Procedural Level Generation and Dynamic Path-finding A Combined Approach

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Where I have quoted from the work of others the source is always given. With the exception of such quotations this dissertation is entirely my own work;

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Abstract

As games evolve and expand with the times there is an increased demand placed upon the hardware of games consoles and personal computers in terms of storage space and memory usage. This project will analyse the approaches currently available and will examine the viability of developing a combined approach to level generation and path finding with the aim of producing a solution that will compete with current approaches in terms of the quality of the terrain generated tested through the results given by the path finding and the distances between nodes that will be placed in sane (flat, reachable) locations on the terrain this will also allow for testing the quality of the path finding approach by testing against different complexities of terrain and existing industry techniques.

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1 introduction

This chapter will outline the basic topics relating to the project in terms of both level generation and path-finding then some of the optimisation techniques that may be used in the project will be discussed. Finally the main goals for the project will be analysed and the layout of the report from this point forward will be given.

1.1 Procedural Level Generation

Procedural level generation is the process of creating a level through an algorithm contained within a computer program instead of using software to create this content then loading it into the program this approach was mainly utilised in the early day of games development where storage space was a major concern.
The first game to contain procedurally generated levels was Richard Garriott's game Akalabeth: World of Doom which was published by California Pacific Computer Company in 1980 [Wikipedia, 2015].

This project is going to utilise procedural level generation to create a average sized game world by creating a height-map which is a grey-scale then reading the data from a height-map and using this data to transform a plane to create a large scale landscape in chunks.

1.2 Path-Finding

Path-Finding is an area of Artificial Intelligence that allows for definition what parts of a given level can be moved to by computer controlled players this is done by creating a set of nodes on walkable areas then linking these nodes together to form a path there are various algorithms that accomplish this task. A time-line of path-finding developments is given at figure: 3. The project will attempt to use path-finding on the generated level in small chunks to allow for faster processing and access to more optimisation techniques.

1.3 Optimisation Techniques

There are many factors that can affect the run-time performance of computer programs and a similar amount of approaches that can be utilised to improve this some of the most prominent techniques in this area include use of multi-threading and parallelism frameworks such as OpenMP for use in single computer based solutions and MPI which allows for parallel implementation over a network.

There are other options that differ from a parallel approach that could be utilised these can include memory alignment of instructions or a graphics processing unit (GPU) based implementation.

1.4 Aims and Objectives

The main aim of this project is to examine and test the viability of combining level generation and path finding algorithms to create a solution that will compete with current practices in terms of performance. This will be achieved through the creation of an application using the chosen solution to allow a user to create various sizes of level. The application will then build the level in sections and perform path finding on each section if there is a section that is not suitable for path finding it will be discarded and regenerated until a logical path can be built.

The objectives for this project is to find a method of combining level generation and path finding and gathering data from both the chosen solution and current practices to make an unbiased comparison between them and establish the viability of a combined approach.

1.5 Report Layout

The report goes on to a review of literature sources associated with the project then technical information on the project will be supplied next there will be an analysis into the methodology used in implementation and finally the testing and results will be given alongside the conclusion of the project which will be based on the results of testing.

2 Literature-Review

2.1 Background and inspiration

The inspiration for this project was based around pushing performance and analysing both level generation and path-finding approaches to find a common area where these methods can be combined to improve run-time performance and to allow testing of the quality of both the terrain and the path that is built in terms of complexity against the amount of nodes and deviations that are made to the path due to constraints posed by the terrain.

For a background of various path-finding techniques please refer to paper[Husdal, 2015]

2.2 Procedural Level generation Techniques

There are a variety of ways to generate either 2d or 3d geometry within a program this section will discuss the documented methods and compare them in terms of usability and performance.

The paper [Hendrikx et al., 2013] examines the different layers of a game that can be procedurally generated this includes a section on game space for levels or maps and defines these both abstract or concrete methods for generation this is useful as there is a breakdown of different types of levels with basic details on aspects of implementation.

