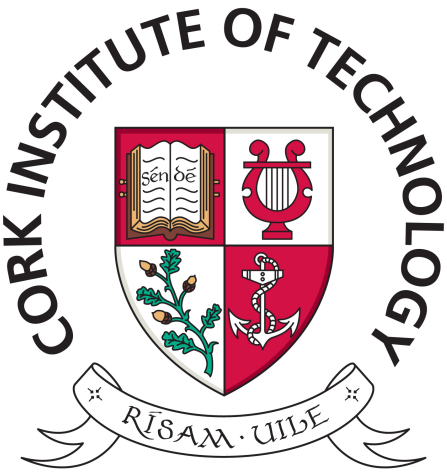

Simulating Evolution and Processes of Natural Selection in a Virtual Ecosystem.

by

Daniel Cosgrove

This thesis has been submitted in partial fulfillment for the degree of Bachelor of Science in Software Development (BSc Honours)

in the
Faculty of Engineering and Science
Department of Computer Science

January 2020

Declaration of Authorship

I, Daniel Cosgrove , declare that this thesis titled, 'Simulating evolution and processes of natural selection in a virtual ecosystem.' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for an undergraduate degree at Cork Institute of Technology.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at Cork Institute of Technology or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this project report is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: _____

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CORK INSTITUTE OF TECHNOLOGY

Abstract

Faculty of Engineering and Science
Department of Computer Science

Bachelor of Science

by Daniel Cosgrove

Darwin's theory of biological evolution states that species arise and develop through the natural selection of inherited variations that contribute to the success of the individual's ability to survive in its environment and reproduce. This project aims to use a video game engine to create a virtual environment in which animals would live, eat, reproduce and pass on their genes to the next generation. With animals possessing various traits which may or may not benefit them in their specific environment, some animals would have a better chance of survival and reproduction. Animals that do reproduce would pass on their traits to their offspring with potential small inherited variations. In this environment an ecosystem could be created over time that is inhabited by animals increasingly suited to their environment. I wish to produce and present data on the evolution of the animals based on of the various environments they inhabit, such as environments scarce of resources or co-inhabited by a predator. I believe this could give people a better understanding of evolution and the context that contribute to natural selection.

Acknowledgements

John Creagh - Semester 1 Project Supervisor

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Chapter 1

Introduction

1.1 Motivation

I was highly motivated to develop this project due to my long-held interest in nature and how living things come to be. With technology making consistent advancements in Artificial Intelligence, many conversations are being had on how we should handle the emergence of intelligent life and what forms can life exist in. I thought the merger of technology and living beings would be an interesting and important topic to study and demonstrate in effect, the natural processes that occur in all animals, regardless of location, species or physical makeup. I decided to develop a virtual ecosystem to showcase these processes of natural selection that take place in our real world and create a tool for presenting how a species evolves and comes to be. I believe such an application would give people a better understanding of the factors that contribute to a specie's evolution and the natural processes that define an animal's physical body.

1.2 Contribution

As a Software Development student, I have had the opportunity to learn a large range of skills in the field of Computer Science in the last three and a half years of college. I believe the biggest skill I have learned is that of how to program and how to use established methodologies of programming to build an application. I have had a considerable amount of experience with Java from modules like Distributed Systems, which provided me with the knowledge of how to develop client-server applications with program architectures like Model-View-Controller and also integrate databases and client interfaces as well as create concurrent programs using threads and sockets. The modules Object Oriented Programming and OO Analysis and Design were also incredibly important to

my programming knowledge as it provided the basis of my understanding of essential programming concepts.

This programming knowledge was also extended with modules like C Programming, Linear Data Structures & Algorithms and Programming for Data Analytics which provided me with the skills to create a number of algorithms and analysis data in not only Java but C and Python. I also undertook a number of database-oriented modules that gave me knowledge of the structure and proper design methodologies of a database as well as the ability to correctly integrate a database into a distributed application.

Lastly, a notably elective module I undertook in my 3rd year of college was Game Development. In this module, I had the opportunity to familiarise myself with the fundamentals of game mechanics and how to structure logical scripting blueprints. I believe the knowledge and skills acquired from these modules will be not only extremely helpful in the implementation of my project but essential to creating the application.

1.3 Structure of This Document

Chapter 1

Section 1.1 details the motivation and reasoning behind why I chose to do this project. Section 1.2 discusses the skills and knowledge I have learnt that contribute to the project. Section 1.3 provides an overview of the structure and the sections of this document.

Chapter 2

Section 2.1 discusses the themes that this project falls under and their place within Computer Science. Section 2.2 gives a brief review of existing work done in the context of the project themes. Section 2.3 describes the state of the art of the technologies and applications created within the themes of the project.

Chapter 3

Section 3.1 defines the problem I wish to solve with this project. Section 3.2 describes the objectives I wish to achieve within this project. Section 3.3 describes the functional requirements of the project while Section 3.4 describes the non-functional requirements.

Chapter 4

Section 4.1 describes the architecture of the project. Section 4.2 evaluates the risks of the project, their probability and potential damage. Section 4.3 describes the methodologies used to complete the project. Section 4.4 provides a plan schedule for the implementation of the project. Section 4.5 provides a plan for evaluating the project objectives and how I will measure how much has been achieved.

Chapter 5

Section 5.1 discusses the problems encountered at this phase of the project and how they may influence the next phase. Section 5.2 discusses the main conclusions I arrived at in terms of the background research done, problem definition and the solution approach I arrived at.

Chapter 2

Background

2.1 Thematic Area within Computer Science

The core topic of the thesis is simulation of evolution and process of natural selection in a virtual ecosystem. The themes of this project are evolution and ecology. The main area of computer science that this project falls under is Software Development and Simulation.

Evolution

Evolution is the change in the heritable characteristics of biological populations over successive generations. [1] The main focus of this project is to demonstrate how the circumstances of an environment affect an animal's chance of survival and therefore their chance of successfully passing on their traits to their offspring in the form of natural selection. I hope to successfully create an environment that demonstrates how the presence (or lack thereof) of each trait of a species changes overtime as a result of the environment they inhabit.

