

CoviSim: Research on the Use of a Simulated Environment to Demonstrate the Transmission of COVID-19

Final Project Report

DT211C

BSc in Computer Science (Infrastructure)

**Kyle Heffernan**

**C17444434**

**Bryan Duggan**

School of Computer Science

Technological University, Dublin

**31/03/2021**

Abstract

Computer simulation has always been an invaluable tool when it comes to researching infectious diseases, as real-life experiments have many potential risks. Over the course of the past year, countless scientists and doctors all over the world have been continuously researching Coronavirus in a global effort to overcome the pandemic and get back to normal everyday life. There have been numerous Coronavirus related simulations made over the past year focusing on a wide variety of aspects of the virus.

Many simulations offer a high-level overview of the pandemic on a large scale, having only a few variables affecting the results. These simulations tend to focus on the spread throughout a city, and the virus is transmitted when agents come within a certain range of an infected agent. While this serves as a good visualisation of spread throughout a population, it is a drastic oversimplification of how transmission can occur and does not show how the virus actually transmits between people.

This project is focused on transmission in a closed environment, highlighting the actual methods of transmission and allowing the user to truly understand how certain countermeasures affect the results. There is a surplus of medical papers and scientific studies from around the world which provide statistics on transmission rates and the effects of various countermeasures. Some of these statistics have been utilised in the simulation as parameters to give a more accurate result.

As Coronavirus continues to grow, so does misinformation about it on social media. While a small amount of information is given to the public about countermeasures that they can take to prevent transmission, the results of these countermeasures are not easy to identify. This simulation is a practical solution to this, using real figures to visualise transmission and the effectiveness of various countermeasures in a real-time closed environment.

Declaration

I hereby declare that the work described in this dissertation is, except where otherwise stated, entirely my own work and has not been submitted as an exercise for a degree at this or any other university.

Signed:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Kyle Heffernan

Date: 31/03/2021

Acknowledgements

I would like to thank my supervisor Bryan Duggan for his continuous support, guidance and motivating words throughout the course of this year. I would also like to thank my friends for keeping me motivated and on track this year with our countless online study sessions.

A special thanks to my family for always keeping me grounded and helping me through the more stressful times, and finally Danniella for her constant love and support which I could not have done this project without.

Table of Contents

[1. Introduction 7](#_Toc21459636)

[1.1. Project Background 7](#_Toc21459637)

[1.2. Project Description 7](#_Toc21459638)

[1.3. Project Aims and Objectives 7](#_Toc21459639)

[1.4. Project Scope 7](#_Toc21459640)

[1.5. Thesis Roadmap 7](#_Toc21459641)

[2. Literature Review 8](#_Toc21459642)

[2.1. Introduction 8](#_Toc21459643)

[2.2. Research Topic 1 8](#_Toc21459644)

[2.3. Research Topic 2 8](#_Toc21459645)

[2.4. Existing Final Year Projects 8](#_Toc21459646)

[2.5. Conclusions 8](#_Toc21459647)

[3. Experiment Design 9](#_Toc21459648)

[3.1 Introduction 9](#_Toc21459649)

[3.2. Software Design 9](#_Toc21459650)

[3.3. Software Test plan 9](#_Toc21459651)

[3.4. Front-End 9](#_Toc21459652)

[3.5. Middle-Tier 9](#_Toc21459653)

[3.6. Back-End 9](#_Toc21459654)

[3.7. Conclusions 9](#_Toc21459655)

[4. Experiment Development 10](#_Toc21459656)

[4.1. Introduction 10](#_Toc21459657)

[4.2. Software Development 10](#_Toc21459658)

[4.3. Front-End 10](#_Toc21459659)

[4.4. Middle-Tier 10](#_Toc21459660)

[4.5. Back-End 10](#_Toc21459661)

[4.6. Conclusions 10](#_Toc21459662)

[5. Evaluation 11](#_Toc21459663)

[5.1. Introduction 11](#_Toc21459664)

[5.2. Software Evaluation 11](#_Toc21459665)

[5.3. Specific Evaluation 11](#_Toc21459666)

[5.4. Questionnaires and Interviews Evaluation 11](#_Toc21459667)

[5.5. Conclusions 11](#_Toc21459668)

[6. Conclusions and Future Work 12](#_Toc21459669)