2.2.1 The Diamond-Square algorithm

This method of level generation was proposed by [Fournier et al., 1982] is based off fractal subdivision to generate randomised terrain based on two steps which are split into the diamond step and the square step hence the algorithms name. The diamond step of this algorithm uses the edge points of a square to generate a random value in the midpoint then the square step of this algorithm performs the same function however uses the edge points of the diamond made previously which gives a square as the result. The algorithm is recursive meaning that it performs multiple passes through each step with the generated surface gaining detail every pass however the increase in detail is due to an increase in geometry each pass this means the algorithm can be memory intensive due to the size of array to store the height values being a power of two + 1 this means for eight passes through the algorithm the array would need up to 256KB memory if storing floating point values [Miller, 1986].

2.2.2 Height-map generation and Rendering

A height map is a grey scale image that makes use of depth to create a section of terrain with areas where the terrain is raised being shown as brighter and lower areas shown as dark for most height maps digital noise is used to produce a suitable terrain for an example of the output of a height map please refer to figure 2.

2.2.3 Perlin Noise

To create the image 2 Perlin Noise was used this is a gradient based noise developed by Ken Perlin in 1983 [Perlin, 1985] to create procedural textures using the algorithm outlined below.

- Get an input point of the image
- Loop through the neighbours of this point
- Generate a pseudo-random gradient vector.
    - perform the following calculation

$$G \cdot (P - Q) \tag{1}$$

Figure 1: G= gradient vector P = input point Q = Neighbouring point

  This equation will give the value of P where G is equal to 0 at point Q.

- Finally you Interpolate between the the points down to your point, using an S-shaped cross-fade curve e.g($(eg : 3t^2 - 2t^3)$) this will give the weighting applied in each dimension.This step will require computing of the curve n times, followed by 2n-1 linear interpolations to get the final result.

2.3 Path-finding Techniques

This section will address some of the key path finding techniques that would address the problem posed within the project an analysis of past work done in this area will be given with the aim to analyse how this can be utilised and expanded within the context of the project.

2.3.1 Dijkstra's algorithm

The algorithm for path finding presented by Edsger Dijkstra in 1959 [Cormen et al.,] allows searching of a weighted graph to determine the shortest route through a set of nodes by working out the shortest path from one node to every other connected node in the graph this is known as a uniform cost search. The nodes can be used to represent space within either a two dimensional grid or a point in three dimensions. This method can be used within the project as the cost of travelling between nodes can be calculated as the euclidean distance between the nodes this will allow us to remain with vector calculations which would benefit a GPU based implementation. If we look at figure 3 it is shown there have been a number of developments to this method of path-finding the main adjustments that are beneficial to the project will be discussed below.

2.3.1.1 Developments to graph based path finding

There have been a multitude of developments to graph based path finding techniques these include the techniques mentioned in 3 the main developments and their benefits in the context of this project will be discussed.

The first development to graph based techniques that is interesting is the article by [Goodchild, 1977] this was where the traditional orthogonal approach to building paths was modified due to the fact that errors were produced with straight line and smoothly curved paths the solution was to look at using both the orthogonal and diagonal steps to reduce the errors produced such as deviation from the path and this also prevents the path from becoming too long.

Another development of interest is the creation of a spread based algorithim for path-finding

2.3.2 Path finding in games

Path finding is an area of artificial intelligence widely used in games to allow computer controlled characters to walk on the geometry that makes up a game world or level the paper by [Graham et al., 2003] describes the method for path finding on geometry by first building a navigational mesh which describes which parts of a given world or level can be traversed or using a node based waypoint system which is traditionally based on the visibility of one node to the next to allow for traversal of the geometry there is also a breakdown of path finding techniques into directed and undirected methods with directed methods such as the A* algorithm which combines the cost based searching of nodes or a navigational mesh with a heuristic search to the goal this allows for greater efficiency over Dijkstra's algorithm.

2.3.3 Analysing the quality of path-finding techniques

2.3.4 Previous work in this field

There has been a previous honours project based on performance of GPU based path-finding. The thesis that was authored by [McMillan, 2014] it contains work on a variety of path-finding techniques including Dijkstra, A* and diffusion methods with both a sequential and parallelised implementation the optimised versions of these path-finding approaches which may be utilised as this project will not be specifically related to performance but rather the production of an elegant constrained path and suitable terrain to allow this.