Ecology

Ecology is the branch of biology that deals with the relations of organisms to one another and to their physical surroundings. [2] This project should be relevant to the first four of the five levels of ecology:

1. Organism: a single member of a species.
2. Population: a group of individuals of a single species that exist in the same area.

3. Community: a group of interacting populations.
4. Ecosystem: a biological community of interacting organisms and their physical environment.
5. Biosphere: the global ecological system.

Software Development

Development of software in a language such as Python or C will be required for the implementation phase of this project. Scripting will be needed for the different animal dynamics as well as environment elements in the video game engine. A pathfinding algorithm is one example of a software feature I plan on implementing in the product.

Simulation

A simulation is an approximate imitation of the operation of a process or system; that represents its operation over time.[3] The form of this simulation will be of a video game engine. This should be the ideal platform for creating a comparable environment for the virtual ecosystem.

2.2 A Review of Ecological Simulations

2.2.1 The top 5 international conferences/journals

1. Ecology & Evolution Ireland Conference - Galway, Ireland. 10-12 January 2019

This academic conference is for professional ecologists working in higher education and research institutions, government and non-government organisations, ecological consultancies and other professionals in ecology. [4]

2. 14th Ecology & Behaviour Conference, Toulouse, France. 19-24 May 2019

The Ecology and Behaviour conference is organised by and for young researchers to discuss their works with other researchers in the field of ecology, evolutionary biology and behavioural ecology. [5]

3. Empirical Software Engineering

This Journal discusses the effectiveness of different software languages in regard to basic maintenance of a marine ecosystem simulation. [6]

4. Forest Ecology and Management

This journal discusses simulated scenarios of the first decades of tree growth on various landscapes and the effect to the ecosystem made from different harvest periods and post-harvest density. [7]

5. Game Developers Conference The Game Developers Conference is an annual 5 day conference of professional game developers. It is a place where developers can come together to exchange ideas, showcase games and discuss design, art, programming and networking. [8]

2.2.2 The top 3 Books

1. Life 3.0: Being Human in the Age of Artificial Intelligence – Max Tegmark

Life 3.0: Being Human in the Age of Artificial Intelligence is a book written by Max Tegmark. [9] The book discusses Artificial Intelligence and its impact on the future of life on Earth and beyond. It also defines three stages of life and their ability to change their hardware (physical makeup) and software (learnt behaviour). Life 1.0 refers to biological origins that are unable to change their behaviour or their physical makeup. This would be equivalent to a microbe and this stage would most relate to the animal I hope to create in this project. Life 2.0 refers to animals like mammals that are able to change their learnt behaviour but are not able to change their physical makeup. Life 3.0 refers to an artificial intelligence capable of changing its learnt behaviour and its physical makeup.

2. Neo-Simulation and Gaming Toward Active Learning – Translational Systems Sciences

This book discusses the role of simulation games as an instrument to understand the dynamics of innovation processes and how simulation games can be used address the issue of implementing innovation in the transport and logistics sector. [10]

3. The Guide to Computer Simulations and Games - K. Becker and J. R. Parker

This book discusses design and development of simulations. It details the definition of a computer simulation and how they differ from live-action and paper-based simulations. The book also describes how models are built and used in simulations. It also gives four examples of these models in use in a functional simulation. [11]

2.2.3 The top 5 organizations/companies

1. Society for the Study of Evolution

The Society for the Study of Evolution is a professional organization of evolutionary biologists. The objectives of the society are the promotion of the study of organic evolution and the integration of the various fields of science concerned with evolution.[12]

2. World Wide Fund for Nature

The WWF is non-governmental organization whose aim is to reduce the impact human beings have on the environment. They are actively engaged in conservation relating to six areas: food, climate, fresh water, wildlife, forests and oceans. [13]

3. The Ecological Society of America

The ESA is a non-profit organization of ecological scientists based in the United States. They hold a number of annual meetings and produce publications relating to ecology and science. They are engaged in issues of diversity, science, education and public policy. [14]

4. United States Fish and Wildlife Service

The USFWS is a governmental agency of the US Department of the Interior. The agency is responsible for management of migratory birds, restoring national fisheries and conserving wildlife habitats. They also distribute funds to state's wildlife agencies as well as aid foreign governments with international conservation efforts.[15]

5. Frontier Developments

Frontier Developments is a UK based video game developer. They have produced multiple tycoon games involving animals such as 'Jurassic Word Evolution', 'Planet Zoo', 'Zoo Tycoon' and 'Kinectimals'. [16]

2.2.4 The top 5 wiki/forums/blogs/Youtube channels

1. Primer – YouTube channel

The YouTube channel 'Primer' contains a number of Life and evolution related videos demonstrating various processes and concepts. The channel creator uses the 3D computer graphics software toolset Blender to created fictional living beings, giving them different traits from video to video for the purpose of demonstrating evolutionary processes and outcomes. These beings are "blobs" and resembles the behaviour and complexity of a microbe. One video titled 'How life grows exponentially' demonstrates how an animal's predicted population size can be calculated, given a spontaneous birth rate, death rate and a chance for replication in a space of time. [17]

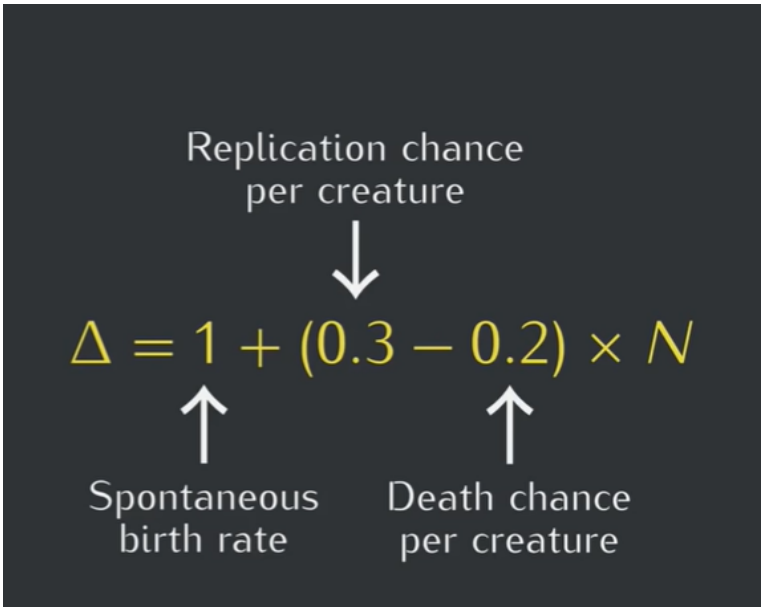

FIGURE 2.1: Primers formula for calculating animal's population.

