources than WebGL, as they have existed longer.

Modern OpenGL can use a GLSL version of up to 4.40. However the more up to date GLSL version used, the more is required from the hardware. This means if a program is using GLSL version 4.40, it will not be supported on as many devices as an older version. As WebGL uses GLSL ES version 1.00, it is supported on the vast majority of hardware. WebGL (1.0) was essentially built to run anywhere. It will run on mobile, tablets, IOS, Android, Chrome, Firefox, Edge and Safari. All of this happens with no plugins or installation.

WebGL requires up to date hardware and graphics drivers. As WebGL runs within a browser, an update to date version of the browser is required. But still, having an update to date browser might not be enough. As WebGL itself is just a specification (not an actual implementation) it is up to browser companies to implement WebGL themselves. Some browsers such as Internet Explorer, Edge and Safari all lack up to date implementations of WebGL (2.0). For this reason, my project only runs in Chrome and Firefox.

WebGL uses something called the programmable graphics pipeline, as opposed to the old fixed function pipeline. This newer pipeline was implemented into versions of OpenGL after 2.0. Hence the new pipeline is in WebGL, as it uses OpenGL ES 2.0.

This pipeline is just the series of steps needed to take some data and display it on the screen. //explain it + then link huge overview

In the old pipeline it was very one size fits all. There was no functionality for doing any custom calculations (lighting/fog), only what was built in. You could opt in for the features that you wanted, for example the pipeline should calculate fog, or you could opt out and not use them. However there was no functionality allowing you to customize the operations, just ones to enable or disable them.

But now, using the new pipeline, it allows you to write programs called shaders which replace parts of the graphics pipeline. Shaders are programs executed on the graphics card, which are written in using a language called GLSL. This is a C style language which allows you to specify how your data should be manipulated on the graphics card.

These shaders allow programmers to manipulate the data how they want, giving you much more power over what gets rendered. The disadvantage of these shaders is that they add complexity to application, as you now have to manage some stages of the graphics pipeline yourself. For simple applications which aren’t going to do any fancy graphics, then an older version of OpenGL (pre 2.0) would better suit your needs, as it uses the fixed function pipeline.

To start learning OpenGL I used:

<https://www.youtube.com/watch?v=6c1QYZAEP2M&list=PLRwVmtr-pp06qT6ckboaOhnm9FxmzHpbY>

<http://www.opengl-tutorial.org/>

https://learnopengl.com/

To start learning WebGL I used:

<https://webglfundamentals.org/>

## Analysis

Taking into account the problem and what you learned from the background work, what was your analysis of the problem? How did your analysis help to decompose the problem into the main tasks that you would undertake? Were there alternative approaches? Why did you choose one approach compared to the alternatives?

There should be a clear statement of the objectives of the work, which you will evaluate at the end of the work.

In most cases, the agreed objectives or requirements will be the result of a compromise between what would ideally have been produced and what was felt to be possible in the time available. A discussion of the process of arriving at the final list is usually appropriate.

As mentioned in the lectures, think about possible security issues for the project topic. Whilst these might not be relevant for all projects, do consider if there are relevant for your project. Where there are relevant security issues, discuss how they will this affect the work that you are doing. Carry forward this discussion into relevant areas for design, implementation and testing.

All WebGL allows you to do is draw triangles on the screen. Apart from that, it’s up to you as to what you do with it. There’s no premade 3D scene where you can drag and drop objects with nice textures and lighting, it is extremely lightweight and from scratch.

A basic WebGL scene has no: physics, event handling, sound, helpful error messages, loading/saving or fast rendering efficiency features. However for me, these are not disadvantages. Instead, these are rewarding tasks that I can implement and by implementing them, I will learn how they work. This completes the one of the main goals of the project, learning how 3D graphics works.

I will mainly research features as I need to build them, so the research process is likely to go on throughout the project. Researching lots at the beginning wouldn’t be very useful as I might not be able to apply the information straight away, as other features are needed first. Working software early is also a priority.