2.4 Optimisation techniques

To optimise the project a wide range of factors and approaches are being considered these will be briefly discussed below.

2.4.1 Parallelism and parallel programming approaches

The first approach to address is that of how to get the most performance out of the development platform (PC) one of the main ways to optimise for this platform is the use of parallel programming this will be implemented through the OpenMP API [Dagum and Enon, 1998]which is built into Visual Studio this will allow for multi-threading of any code running on the central processing unit (CPU) through the use of pre-processor directives to specify sections of code to incorporate parallelism this approach should give a performance increase by utilising the multiple cores in the central processing unit over a sequential implementation that uses a single core.

Other parallel frameworks have been considered however are not at this point set to be implemented these are the MPI (Message Passing Interface)[Snir, 1998] which allows for distributed parallelism over a network this would be extremely beneficial to performance as the PC that the program is running on would have more resources available however this approach can have issues mainly due to the communication being network based meaning that bandwidth can affect the performance of the program to produce a performance decrease due to these factors it is unlikely that the project will utilise this technique.

2.4.2 Graphics Processing Unit (GPGPU)

2.5 Commercial packages

3 Technical Information

4 Implementation Methodology

This section will analyse how the different areas of the implementation are approached and how these approaches work at a technical level.

For a basic outline of the expected execution of the project please refer to figure 5

4.1 Level Generation

To generate the three dimensional terrain used in the project a height-map was generated through the use of the Libnoise external library which is discussed below.

4.1.1 Libnoise external library

This external library generates different types of noise by use of various modules also the library allows the noise generated to be written to various file types for the height-map in the project a Bitmap (BMP) graphical file type was produced which was then loaded into the project and stored in a data structure for manipulation and rendering.

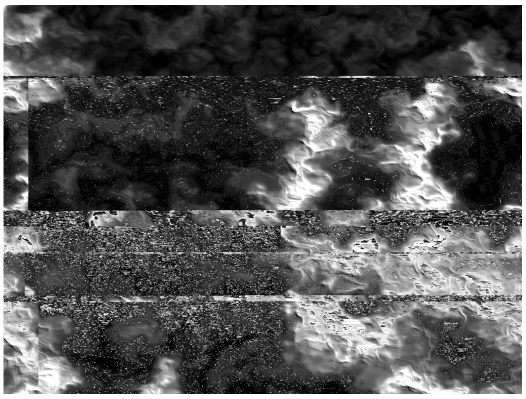

Figure 2: An image showing of one of the height-maps generated by noise

4.2 Additional Information / Knowledge Required

Experience with Linux and managing Virtual machines, networking. So on and so forth...

5 Testing and results

Test Id	Test Name	Test Rationale	results	Retesting result (if modified)
1	Height-map generation and loading	This is the first chosen level generation technique used within the project	pass	n/a
2	Storage and rendering of height-map	This is necessary to test to allow continued use of the height-map technique	ongoing	n/a
3	Height-map performance	This is needed to establish the viability of the height-map method for the project	ongoing	n/a
4	Other level generation techniques	This could be required if the height-map approach has issues or is not viable due to low performance	ongoing	n/a

6 Conclusions

7 Bibliography

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Appendices

A Project Overview

Keywords— Level-Generation,Path-Finding,Algorithm,Optimisation

A.1 Overview of Project Content and Milestones

This project will include research into current practices used in industry for path-finding and level generation with the emphasis being performance based compared against realism. The main milestone for this stage will be coming across a method to integrate both level generation and path-finding into an algorithm which will be carried forward to the development stage.

Development of an application which will utilise both level generation and path-finding either by the modification and optimisation of existing approaches or the creation of a new algorithm. The application will allow the user to create various sizes of level and the application will then give a visual representation of both the level and path that has been built.

The application will then be optimised and tested against some of the methods researched with the aim to show that a combined approach may achieve better results in a similar or faster run time with the paths created being checked for mistakes or inconsistencies based on various sanity checks (no path nodes on areas that should not be traversable such as extreme slopes or dips in the level).