[6.1. Introduction 12](#_Toc21459670)

[6.2. Conclusions 12](#_Toc21459671)

[6.3. Future Work 12](#_Toc21459672)

[Bibliography 13](#_Toc21459673)

# Table of Figures

[Figure 1 – Grocery Store simulation 11](#_Toc59054345)

[Figure 2 – Spread simulation 12](#_Toc59054346)

[Figure 3 – Live output 13](#_Toc59054347)

[Figure 4 – Case studies 13](#_Toc59054348)

[Figure 5 – Sample assets 18](#_Toc59054349)

[Figure 6 – Office environment 19](#_Toc59054350)

[Figure 7 - NavMesh 19](#_Toc59054351)

[Figure 8 – Prototype Agent 20](#_Toc59054352)

[Figure 9 – Movement Code 20](#_Toc59054353)

[Figure 10 - Architecture 22](#_Toc59054354)

[Figure 11 – System Diagram 22](#_Toc59054355)

[Figure 12 – View of simulation 24](#_Toc59054356)

[Figure 13 - GUI 24](#_Toc59054357)

[Figure 14 – Use Case 25](#_Toc59054358)

[Figure 15 – Class Diagram 26](#_Toc59054359)

# 1. Introduction

## Project Background

As the number of Coronavirus cases continue to grow worldwide, scientists and medical professionals from all over the world have been researching and studying the virus and its transmission to better understand and subsequently overcome it. Due to many real-life experiments being too risky to carry out, computer simulation has been an invaluable tool for developing further understanding of the virus and its transmission. This project involves creating a simulation of an environment in which transmission commonly occurs, an office.

There is a vast number of platforms available for developing in this field, but Unity stands out with its countless invaluable features and tools that enable swift and efficient development of real time simulations. The use of Unity also allows the use of various complex technologies, such as navigation mesh which creates a map of traversable areas in a scene and grants agents the ability to find the shortest path to their destination. A behaviour tree is another technology available in Unity which is a mathematical model of plan execution, meaning an artificially intelligent agent can switch between a set of tasks in a modular fashion. Unity also grants the ability to implement particle systems which can be used to simulate particles being expelled during breathing. Finally, Unity also has the entity component system, which is a new data-orientated design system which significantly boosts performance of the simulation if implemented correctly.

## Project Description

The purpose of this project is to simulate the environment of a populated office. The program starts off on a screen that allows the user to adjust certain variables which will affect the result.

Once the simulation is started, autonomous agents enter the building representing workers going about their daily work shift. The building has a navigation mesh which is utilised by the agents so they can path find through the office. At the start of the simulation, each agent goes to their respective desk, which is chosen at random at the start and begins working. Agents will intermittently do various tasks such as retrieving a file or printing something off and then return to their desks. This is due to each of the agents having a behaviour tree, so they have a set of tasks that they switch between.

One of the agents is infected with COVID-19 and is continuously spreading it throughout the office as the day goes on via a particle system that emulates breathing. The virus is spread by the particles emit, which can contaminate a surface or expose an agent if they collide with it. Agents also have a chance of becoming exposed if they touch another exposed agent or if they touch a contaminated surface. The chances of an agent becoming exposed when they come in contact with an infectious particle are affected by what the user selected at the start of the simulation, and the figures used in these calculations are taken from a WHO backed study. (x)

As the simulation runs, the user can walk around the office to get a better view of the virus spreading, or they can look through the office security cameras. The user is also able to change the rate at which time passes, so they could have the simulation run at times ten-speed to see the results faster.

Once the working hours set by the user have ended, the agents begin to leave the office. Once they all leave, a screen is displayed to the user with statistics from the simulation that was just run, and the user has the option to run the simulation again with different options.