2. Sebastian Lague – YouTube channel

The YouTube channel 'Sebastian Lague' contains a number of videos about video game dynamics in the video game engine Unity. Topics covered on the channel include procedurally generating landscapes, pathfinding algorithms and modelling. [18]

3. HobbyGameDev - Blog

HobbyGameDev is a blog by Chris Deleon that discusses development of video games for independent readers. The blog post tutorials for those looking to learn about developing their own games and tips and techniques for doing so. The blog also conducts interviews

with various people in the game development industry as well as articles relating to current news and discussions. [19]

4. Pixel Prospector - Blog

Pixel Prospector is a blog for game developers to learn more about the process of creating and distributing indie games. Readers can learn about game design, programming, project managing and marketing. [20]

5. Gaming Your Way - Blog

Gaming Your Way is a blog by Oliver Sons and Richard Myles that discusses various game dynamics for video game development, programming and design, particularly in Unity. The blog also publishes news and experiments. [21]

2.3 State of the art

Video Game Engine: Unreal Engine 4

The Unreal Engine is a game engine developed by video game and software development company Epic Games. [22] First showcased in 1998 in the first-person shooter game 'Unreal', the first-generation engine integrated rendering, collision detection, AI, networking, scripting and file system management in one complete engine. Its code is written in C++ and provides a high degree of portability and scope for game developers as a wide range of games have been developed with the engine such as first person shooters, platformers, fighting games and RPGs. Some examples of the most successful triple A games that have been made with the Unreal Engine are 'Fortnite', 'Gears of War', 'Borderlands' and 'Mass Effect'. Unreal Engine games have also been made for a huge range of platforms from PC to consoles to Mobile and VR.

The Unreal Engine appeals to a wide range of people as courses are available for individuals to create their own projects and learn about python scripting, effectively using the blueprint interface and comprehending projects and file structure as well as working with in-game dynamics like actors, lighting and physics. A large selection of pre-made assets are also available, making it easy for world building and scene creation.

Not only is the engine used in the development of video games but is also a valued asset in commercial enterprise use with Unreal Studio. Unreal Studio is an advanced toolset for development of photorealistic 3D environments. It is also used in the design of architecture, visual effects, animation and 3D model rendering. For example, Audi

uses the Unreal Studio for a digital showroom in more than 1000 of their dealerships to showcase their vehicles with real-time lighting, shadows and reflections. [23]

FIGURE 2.2: An Audi made in the Unreal Engine.

Video Game Engine: Unity

Unity is a game engine developed by software development company Unity Technologies, first released in June 2005 at Apple's Worldwide Developers Conference. [24] The engine can be used to create 2D and 3D games for consoles, PC, mobile and VR. Unity is usually made for smaller scale games or indie games. According to a 2017 blog post, over 50% of mobile games and 60% of VR content are made with Unity. [25] Some notable games made with Unity are 'Kerbal Space Program', 'Besiege' and 'Hollow Knight'.

Unity features API scripting in C# for scripting games and plugins in the Unity editor. Sprites are used for 2D games as well as an advanced 2D world renderer. For 3D games a number of features are supported such as mipmaps, animation, high fidelity lighting, photogrammetry, bump mapping, reflection mapping and shadow maps. Similar to the Unreal Engine, Unity is in use in multiple industries for enterprise in architecture, engineering, construction and real time film and animation. It is used in manufacturing and automotive as CAD data can be used to produce 3D models in the engine.

Unity Simulation is a tool in the beta phase that uses cloud computing to allow users to test multiple complex scenarios in parallel in a virtual environment and then train autonomous systems on thousands of scenarios and validate the results. [26] For example, this could be used for autonomous vehicles to gather the 11 billion miles needed before being considered road safe.

Simulation: Microsoft Flight Simulator 2020

Microsoft Flight Simulator 2020 is a flight simulation video game releasing in 2020 for PC developed by Asobo studio and published by Xbox Game Studios. [27] It is the most advanced flight simulator game to date and implements a number of new features never done before in a video game. The game allows players to fly aircraft from the small Cessna 172 to the massive Boeing 747-8. The world in MFS2020 is a 1:1 scale replica of the earth. This is done by using 2 petabytes worth of Bing mapping data consisting of satellite images, aerial images and photogrammetry with accuracy down to 5cm. In addition to Bing mapping data, elevation data and scans of 400 cities and 40,0000 airports were used to create the world. [28]

As some elements of the world cannot be generated from images, the developers created an algorithm that detected the world element and generated in game. This allowed for the creation of procedurally generated grass and 1.5 trillion trees. Water is also a world element that is affected by natural processes such currents and wind to create waves. The Microsoft Azure cloud computing platform is used to deliver the scenery data on demand at low latency to the player. The level of detail of the scenery data is determined by the players internet speed.