Creation of a report that contains all project information and related work with a detailed analysis and testing of the approach used to provide an evaluation of the solution using performance figures to accurately examine the viability of this approach in comparison to the current industry standards and draw a conclusion over the project as a whole.

For a more detailed look at the time-line for this project please refer to Figure 4

A.2 The Main Deliverables

- A application that will allow the user to create various sizes of level and will give a visual output of the level and path built with a focus on the optimisation techniques used to integrate level generation and path finding.

- A detailed report containing an analysis on the approach taken and a comparison between the solution and other methods used currently using figures from both to evaluate the effectiveness and viability of the approach used.

- Test logs of the finished application and an industry standard practice to allow for an unbiased comparison to be made based on results obtained from these tests when documenting the project.

A.3 Target audience for the deliverables

The deliverables of this project may be of interest to people involved with both level generation and path finding in the games development industry. Researchers involved in this field may find the report and comparison of techniques used to be of interest. Other people may find this project helpful with regards to optimisation techniques. The main aim of the project is to show the performance of a combined approach to level generation and path-finding and an evaluation of the quality of paths built.

A.4 The work to be undertaken

- Research into current industry practices for level generation and path finding to allow for visualization of a solution to combine these algorithms.

- Development of the application and chosen approach with a focus on performance while maintaining a level of realism.

- Optimisation of the developed solution and gathering of test data from the solution and an industry approach.

- Creation of a report detailing the approach taken to implementing the project and providing an evaluation between the solution compared to industry practices.

There is a diagram showing expected steps of execution within the application shown at Figure 5

A.5 Knowledge and skills required

To be able to complete the project to a high standard I will first need to research the field's of both level generation and path finding as a solid knowledge will be needed to create a combined approach. In terms of development further research into optimisation techniques for C++ in Visual Studio will allow for a more polished and better performing solution also as a level of realism will be maintained experience with graphic programming would also benefit the project.

A.6 Information sources that provide a context for the project

The video available at [lev,] gives a few very basic examples of levels that can be generated and also details some methods to define areas within a level(slopes,walls,and others) this definition of areas within a level could be used for testing the path finding within the project and may give a basic concept on how to generate content within the level produced in relation with the project.

The paper[Sturtevant and Buro, 2005] analyses various path-finding algorithms however the purpose of their project was to look at an alternative approach to the A* path finding algorithm. Use of concepts such as map abstraction could be of interest to this project as it would allow a way to break the level into chunks which can then be processed individually by a path finding algorithm.

The textbook for level generation [Shaker et al., 2015] Provides extensive research into procedurally generated content in games from grid based levels to full landscapes there are multiple approaches detailed within the textbook that can provide a basis to generate a level within the project.

Previous honours projects to note
This paper[McMillan, 2014] analyses various path finding algorithms and discusses at optimisation options this will be the inspiration for optimising the project and will give a wide variety of path finding algorithms to research

going forward.

For a timeline of research into path finding algorithms please refer to Figure 3

A.7 The importance of the project

This project is important as it will seek to integrate level generation and path finding which could allow for faster loading times in games while reducing the storage space taken by a game. When comparing the difference between developed solution and current industry practices - if the solution proves to be better in terms of performance and the quality of the path built is of a suitable standard for the complexity of the level that is generated.

A.8 The key challenges to be overcome

- Research of a variety of level generation and path-finding techniques to gain knowledge and propose a viable solution for development.