### Factors the user can change:

**Working Hours:** The amount of time the users stay in the office.

**If healthy agents are vaccinated**: This alters the chances of a healthy agent becoming exposed.

**If healthy agents wear masks**: This alters the chances of a healthy agent becoming exposed.

**If infected agents wear masks**: This alters the number of particles emit by the infectious agent.

**Time scale:** The rate at which time passes in the simulation.

## Project Aims and Objectives

1. Identify and review suitable literature and other references relevant to this project
2. Describe some other software systems that are like this project
3. Undertake a thorough design process, including a methodology and detailed design
4. Develop a working software system using suitable technologies
5. Test and Evaluate the developed system
6. Critically reflect on the outcomes of this entire process

## Project Scope

This project allows users to view a COVID-19 simulation in real time and alter certain variables to see how they affect the transmission results. The simulation is made using Unity, and the environment in which the simulation takes place in is a populated building with autonomous agents using behaviour trees. Navigation Mesh is used to map out the walkable paths for the agents throughout this environment. The agents have human models and custom AI allowing them to go to their assigned desk and work, intermittently going to do various tasks around the office. Then once their working hours end, they leave the office.

Infected agents emit particles using Unity’s Particle System that leave surfaces contaminated and they can expose other agents to the virus based on their susceptibility. Agents can also become exposed from a contaminated surface or from getting too close to a different exposed agent. As the simulation is running, the user can walk around or look through the office security cameras. The user can alter the time scale to speed up the simulation, and they can also adjust variables that affect the result of the simulation. When the agents all leave the office, a screen is displayed with some statistics from the simulation that was just run, and the user can then restart the simulation with different variables.

## Thesis Roadmap

### Literature Review

In this chapter, a description of the main technologies and resources researched is presented, including academic papers, tutorials, books, and websites. The main technologies involved with the system are discussed, along with some other related research. It also looks at existing virus simulations made in Unity and previous final year projects with similarities to this project.

### Experiment Design

In this chapter, the software methodology used during the development process is discussed with the reasoning behind its choice, and an overview of the system is presented. The technical architecture of the system is presented, and the design of the front-end and back-end of the system is described with the aid of numerous diagrams.

### Experiment Development

In this chapter, the entire software development process is discussed in detail. Beginning at the prototype stage and moving through the process describing the development of each feature in detail, along with the issues faced and how they were overcome.

### Evaluation

This chapter discusses how the system was tested and how feedback was considered during the development process. The chapter also contains an in-depth evaluation of the system, discussing its performance, accuracy, and comparing its results to alternative similar systems.

### Conclusions and Future Work

This chapter summarises the complete project, discussing the major concepts learned during the development process as well as the issues that arose and how they were approached. Finally, this chapter concludes with a discussion of the future of this project and how it can be expanded upon with certain features and generally improved.

# 2. Literature Review

## 2.1. Introduction

In this chapter a review of relevant research and other software is presented as it relates to the simulation system. First existing software that performs similar functions to this project are presented, and following that, the technologies be used in this system Other research including academic papers and web information are presented. Finally, two existing final year projects are discussed.

## 2.2. Alternative Existing Solutions to Your Problem

### Exploring new ways to simulate the coronavirus spread (1)

Released in May 2020, this Unity Blog is about a Coronavirus spread simulation which is developed in Unity and C#. The project contains a simulation of a grocery store, with customers coming and going to and from the store. Some customers are infected and can expose other customers to the virus if they are within a certain range for long enough. The project has a GUI at the side of the screen which allows the user to alter various parameters, apply the changes, and see how they affect the results which are also displayed on the GUI.



Figure – Grocery Store simulation

### Software Features:

**Grocery Store Environment:** The project contains a simulated grocery store, with aisles, registers, entrances etc. The shoppers travel around this simulated store.

**Shoppers:** There are agents in the shape of capsules which represent shoppers. They follow certain routes throughout the store.

**Configurable parameters:** Parameters like exposure distance and transmission probability are adjustable using the sliders in the GUI on the right of the screen. Once the “Apply and Reset” button is pressed, the actual variables which are used in the simulation are updated accordingly, and the effects will be visible.

**Time scale:** The scale of the simulation can be adjusted using the GUI, allowing the user to choose how fast they would like time to go by in the simulation.

**Mapping:** The traversable routes are determined procedurally based on criteria including entrances and exits, whether certain sections are one way only, and making sure there are no collisions.

**Movement:** When shoppers spawn, they pick random traversable paths throughout the store. These paths start at the entrance, have random amounts of intermediate goals, and end at the exit.

**Exposure:** Shoppers spawn as either healthy or infectious. When infectious shoppers come close with other shoppers, they can expose them to the virus based on some set parameters. These shoppers are then set to exposed.

**Queuing:** Before each shopper approaches the registers, they check if there are any open registers, and then get queued accordingly based on the store policy parameters.