The game is made in Asobo's propriety engine. The worlds atmosphere is split into 32 layers, each defining the density and shape of clouds. The clouds in-game are formed from the humidity in the atmosphere and are affected by wind and currents. Weather can be set randomly, predetermined or even streamed live from that locations current real-world weather. The engine also supports a number of intricate features essential for realistic flight simulation such as storms, rain and winds creating wind shear and jet streams. Clouds also create shadows on the world and can be seen up to 600km away. Sunlight, moonlight, city light and pollution all affect the volumetric cloud rendering and how they reflect and scatter light onto each other and the world below. For example, a dark and dreary day will cause a change in colour to the reflections of the sea and building windows. Outside conditions will affect ability to read aircraft instruments. All buttons, dials and touchscreen systems are fully interactive. The world time runs on a real day and night cycle and the year cycle will dictate the sun, moon and stars accurate position.

In past simulators a single point in the middle of the aircraft was used to be the reading point of atmospheric data, look up tables were then used to determine what would happen under certain scenarios. In MFS2020 thousands of points are used all over the aircraft and each surface has a full dynamic simulation of air pressure, wind speed and different types of stalling. This means that a single piece of the aircraft can stall while

the rest remains fully function. For example, players could find themselves in a scenario where the middle of the left wing stalls during flight.

Wind is simulated worldwide and can change based on the location the player flies their aircraft. Clouds are volumetric and will create updrafts with winds affecting the plane surface by surface. Colliding winds will create turbulence as well as large structures like mountains or small structures like stadiums or skyscrapers. An aircraft aerodynamics will be affected by the landing gear and landing gear have collision models for take off and landing. Take off of an aircraft is affected by the surface irregularity of a runway or field and tyres have simulation of friction and rubber tearing.

Project: 'Coding Adventure: Simulating an ecosystem' - Sebastian Lague

'Coding Adventure: Simulating an ecosystem' is the title of a YouTube video by the YouTube creator Sebastian Lague. [29] In this project, Lague created a virtual ecosystem in Unity consisting of a plain landscape with grass, plants, trees and rivers.

The subject of the ecosystem is a 3D rabbit that needs to eat, drink and reproduce. The rabbit also has individual traits.

Speed: increasing speed comes at the cost of increasing energy consumption per step but increases how fast a rabbit may find food or evade a potential predator. Sense: is dependent on the time the rabbits mothers gestation time and gives the rabbit a larger area of view in which they can see food.

Reproductive urge: is the time the rabbit spends looking for a mate instead of searching for food or water.

Gestation: is a female specific trait. This is the amount of time a female rabbit will spend pregnant. The rabbit may have many less developed offspring or a small number of offspring with a larger sense.

Desirability: is a male specific trait. This is dictated the colour of the male with darker male rabbits having a higher chance of being accepted by a female for mating.

The rabbits pass on their traits to their offspring with the chance of a small mutation. The ecosystem may also have a fox a natural predator that's seeks out the rabbits as their source of food. When the ecosystem is run on the game engine, various outcomes in the rabbit's traits emerge based on the scarcity of food as well as the introduction of a predator.

Project: 'Simulating natural selection'

'Simulating natural selection' is the title of a YouTube video by the YouTube creator 'Primer'. [30] The video demonstrates how the simulation environment produces different outcomes in the traits of 'blobs' depending on the set scarcity of food available. Blobs are simple animals whose behaviour could be compared to that of a microbe.

In this project, the blobs are tasked to leave the edge of a plain each day cycle, seek food and return to the edge of the plain. If they do not find food before the end of the day they will starve and die. If they find 2 pieces of food then they can reproduce, passing on their traits with small mutations. They are given 3 traits.

Size: increasing the blobs size comes at the cost of increasing the blobs energy consumption per step but gives them the ability to eat other blobs if they are 20% larger than them, granting them an additional source of food.

Speed: increasing the blobs speed will also increase the blobs energy consumption per step but gives the blob the ability to find food faster and evade other larger blobs.

Sense: increasing sense comes at the cost of increasing the blobs energy consumption per step but gives the blob a larger area of view in which they can see food.

Project: Evolution in Minutes: A Simulation in Natural Selection - Rohan Padhye

Evolution in Minutes is a web application by Rohan Padhye. [31] The application is written in JavaScript and is a demonstration of how microorganisms change depending on their environment. The environment is a spherical plain consisting of food pieces that the organisms seek out and eat. A set number of food pieces are placed on the plain for every set number of seconds. The organism has three traits or coloured "genes". The first gene is Blue and increases the organism's movement speed. The second is Green and increases the organism's sense for food. The third is Red and increases the organism's lifespan. The organism is comprised of a combination of 255 of these three genes and colour is based on the mixture of each.

Organisms reproduce asexually each time they eat a certain number of food pieces and pass on their genome to their offspring with a small mutation. This number depends on the number of genes the organism is comprised of. When the application is run, the resulting typical organism varies depending on the frequency and amount of food that is placed on the plain. For example, when the application is run with food set to come infrequently the organisms evolve more red genes to live longer and less genes for speed and sense. Another example is when the program is set to run with food

appearing rapidly in small quantities, the organisms evolve to have less red genes and instead invest in speed and sense.

Pathfinding Algorithm: A*

The A star path traversal algorithm aims to find a path to the given node whilst having the least distance travelled across a grid. It does this by creating a tree of paths originating from the start node and extending each path one edge at a time until it finds the given node. [32]

The setting area of which the two points reside is a two-dimensional grid. Each square in the grid is a point and a node. We assume that the distance between two nodes next to each other is one. This means that the distance between two nodes diagonally is the square root of 2 or approximately 1.41. We will multiply this by 10 for simplicity. Each node surrounding the starting node will be calculated by how close it is to the starting node (G cost) and how close it is to the ending node (H cost). The F cost of a node is the G cost plus the H cost or f(n) = g(n) + h(n). The algorithm will calculate the F cost of every node surrounding the starting node and choose the one with the smallest F cost to be the next node. The next node will then calculate the F costs of all surrounding nodes.

Now that there are two nodes that have been calculated, the algorithm has a larger range of nodes to calculate the smallest F cost available. The node with the smallest F cost may not always be a node surrounding the last node chosen. This means that the path can backtrack to a different edge of the explored path. This is a very effective way of finding the shortest path possible as the algorithm will explore multiple paths and always follow the one with that is closest to the end node.