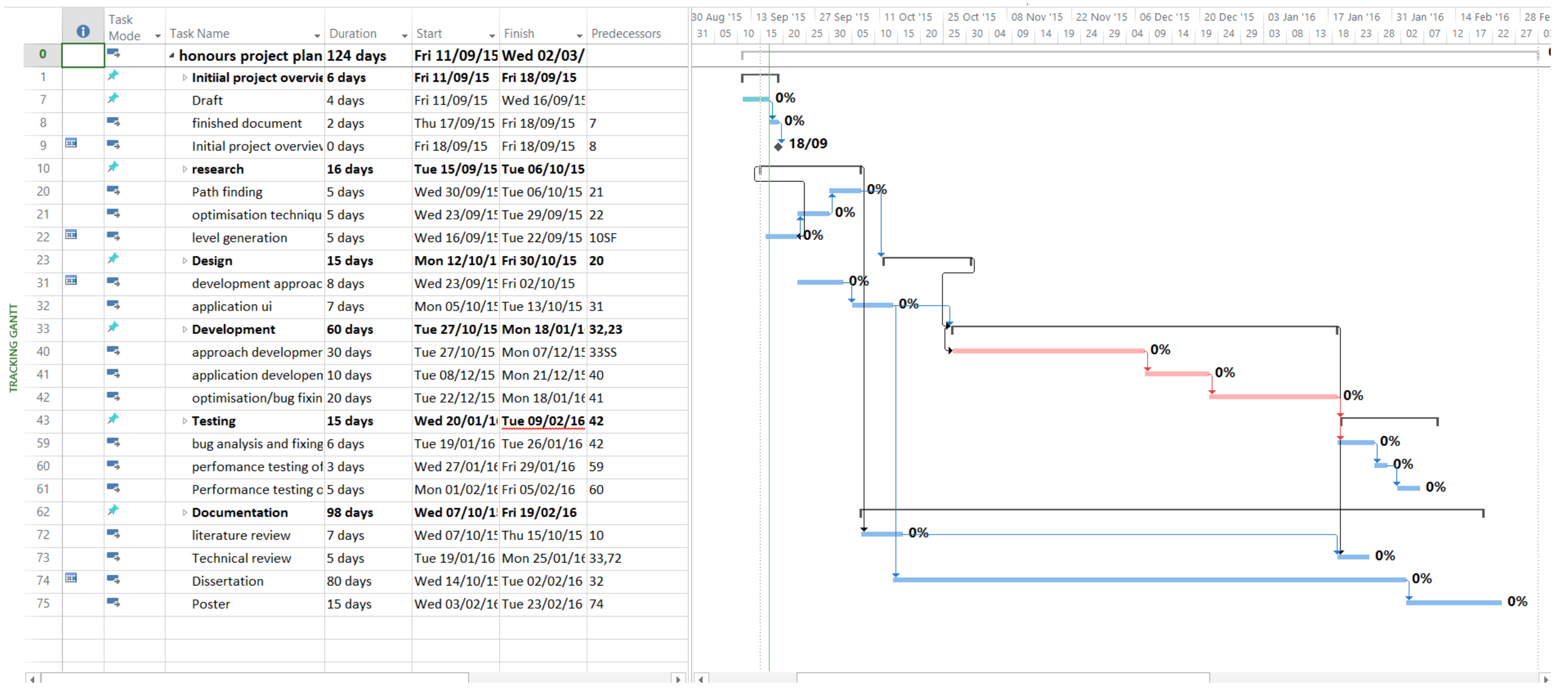
- Development of an application that will use the envisioned solution and give a visual output to the user of both level and path built.

- Research into a way of determining the quality of path finding and level generation techniques.

- Writing of a detailed report that will clearly explain the solution chosen and give a view into past work done within this field then the report will provide an unbiased comparison between the approach and current industry practices to evaluate the project in terms of the quality the path built when compared to the complexity of the level generated.

Creator	Method	Year
Dijkstra [Cormen et al.,]	Graph searching	1959
Goodchild [Goodchild, 1977]	Orthagonal and diagonal movement	1977
Huber and Church [Huber and Church, 1985]	analysis of neighboring cells	1985
Eastman [Eastman, 1989]	Pushbroom procedure	1989
Lombard and Church [Lombard and Church, 1993]	GSP(Gateway-shortest-path)	1993
Mcilhagga [McIlhagga, 1997]	Fixed cost distance	1997
Andrea Califano [Califano, 2000]	Splash algorithm	2000

Figure 3: A time-line of path finding algorithms
[Husdal, 2015]