Some general information about the project and game mechanics:

* Focus on first person, perhaps adding in third person later on. A first person view will feel more interactive
* User will interact via keyboard and mouse
* I will need to test and cater for multiple browsers

Tasks (in loose priority order, highest priority first):

* Build terrain, currently using perlin noise - would be cool to build from existing height maps. However with perlin noise I get flexibility of what I want. Adding collision to existing terrain that I haven’t generated would be difficult. This terrain building process would probably be ongoing, as I add new areas and such throughout the project.
* Allow user to move around terrain, camera class needed
* Add collision with terrain, rather than flying over it. Possibly connect terrain vertices with quad strip for more realistic collision, rather than existing triangle strip
* Give terrain texture, procedurally generated perhaps
* Add in rocks. I’ve found a procedural rock generation library I could use to generate awesome rocks. However I would rather try implement rocks myself. I could use a sphere geometry and use perlin noise on the vertices to give a bumpy geometry.
* Start work on GUI’s, with a possible (not necessary) minimap, and other GUI’s showing the rovers stats and location (perhaps just their coordinates). Commands from mission control would get sent here, the user would then complete them. Example: go to the X,Y,Z quadrant, find and sample X rock.
* Add in various missions for the player to complete, perhaps adding in levelling mechanics. For example once the player has completed x number of missions he can access new areas.
* Add audio
* Add clouds
* Add sunlight, shadows – I’m unsure how to do lighting in WebGL so would require a lot of research, perhaps taking up a whole sprint. Or it might not be feasible to do this at all., just an idea.
* Add initial loading scene, rover jetpacks into the landing site, terrain comes towards player. This wouldn’t take long.
* Add water, I imagine this would take a whole sprint in itself but it’s something that would be good to add, from a technical and graphical side. I would have to use various tutorials and resources to be able to do this.

I expect many more features will get added to this in future, the main focus of this list was to get the main mechanics down.

Project deliverables

* Terrain generation
* User navigating terrain
* User collision with terrain
* Textured terrain/added in rocks
* Some GUI’s and the user receiving and completing missions
* Then after this, probably random extra features like clouds and audio

Analysis:

Analysis of the problem, it was pretty much up to me. So originally I knew I needed a 3D scene to move around in, then it was just about adding in features, terrain and rocks mainly.

Looking at images of Mars,

Finding libraries to help with matrix math + tutorials, books, papers

As I wanted to do it in a low level library, this ruled out all game engines etc

Mentions the main task, so talk about product backlog

Talk about security and how it doesn’t matter

// copy initial task list from outline spec

## Process

You need to describe briefly the life cycle model or research method that you used. You do not need to write about all of the different process models that you are aware of. Focus on the process model that you have used. It is possible that you needed to adapt an existing process model to suit your project; clearly identify what you used and how you adapted it for your needs.

Used scrum because:

Had good understanding of it through the agile module

little experience with language, allows to focus on important tasks first, docuemtation can wait until I have something to document, heavily reducing risk of not delivering – if I was really struggling I could just decide to use a library I was familiar with

Scrum very adaptable, even halfway through the project I could easily change direction

Pirortize to-do list into tasks, product backlog, sprint backlog

Sprint plan, retrospective,

Throughout the project constantly learning and implementing

-it wasn’t even possible to do a big up front design, as I had no idea what I was doing

Responding to change important, learn technique, go implement it

Week long sprints, sprint plan, daily plan, release after each version

Git version control

Link the github somewhere?

# Design

You should concentrate on the more important aspects of the design. It is essential that an overview is presented before going into detail. As well as describing the design adopted it must also explain what other designs were considered and why they were rejected.

The design should describe what you expected to do, and might also explain areas that you had to revise after some investigation.

Typically, for an object-oriented design, the discussion will focus on the choice of objects and classes and the allocation of methods to classes. The use made of reusable components should be described and their source referenced. Particularly important decisions concerning data structures usually affect the architecture of a system and so should be described here.

How much material you include on detailed design and implementation will depend very much on the nature of the project. It should not be padded out. Think about the significant aspects of your system. For example, describe the design of the user interface if it is a critical aspect of your system, or provide detail about methods and data structures that are not trivial. Do not spend time on long lists of trivial items and repetitive descriptions. If in doubt about what is appropriate, speak to your supervisor.

You should also identify any support tools that you used. You should discuss your choice of implementation tools - programming language, compilers, database management system, program development environment, etc.

Some example sub-sections may be as follows, but the specific sections are for you to define.

// UI screenshots, standard setup() and render()

// Worked out main components, terrain, rockGenerator,

// thinking about terrain, existing heightmaps over perlin noise, just loading an obj no skill

//show how the design evolved over the project?