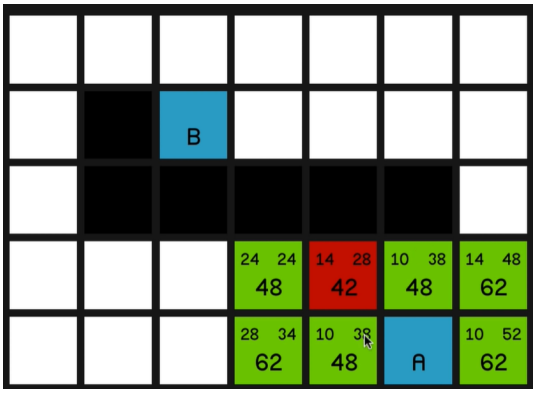

FIGURE 2.3: A* after one move.

Here we can see in figure 2.3 the first node chosen was the node above and left diagonally to the starting node. From that node three nodes with the same H cost are available to be the next node. The left one is chosen randomly.

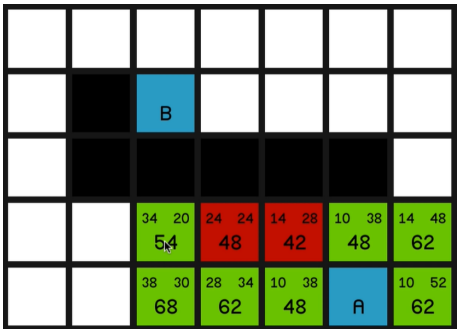

FIGURE 2.4: A* after two moves.

In figure 2.4 we see the left node is chosen, and all surrounding nodes H cost are calculated. The two new nodes H costs are larger than the two nodes available with the smallest H cost of 48. The algorithm can now reverse the direction of the path and explore the two available nodes. If ultimately their directions are not as efficient to the path on the left - maybe due to obstacles - the algorithm can simply reverse path again and will ultimately find the most efficient path available.

Chapter 3

Problem - Simulating Evolution and Processes of Natural Selection in a virtual ecosystem.

3.1 Problem Definition

The problem being addressed in this project is 'Can evolution and processes of natural selection take place in a virtual setting?' As today's technologies make consistent advancements, more discussion is being had about the possibility or inevitability of artificial life and what form life can take place in. Charles Darwin's theory of evolution states that an animal's characteristics can change over several generations due to their environment and that natural selection is the process that evolution relies on to do this. Today's technologies bring us further from the world of Charles Darwin and closer to that of one where the clear line linking life and biology is increasingly blurred.

What I hope to achieve is to demonstrate that these incredibly complex processes of evolution that have brought us the millions of unique and varied species of animals is not exclusive to the real world. But to simulate these processes we need to create our subject animal and simulate its life from beginning to end over several generations. It is the life that the animal lives that will determine whether or not they will be able to contribute their genetics to the next generation and thus have an effect on the physical makeup of the species. A problem arises however when trying to achieve this task, as to simulate an animal's life perfectly would mean to simulate all of the earth and the entire ecosystem of the world. I believe that the next best platform for this virtual environment to be in is a video game engine.

3.2 Objectives

Create environment

In the game engine, I will need to create an environment that not only is suitable for the subject species habitat but one that allows me to more easily implement environment elements and animal dynamics such as looking for food. I will aim to create a large 3D grid as the space the subject will live. This would be very useful later in the project when I will need to implement a pathfinding algorithm for the animals to get to food and water.

Add elements

I will then need to add essential elements of the environment that will be used to change for the affecting environmental factors. I will add sources of water in the form of pools or rivers for the animal to seek and plants for sources of food. I will also add elements to the landscape such as trees and large rocks that the pathfinding algorithm will have to avoid.

Model animal

I also aim to create a basic 3D model of the subject animal species. I also aim, if possible, to change their physical features based on how present a certain trait is in the individual.

Add traits

I will then consider all the traits of animals I found in research and choose the most suitable ones to implement in the subject animal. These traits will essentially be numbers that score the effectiveness of the animal's abilities. There are 3 traits that were common in all the projects I researched. Speed, size and sense. The rating of an animal's speed will dictate how fast the animal can move, size will determine how large it is and sense will determine how far away animals can see objects like food, water or predators. I will also then need to add traits that are determined by the environment such as hunger, thirst and reproductive urge.

Add behaviours

I will need to create a number of behaviours such as seeking food, seeking a mate, evading a predator etc. I will then need to create a system that determines what the current behaviour of an animal will be. This could be done through a value system of needs with the need with the lowest current value being the one that is given priority.

Collect data

I will need to implement into the video game engine, a system that collects data from multiple sources and a database where the data will be stored. The data that I will be collecting will be a number of variables that are given to each subject animal, such as their size, speed and sense as well as data that is relevant to the animal's environment like the quantity of food available in a given day. I will need this data to evaluate the outcome of the specific scenario that is being simulated.

Change factors and Collect data

I will then need to decide what factors in the ecosystem I will change. For example I may wish to find the outcome of a scenario where food quantities are low or when a predator is present. I will then need to collect the data produced from the scenario and compare it with the data collected from other scenarios.

3.3 Functional Requirements

1. An interface should be available to the user to change the environment and animal variables.
2. User should be able to change the quantity of food available in the environment.
3. User should be able to change the frequency of food available in the environment.
4. User should be able to set the whether a predator is present or not.
5. User should be able to set the initial values of subject's traits before running the application.
6. Data should be collected from the application continuously when appropriate.
7. The application should be able to be ended at any point with data still gathered.
8. Statistics should be automatically calculated from the data gathered at the end of running a scenario. An example of this would be calculating averages and medians.

9. Data should be automatically presented in a single location at the end of running a scenario.

3.4 Non-Functional Requirements

1. The application should be able to run on low-end PCs.
2. The application should take no longer than 8 seconds to start.
3. The application should be able to be ended without error.
4. The application should be able to be ended in no longer than 6 seconds.