This grocery store simulation has many similar features to this project. The concept of having a GUI screen with configurable parameters is close to the GUI that this project has, although this project has project has the GUI screen only at the start. A lot of the other features are rather similar too, such as having agents walk throughout the simulated environment with a chance of becoming exposed. The logic of having infectious agents exposing healthy agents to the virus is the same, although this project is much more in depth, having the actual particles emit from breathing being the carrier of the virus rather than just a simple collision behaviour. The grocery store itself is also similar to the simulated office in which this project takes place in, although this project offers a 3d space in which the player can move around in rather than just a top-down view.

Both the grocery store project and this project are made completely in Unity and C#, so the technologies used are closely related, although this project makes use of some more complicated technologies such as behaviour trees for AI and particle systems to emulate breathing.

How coronavirus spreads through a population and how we can beat it (2)

Published in early 2020, this article presents a simulation of the spread of certain viruses throughout a population of people. It allows the user to adjust some parameters using the sliders at the top, and then shows how the virus would spread over a period of time. As well as allowing the user to adjust these parameters, they can also select one of the case studies and see a visualisation of the spread using statistics from the actual case study.



Figure – Spread simulation



Figure – Live output

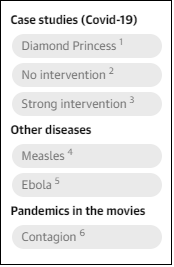


Figure – Case studies

### Software Features:

**Infectious indicators:** Members of the population start off as yellow which indicates a healthy person. Red indicates they are infected with the virus, and purple represents people who have died from the virus.

**Adjustable parameters:** As seen in the top of the screenshot, the user can move the sliders to change the parameters of the simulation. They can then see of visualisation of how the chosen values would affect the results.

**Case studies:** The user can select from a short list of case studies to see a visualisation of the spread that took place during these case studies.

**Utilising real statistics:** If a case study is chosen by the user, the simulation will run using parameters taken from real life statistics.

**Displaying results:** As the simulation runs through the phases, it updates the visualisation of the population with the corresponding colours. It also displays the numbers after each phase and displays the stage on a chart as it updates.

This population spread simulation also has numerous similarities to this project. Both projects take some statistics from real life and use them as parameters for the simulation, and also allow the user to adjust variables and see the results. They also both focus on visualising the spread of the virus, although the population spread simulation went in a completely different direction, focusing on spread over a long amount of time, and as a result it is much less detailed than this project is and does not touch on the transmission methods of the virus, in turn making it a somewhat simple system.

## 2.3. Technologies you’ve researched

### Godot (3)

Godot is an open-source game engine that is known for its node-based architecture and object-oriented API. It was released under the MIT license and runs on most operating systems. It has many useful tools for game development, such as the scene tree editor, the script editor, a script debugger, etc. It also has an asset store from which numerous plugins can be downloaded to extend functionality. Godot contains engines for physics and lighting and many other mechanics that make game development swift and efficient.

Godot is a useful tool for developing projects such as simulations due to its long list of features, although it is nowhere near as widespread or as popular as Unity, therefore there is much less documentation and tutorials available online for it.

### Unity (4)

Unity is cross platform game engine that is widely used for a variety of applications. It was developed by Unity Technologies and released in 2005. The Unity asset store has an ever-growing catalogue of assets and tools which make project development with Unity considerably faster than many alternatives. Unity is also full of useful tools such as a debugger, a script editor, a scene editor etc.

It is extremely accessible and used globally, so there is a surplus of tutorials and online resources to learn from. These resources include plenty of sample projects full of detailed documentation which allows users to develop a detailed understanding of the underlying concepts in these projects. It also excels in real-time simulation, which is perfect for this project.

### Unity Render Pipelines (5)

In Unity, a project can use one of various render pipelines. The render pipeline performs a set of operations which entail taking the contents of a scene and displaying them on the screen. Different render pipelines have different capabilities and performance, so it depends on the nature of the project. The built-in render pipeline is the default render pipeline for Unity. It has limited customisation, for general purposes. There are other render pipelines available which focus more on graphics, but this project does not centre on graphics, so it is using the built-in render pipeline.