## Overall Architecture

// flow diagram

## Detailed Design

// class diagram

### Even More Detail

## User Interface Design

// show screenshots

## Other Relevant Sections

# Implementation

The implementation should look at any issues you encountered as you tried to implement your design. During the work, you might have found that elements of your design were unnecessary or overly complex; perhaps third party libraries were available that simplified some of the functions that you intended to implement. If things were easier in some areas, then how did you adapt your project to take account of your findings?

It is more likely that things were more complex than you first thought. In particular, were there any problems or difficulties that you found during implementation that you had to address? Did such problems simply delay you or were they more significant?

You can conclude this section by reviewing the end of the implementation stage against the planned requirements.

// explain graphics pipeline, and shaders, vert/frag

Graphics pipeline

-how to get some data to appear on the screen

-example data, triangle coordinates

3d description of world, turn it into a 2d image

Moving from, easy to think about it, have a model, put into the world, view from a camera, display on screen.

model to world, world to view, view to projection

model has own origin at centre, own coordinate system, origin of triangle

scaling, rotating, translating, its now in world coordinate space (T,R,S)

clipping happens in worldsapce, removing a piece of somethiong from pipeline, we cant see it, clip a triangle loses a vertex, how do drw it with 2 points? Need to create new points along the edge, and split it into separate triangles

culling excludes entire object

WORLD SPACE above (2nd stage)

We define camera in the world, it has a position

Now world to view, need to shift entire world infront of camera, which doesn’t exist, program as if it does, easy to think about

Camera space, everything relative to camera, camera is at 0,0

View to projection

Geometry in screen space, map traingles to screen pixels, rasterization

Generates fragments

Process fragments,

Build image, replacing fragments

Depth buffer, stores depth per pixel

Specifify colour information for every vertex, rather than every fragment. Colour doesn’t vary much across object, blending with interpolation will look ok. Calculating at every fragment, not worth it

// need to create a context to be able to talk to webgl, and get it tointeract with the hardware

// Show initial screenshot, in 1st week,

// quickyl

# Testing

Detailed descriptions of every test case are definitely not what is required here. What is important is to show that you adopted a sensible strategy that was, in principle, capable of testing the system adequately even if you did not have the time to test the system fully.

Provide information in the body of your report and the appendix to explain the testing that has been performed. How does this testing address the requirements and design for the project?

How comprehensive is the testing within the constraints of the project? Are you testing the normal working behaviour? Are you testing the exceptional behaviour, e.g. error conditions? Are you testing security issues if they are relevant for your project?

Have you tested your system on “real users”? For example, if your system is supposed to solve a problem for a business, then it would be appropriate to present your approach to involve the users in the testing process and to record the results that you obtained. Depending on the level of detail, it is likely that you would put any detailed results in an appendix.

The following sections indicate some areas you might include. Other sections may be more appropriate to your project.

## Overall Approach to Testing

// use testing document for this

## Automated Testing

### Unit Tests

// in code

### User Interface Testing

// show screenshots

### Stress Testing

// show high rock count, big terrain size,

// load times

// memory

### Other Types of Testing

// acceptance testing for UI

## Integration Testing

// rendering components in order, terrain to generate rock render indices

## User Testing

// get people to test it? What they liked or didnt

# Critical Evaluation

Examiners expect to find in your dissertation a section addressing such questions as:

* Were the requirements correctly identified?
* Were the design decisions correct?
* Could a more suitable set of tools have been chosen?
* How well did the software meet the needs of those who were expecting to use it?
* How well were any other project aims achieved?
* If you were starting again, what would you do differently?

Other questions can be addressed as appropriate for a project.

Such material is regarded as an important part of the dissertation; it should demonstrate that you are capable not only of carrying out a piece of work but also of thinking critically about how you did it and how you might have done it better. This is seen as an important part of an honours degree.

There will be good things and room for improvement with any project. As you write this section, identify and discuss the parts of the work that went well and also consider ways in which the work could be improved.

In the latter stages of the module, we will discuss the evaluation. That will probably be around week 9, although that differs each year.