Chapter 4

Implementation Approach

4.1 Architecture

Unity

The video game engine I intent to use is Unity. I believe this is the best choice of video game engine for my particular project as Unity is known for being the engine for smaller indie games as well as small personal projects. Some alternatives I could use are engines such as the Unreal Engine, however this engine is generally used for more realistic video games with massive scale as well as projects that focus on realistic visuals and physics. As my project will focus on the theme of evolution and the processes of natural selection, I do not think it would be wise to use a more advanced engine as elements such as visuals and physics will be irrelevant to the outcome of the project.

C#

Unity supports 3 scripting languages, C#, UnityScript, (JavaScript), and Boo. The only language I am familiar with from these is JavaScript but only to a very small extent. I believe my best decision would be to choose C# for scripting as I have become very familiar with the C programming language in my time in college from the C Programming and Embedded Systems modules. I think it would be easier to learn C# given my knowledge in C than to learn JavaScript or Boo from scratch.

C# should provide the means to script behaviours for the subject animal as well as environmental changes. I will also need to learn how to create objects and implement object-oriented architecture to effectively create and store data into a database.

Database

For my database I will use MySql. I will be using a relational database management system as I have used it in multiple previous projects and I believe this will be the optimal choice for the data I wish to store. I am also very familiar now with SQL querying so I believe I will be able to make full use of the relational database.

Web page And R

I plan to create a single location to display data and statistics of each scenario simulated. I think the simplest solution for this would be a webpage. I plan to learn and implement the language R to calculate and display relevant data and graphs for each scenario on the webpage.

4.2 Risk Assessment

TABLE 4.1: Risk 1

Risk	Sprint goal not reached
Risk Category	Critical Rare
Explanation	A sprint goal not being reached due to a underestimation of the scope or difficulty of tasks.
Mitigation	Allocation of extra time to complete the tasks not met. An evaluation of the product backlog should also take place if tasks are to be postponed to a later sprint.

TABLE 4.2: Risk 2

Risk	Unity no longer supports free licensing
Risk Category	Fatal Remote
Explanation	Unity Technologies no longer provides free licensing of Unity for personal use.
Mitigation	All progress made in Unity would be lost. An alternative game engine would have to be chosen and the in-game element of the project would have to begin again from scratch.

TABLE 4.3: Risk 3

Risk	Failure to grasp proper understanding of R language
Risk Category	Critical Rare
Explanation	I am unable to grasp the R language to a level needed for implementing data presentation.
Mitigation	Additional time would have to allocated in sprints for me to properly educate myself on the R language or a substitute language would be implemented its place.

TABLE 4.4: Initial risk matrix

Frequency/ Consequence	**1-Rare**	**2-Remote**	**3-Occasional**	**4-Probable**	**5-Frequent**
4-Fatal		**2**			
3-Critical	**1, 3**				
2-Major					
1-Minor					

4.3 Methodology

Research

I began my research by tackling the most approachable material first which was the existing projects involving Artificial Life. I felt that his would be a good point to start as it would give me a greater vision of the structure of a project involving Artificial Life and the common characteristic that each share. I also found this very helpful from the point of view as a student developing a project as all these projects were created by a single person for educational purposes or just for fun so this allowed me to get a sense of what the scale of my project will be. By comparing each of the projects I was able to analyse each method of implementation of environment, traits, behaviours and how each trait effected one of the subject animal's behaviours. I think the most beneficial part of this research was being able to observe the common traits of the subject animal in each project; sense and speed. This will be hugely beneficial to me in my implementation of my subject animal's traits and behaviours.

I then proceeded with my research by studying the state of the art to get a stronger understanding of the fundamentals of simulations and the various video game engines I could choose for my environmental setting. I also knew that I would like to implement a pathfinding algorithm for the multiple behaviours of my subject animal like finding food or evading predators. From my previous research in the existing projects I found multiple ways of creating the environment for the subject animal. It was at this point

when researching pathfinding algorithms, I decided that the 3D grid would be the perfect base for the environment as I could integrate the A* pathfinding algorithm directly onto it as it also uses a grid format. I then continued my research into the various books, conferences and journals that would provide me with a further understanding of the core themes of my project.

Technologies

Another element in the implementation of this project is the skills I will need to apply as a computer science student. I am relatively confident in my ability to apply the programming skills and techniques I have learnt to the scripting element of the project. However, I will also need to learn a range of new skills and languages like C# for scripting and R for data representation. A non-computer science skill I will also need to learn is how to 3D model simple animals and environment elements like trees, rocks and plants in Unity.

Approach

I plan to use an agile methodology throughout the course of the project. I predict that I will need to evolve my solutions for various parts of the development of the in-game application as I become more familiar with game engine and my capabilities and limits. I also plan to follow a scum framework for the implementation of the project. I believe this will be optimal for scheduling progress as well as allowing myself to change and adapt solutions as better ones present themselves.

4.4 Implementation Plan Schedule

Week 0-2

- Learn C# fundamentals.
- Learn R fundamentals.
- Diagram subject animal objects.
- Diagram formula for energy spent per step.
- Create database.

Week 2-4

- Diagram predator objects.
- Diagram behaviour decision system.
- Create grid environment.
- Model environment elements.
- Insert environment elements.

Week 4-6

- Model subject animal.
- Code Predator objects.
- Code behaviour decision system.
- Code subject animal objects.
- Insert subject animal.
- Create step animation.

Week 6-8

- Create pathfinding algorithm.
- Implement pathfinding algorithm onto environment grid.
- Implement behaviour: seek food.
- Implement behaviour: seek water.
- Implement trait: sense
- Implement trait: speed.
- Implement trait: size.
- Implement energy spent per step.

Week 8-10

- Code food spawning schedule system.
- Implement behaviour: seek mate.

- Code predator objects.
- Model predator.
- Insert predator.
- Implement predator behaviour: hunt.
- Implement behaviour: evade.