		Task Mode	Task Name	Duration	Start	Finish	Predecessors
0			honours project plan	124 days	Fri 11/09/15	Wed 02/03/	
1			Initiial project overvie	6 days	Fri 11/09/15	Fri 18/09/15	
7			Draft	4 days	Fri 11/09/15	Wed 16/09/1!	
8			finished document	2 days	Thu 17/09/15	Fri 18/09/15	7
9			Initial project overviev	0 days	Fri 18/09/15	Fri 18/09/15	8
10			research	16 days	Tue 15/09/15	Tue 06/10/15	
20			Path finding	5 days	Wed 30/09/1!	Tue 06/10/15	21
21			optimisation techniqu	5 days	Wed 23/09/1!	Tue 29/09/15	22
22			level generation	5 days	Wed 16/09/1!	Tue 22/09/15	10SF
23			Design	15 days	Mon 12/10/1	Fri 30/10/15	20
31			development approac	8 days	Wed 23/09/1!	Fri 02/10/15	
32			application ui	7 days	Mon 05/10/1!	Tue 13/10/15	31
33			Development	60 days	Tue 27/10/15	Mon 18/01/1	32,23
40			approach developmer	30 days	Tue 27/10/15	Mon 07/12/1!	33SS
41			application developen	10 days	Tue 08/12/15	Mon 21/12/1!	40
42			optimisation/bug fixin	20 days	Tue 22/12/15	Mon 18/01/1(	41
43			Testing	15 days	Wed 20/01/1	Tue 09/02/16	42
59			bug analysis and fixing	6 days	Tue 19/01/16	Tue 26/01/16	42
60			perfomance testing of	3 days	Wed 27/01/1(	Fri 29/01/16	59
61			Performance testing c	5 days	Mon 01/02/1(	Fri 05/02/16	60
62			Documentation	98 days	Wed 07/10/1	Fri 19/02/16	
72			literature review	7 days	Wed 07/10/1!	Thu 15/10/15	10
73			Technical review	5 days	Tue 19/01/16	Mon 25/01/1(	33,72
74			Dissertation	80 days	Wed 14/10/1!	Tue 02/02/16	32
75			Poster	15 days	Wed 03/02/1(	Tue 23/02/16	74