// look into some debugging ide, or use directX for useful tools

// horrible amounts of time starting at unhelpful webgl errors, offscreen erros in attriubte 0

// Midway through the project I realized Webgl not properly documented, few tutorials for advanced features, no tools to help debug

# Appendices

The appendices are for additional content that is useful to support the discussion in the report. It is material that is not necessarily needed in the body of the report, but its inclusion in the appendices makes it easy to access.

For example, if you have developed a Design Specification document as part of a plan-driven approach for the project, then it would be appropriate to include that document as an appendix. In the body of your report you would highlight the most interesting aspects of the design, referring your reader to the full specification for further detail.

If you have taken an agile approach to developing the project, then you may be less likely to have developed a full requirements specification. Perhaps you use stories to keep track of the functionality and the ’future conversations’. It might not be relevant to include all of those in the body of your report. Instead, you might include those in an appendix.

There is a balance to be struck between what is relevant to include in the body of your report and whether additional supporting evidence is appropriate in the appendices. Speak to your supervisor or the module coordinator if you have questions about this.

* 1. Third-Party Code and Libraries

If you have made use of any third party code or software libraries, i.e. any code that you have not designed and written yourself, then you must include this appendix.

As has been said in lectures, it is acceptable and likely that you will make use of third-party code and software libraries. If third party code or libraries are used, your work will build on that to produce notable new work. The key requirement is that we understand what is your original work and what work is based on that of other people.

Therefore, you need to clearly state what you have used and where the original material can be found. Also, if you have made any changes to the original versions, you must explain what you have changed.

As an example, you might include a definition such as:

**Apache POI library** – The project has been used to read and write Microsoft Excel files (XLS) as part of the interaction with the client’s existing system for processing data. Version 3.10-FINAL was used. The library is open source and it is available from the Apache Software Foundation [5]. The library is released using the Apache License [6]. This library was used without modification.

* 1. Ethics Submission

This appendix includes a copy of the ethics submission for the project. After you have completed your Ethics submission, you will receive a PDF with a summary of the comments. That document should be embedded in this report, either as images, an embedded PDF or as copied text. The content should also include the Ethics Application Number that you receive.

* 1. Code Samples

This is an example appendix. Include as many appendices as you need. The appendices do not count towards the overall word count for the report.

For some projects, it might be relevant to include some code extracts in an appendix. You are not expected to put all of your code here - the correct place for all of your code is in the technical submission that is made in addition to the Final Report. However, if there are some notable aspects of the code that you discuss, including that in an appendix might be useful to make it easier for your readers to access.

As a general guide, if you are discussing short extracts of code then you are advised to include such code in the body of the report. If there is a longer extract that is relevant, then you might include it as shown in the following section.

Only include code in the appendix if that code is discussed and referred to in the body of the report.

Random Number Generator

The Bayes Durham Shuffle ensures that the pseudo random numbers used in the simulation are further shuffled, ensuring minimal correlation between subsequent random outputs.

// Some example code here…

# Annotated Bibliography

This final section should list all relevant resources that you have consulted in researching your project. Each reference should also include a brief annotation.

1. Sylvia Duckworth. A picture of a kitten at Hellifield Peel. <http://www.geograph.org.uk/photo/640959>, 2007. Copyright Sylvia Duckworth and licensed for reuse under a Creative Commons Attribution-Share Alike 2.0 Generic Licence. Accessed August 2011.  
     
   This is my annotation. I should add in a description here.
2. Mark Neal, Jan Feyereisl, Rosario Rascunà, and Xiaolei Wang. Don’t touch me, I’m fine: Robot autonomy using an artificial innate immune system. In *Proceedings of the 5th International Conference on Artificial Immune Systems*, pages 349–361. Springer, 2006.   
     
   This paper…
3. W.H. Press et al. *Numerical recipes in C*. Cambridge University Press Cambridge, 1992.  
     
   This is my annotation. I can add in comments that are in **bold** and *italics*and then further content.
4. Various. Fail blog. <http://www.failblog.org/>, August 2011. Accessed August 2011.  
     
   This is my annotation. I should add in a description here.
5. Apache Software Foundation (2014) “*Apache POI - the Java API for Microsoft Documents*” (Online) Available at: <http://poi.apache.org> Accessed: 14th March 2014.
6. Apache Software Foundation (2004) “Apache License, Version 2.0” (Online) Available at: <http://www.apache.org/licenses/LICENSE-2.0> Accessed: 14th March 2014.