Midterm

- Implement writing to database from game engine.
- Create Interface for setting scenario variables.

Midterm – Week 13

- Create webpage for data representation.
- Implement data representation.

4.5 Evaluation

The first way I will evaluate if I have achieved my goals is by assessing the completion of all in-game environmental elements and the implementation of all animal behaviours and traits. This will be crucial for the final outcome of the project and the data I wish to produce. It is in-game world where these animal traits will directly affect behaviours and the animal's chance of survival. Without fully implementing all traits and behaviours, the data that I wish to produce and study will not be as relevant to the theme of evolution and natural selection as I intend to draw clear correlations between the animals environment and the average traits of the animal population. Therefore, it is vital that all intended behaviours and environmental elements are fully implemented for the sake of observing the preferred traits produced for that given ecosystem.

Another way I will measure the success of my project is by the production and presentation of data. This is the single most important element of the project as it will showcase the preferred animal traits produced by each scenario given different environmental factors. This data produced will ultimately be the foundation of the evolution theme of this project. I also hope to draw correlations and conclusions from the data for the ecology theme of the project by observing the effect on the population of the subject

animal and the relationship between animal population and the availability of resources in the environment, thereby giving credence to the ecosystem aspect of the project.

4.6 Prototype

ID	Sex	Speed	Sense	Size	Birth Day	Death Day	Cause of death
1	Male	1.2	0.9	1.3	7	14	Starvation
2	Female	0.8	1.3	1.5	2	2	Hunted
3	Female	1.3	1.5	0.8	4	15	Starvation
4	Male	1.6	0.8	0.7	11	20	Dehydration

FIGURE 4.1: Database table for animal data.

Figure 4.1 shows an early idea of what the database table will look like for the subject animal. I will need to include variables that will allow me to query the population of the animal for any given day for the purpose of calculating averages and observing trends over time.

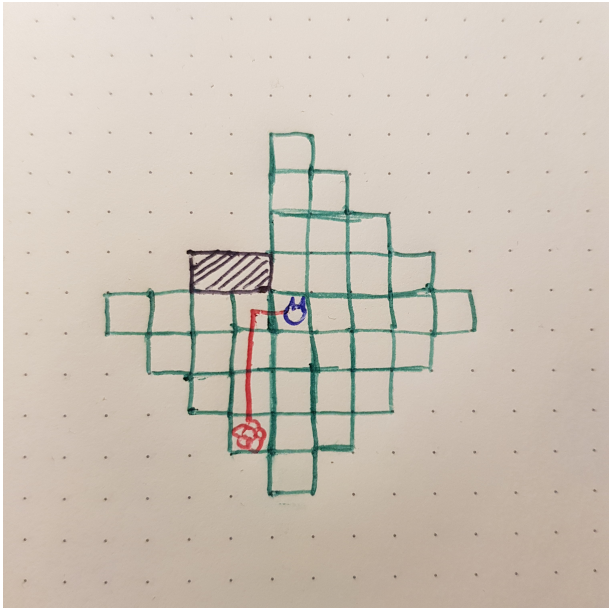

FIGURE 4.2: Sense range of animal on grid.

Figure 4.2 depicts the sense range of the subject animal. The animal is located in the centre with a rock above to the left. The green squares represent the range of vision of the animal with the rock obstructing part of it. A food source is depicted in red and a path is created from the animal to the food source.

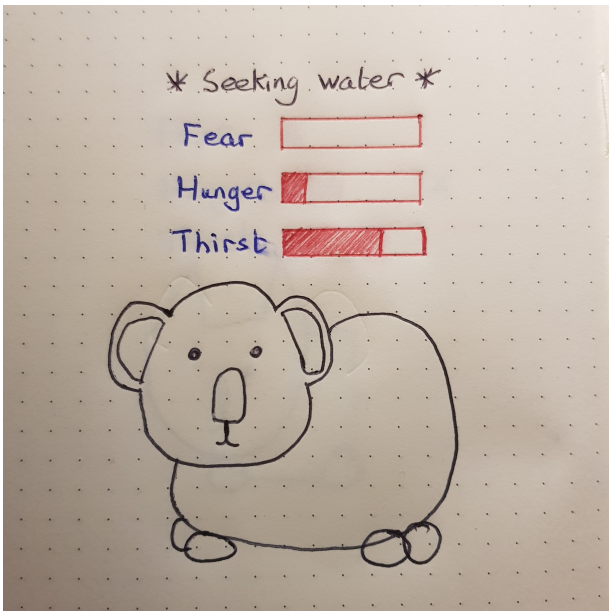

FIGURE 4.3: Animal with needs system.

Figure 4.3 dipicts an early depiction of the system I wish to implement to display an individual animal's needs above them. As you can see the thirst need is highest and thus the behaviour of the animal is set to seek water. If for example, a predator was chasing the animal, the fear bar would become the highest and the evade behaviour would be set to that individual.

Chapter 5

Conclusions and Future Work

5.1 Discussion

One issue I found difficult when researching this project is the lack of existing material to study. Artificial life is a smaller field of study and finding projects relating to evolution specifically proved to be harder than expected. Examples of these projects were exclusively produced by independent software engineers or YouTube creators for the sole purpose of demonstration and education. I did not have any trouble researching the simulation aspect of my project as examples of simulations can be found in many forms, with some of today's video games themselves providing a persuasive replication of real world driving and flying. However, it was only in the few independent projects I researched where I found examples of virtual creatures with inheritable traits that allowed for the evolving of a species over time. Due to this lack of existing material I was unable to find any pre-established methodology framework for developing such a project. That being said I was still able to draw similarities between projects and observe mutual features shared by all of them. These findings alone will be incredibly beneficial to me moving forward in the implementation of my project as it will provide me some fundamentals needed for creating a project involving natural selection simulation.