Figure 4: An image of the project gantt chart

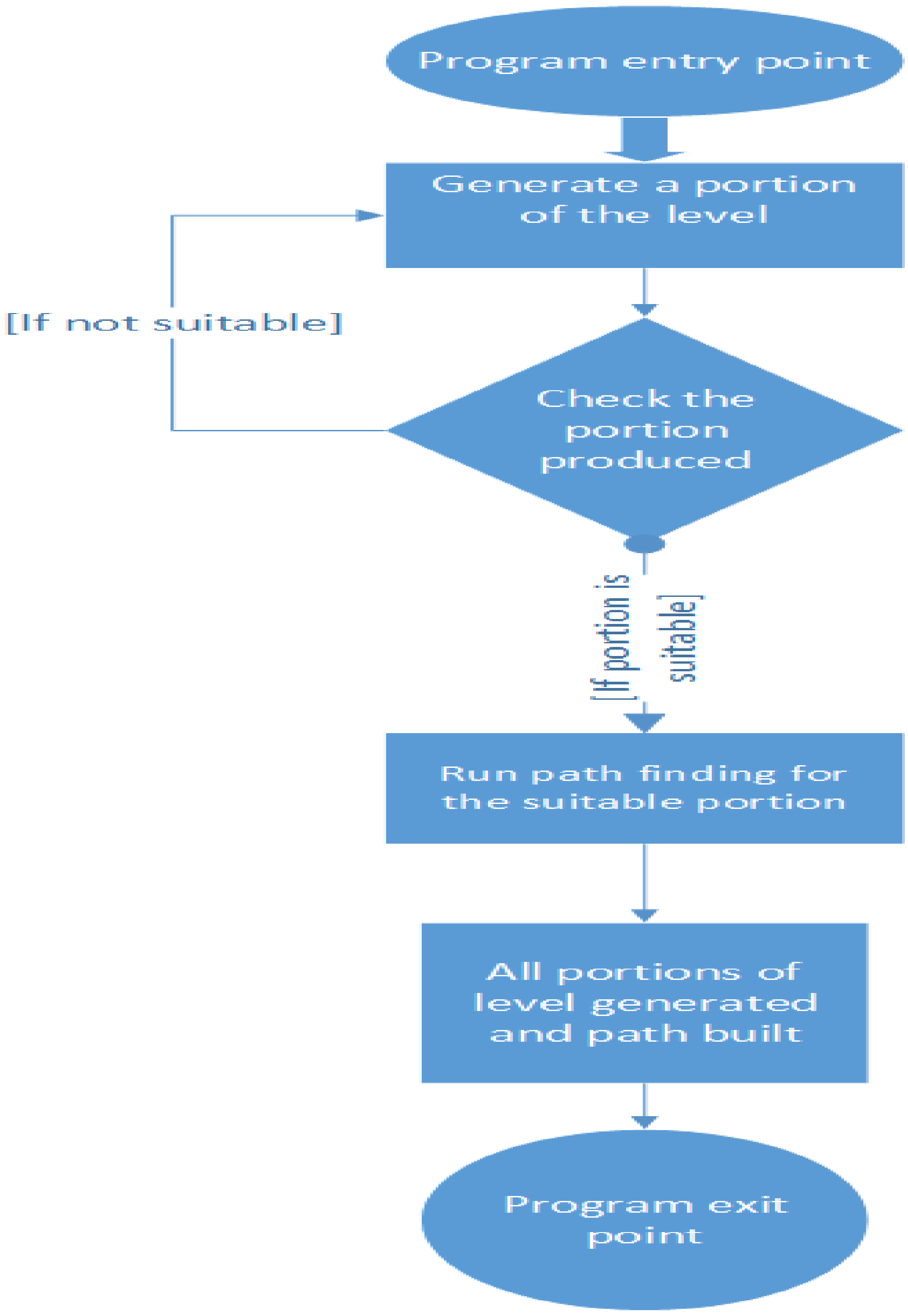

Program entry point
Generate a portion of the level
[If not suitable]
Check the portion produced
[If portion is suitable]
Run path finding for the suitable portion
All portions of level generated and path built
Program exit point

Figure 5: This shows how the program will execute

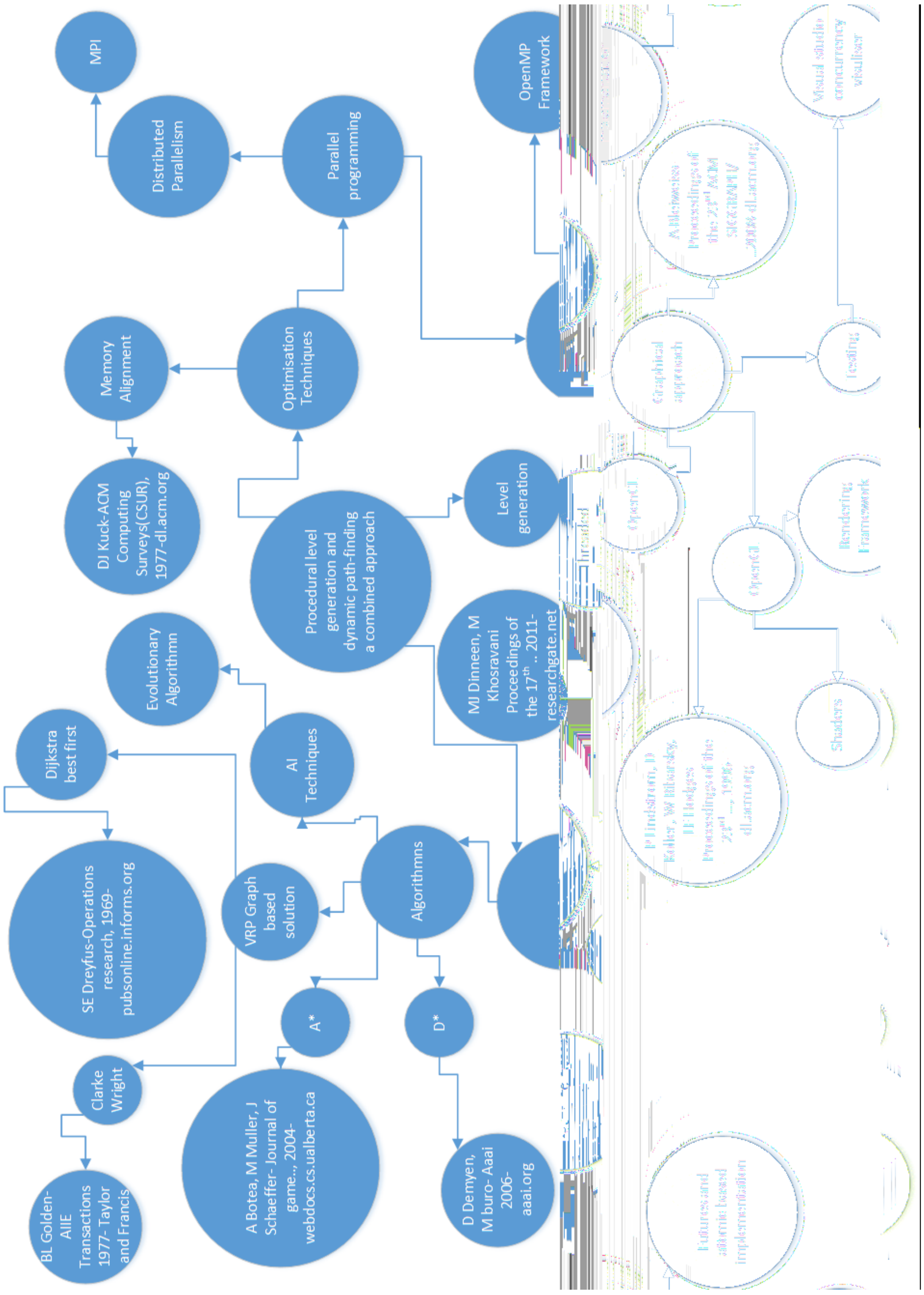

MPI
Distributed Parallelism
Parallel programming
OpenMP Framework
Memory Alignment
Optimisation Techniques
DJ Kuck-ACM Computing Surveys(CSUR), 1977-dl.acm.org
Level generation
Procedural level generation and dynamic path-finding a combined approach
Evolutionary Algorithm
MJ Dinneen, M Khosravani Proceedings of the 17th .. 2011- researchgate.net
Dijkstra best first
AI Techniques
SE Dreyfus-Operations research, 1969- pubsonline.informs.org
VRP Graph based solution
Algorithmns
Clarke Wright
A*
D*
BL Golden- AIIE Transactions 1977- Taylor and Francis
A Botea, M Muller, J Schaeffer- Journal of game.., 2004- webdocs.cs.ualberta.ca
D Demyen, M buro- Aaai 2006- aaai.org
Graphical approach
OpenCL
Shaders
Rendering Framework
Visual studio concurrency visualizer

Figure 6: This is a mind map covering the scope of the project

Progress
Mind map finished and added to thesis.
Loading of height-map code fixed.

B.7 Meeting 6 27/10/15 Week 8

Meeting was missed however general discussion was had with supervisor during the week to state goals for this week and record progress informally.

B.8 Meeting 6 3/11/15 Week 9

Objectives
Update thesis
Look at commercial packages for comparison
Implementation work (Test cases)
Print and bring thesis to next meeting

Progress
Numerical experimentation for level generation
Started writing implementation methodology
almost finished lit review(Draft version)

Comments
Coursework week(busy)
Second marker meeting next week

B.9 Meeting 7 10/11/15 Week 10

Objectives
Update thesis
Fix rendering
Implementation work (Test cases)
Blog/Website updates Print and bring thesis to next meeting

Progress
Started to fix development issues(rendering)
Thesis Work
Re-done blog/website (more structured)

Comments
Review thesis progress next week
Week 10-Second marker meeting organisation

C Second Formal Review Output

D Appendix 4 and following