Another aspect I found challenging in the research phase of my project was understanding the scope and difficulty of implementing the project. Due to the nature of the research phase itself, it was difficult to estimate the time required to complete various tasks in the implementation of the project without actually beginning them. As Unity is a new game engine to me, I have little understanding of how long each one of my tasks should take to implement. For example, scripting the animal's behaviours may be a task that I vastly overestimate the complexity of, while 3D modelling the animal may

take much longer than anticipated and require additional time to learn the basics of the particular feature of the game engine.

5.2 Conclusion

Overall, I feel the research phase of this project went quite well. Evolution and ecology have always been of great interest to me and are fields of study that I have been exploring and educating myself on for a number of years now. I believe this interest provided me with a clear vision of what I intend to implement and demonstrate as well as helped me more clearly define the problem definition section of the project. I also found the background chapter of this project to be the most rewarding chapter that I worked on as it gave me the opportunity to research the various elements of my intended project and provided me with a greater understanding of similar projects and their shared features as well as the current state of the art in simulation, video game engines and various pathfinding algorithms.

I found the implementation approach chapter to be the most challenging part of the project. Scheduling tasks in sprints proved to be more difficult than anticipated due to my lack of knowledge in some of the technologies I plan to use. I could not be certain of what tasks can be achieved within the sprint goal and if my sprints are too ambitious or not ambitious enough. However, this unknown variable should reveal itself in the implementation phase.

This phase of the project also gave me a important insight into how a thesis is written and the framework needed to properly write one. This was my first thesis I have written, and it has provided me with a clearer understanding of the research required for a project and how to correctly present the context of a project theme as well as discuss the theme itself. I believe this phase alone will be hugely advantageous to me in the corporate world and in my future career as a Software Engineer.

5.3 Future Work

Given additional time for the research phase of this project I would aim to complete a number of things. First, I would like to create a similar simulation in Java using objects and random chance in lieu of animal behaviours. I would generate several objects that would take the place of the subject animal with each object having a number of variables that would act as the animal's traits. I would then create a grid using arrays with food sources sporadically placed within. Without having the ability to set a speed of the

animal's step, I would create a turn-based system with animals with the highest speed rating having the first turn and the slower animals proceeding. I would also like to experiment with multiple formulas for the animal's energy spent per step and find one that does not generate vastly different energy spent per step ratings for every animal but rather add or subtract a small margin of energy spent per step with each change of a trait rating.

I would also like to create an A* pathfinding algorithm in Java using arrays and experiment with creating various obstacles for the path to navigate around. This would be very beneficial to me in the implementation phase as I would have a greater understanding of how I should go about implementing it onto the game engines grid environment. Finally, if given more time in the research phase I would have liked to take a short course on Unity to familiarise myself with the game engine and learn the fundamentals of creating an environment in that specific engine.

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Appendix A

Wireframe Models

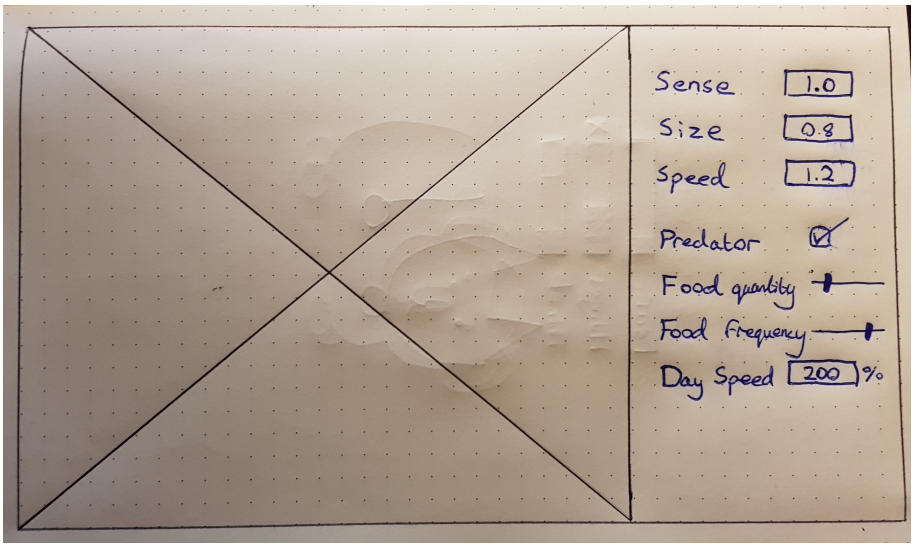

Figure A.1: Application Wireframe

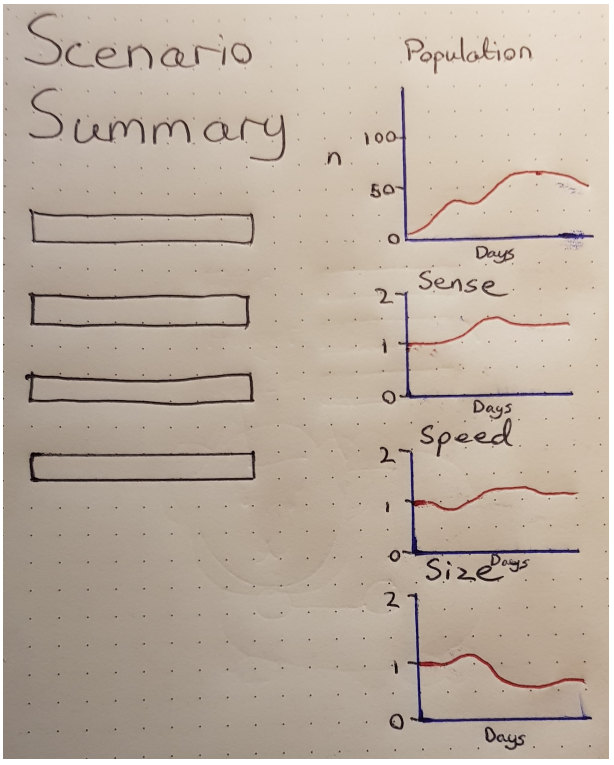

FIGURE A.2: Summary report Wireframe