### Unity Navigation Mesh (6)

NavMesh (Navigation Mesh) is a tool for mapping out the traversable areas of an environment and the paths that agents can take through this environment. The process entails rendering a mesh of the walkable areas, allowing agents to determine the shortest possible paths between locations. This helps AI look more natural as it travels through an environment. This project has autonomous agents following paths through the course of the simulation, so navigation mesh was an obvious choice to assist in the pathfinding.

### ParticleSystem (7)

ParticleSystem is Unity’s in-built implementation of a particle system, containing a vast number of properties and methods which can be altered to get different effects. When properties are set, they are passed immediately into native code to give the best performance. ParticleSystem is used to display a wide array of items such as fire, liquids, explosions, gasses etc.

This simulation uses ParticleSystem to emulate breathing and implement the actual virus particles being expelled from infectious agents which is the method of virus transmission.

Behaviour Trees (x)

Behaviour trees are a hierarchical branching system of nodes which all share a parent known as the root. They begin evaluating from the top and run through each child based on certain set conditions. They allow for an AI agent to follow a strictly defined set of rules based on each nodes position in the hierarchy. They have slowly become extremely popular, being used for the AI in well-known games such as Halo and The Sims.

Behaviour trees were perfect for this project as the agents need to have AI which made them enter the office, work, do random tasks, and eventually go home. Behaviour trees make this kind of AI possible and less complicated than other options.

### Entity Component System (8)

Entity Component System (ECS) is a new way to develop in Unity that focuses on data-oriented design rather than object-oriented design. It breaks the project into 3 sections:

**Entities** – The actual things in your simulation

**Components** – The data associated with these entities but organised by the data rather than by entity.

**Systems** – The behaviours that update the component data. For example, A movement system would update positions of moving entities by their velocity and time passed.

Projects using ECS have greatly improved performance, making it an extremely useful instrument for simulations with a lot going on, however it is still in beta and can be quite unreliable and buggy.

### C# (9)

C# is a modern object oriented, component orientated programming language. It was developed by Microsoft in 2000 as part of its .NET initiative, and approved as an international standard in 2002. Like Unity, due to its widespread use, there is a vast number of resources available online to assist in understanding the underlying concepts. Applications made with C# are generally quite robust due to its many supportive features. Exception handing is a feature of C# which allows the detection and recovery of errors. Garbage collection is another useful feature which automatically reclaims unused memory.

It is the language that Unity scripts are mainly written in, so the coding in this project is mostly done in C#.

### C# job system (10)

The Unity C# Job System allows users to have multithreaded code in their projects. It integrates with Unity’s native job system, so user-written code and Unity share worker threads. This ensures that there are not more threads than CPU cores. This multithreaded code can greatly improve performance of the project. The C# job System works well with the Unity Entity Component System due to its efficient way of writing code.

The C# Job System improves performance, although it can be very confusing and there is not as much documentation or resources available online.

## 2.4. Other Research you’ve done

### COVID-19 Transmission Research

There has been a great amount of research done in the last year regarding the transmission of COVID-19, and numerous factors have been found to influence the probability of transmission. Physical distancing has been shown to reduce transmission rates (11) as the infected particles can only be expelled a certain amount. (12) Masks have also been shown to reduce the particles expelled from an infectious person and reduce the chance of someone breathing in infectious particles. (x) Factors such as vitamin D levels (13) or age can determine a person’s susceptibility to the virus due to the strength of their immune system. Vaccinations can reduce the risk of transmission by over 95%. (x)

Closed environments have also been found to be a contributor to secondary transmission and can lead to superspreading events. (14)

This simulation has a number of parameters that the user can change and see how they alter results. The parameters this system uses have been chosen as they have been shown to have an effect on transmission.

### Data Visualisation

The use of images and simulations to visualise data has been shown to help develop a greater understanding and comprehension of data than ever before. (15) Many people struggle to truly grasp the implications of raw data without some useful kind of visualisation. Some methods of visualisation do a much better job than others though.

Game techniques and mechanisms such as real time simulations have been shown to aid in the understanding of certain topics as they are a more engaging form of learning. (16)

## 2.5. Existing Final Year Projects

### Traffic Simulation System for Driverless Vehicles by Fionn McGuire.

A traffic simulation system for the deployment of driverless vehicles in modern day society by using Unity3D. The platform utilizes an interactive OSM map of Manhattan populated with both drivers and driverless vehicles. The vehicles generate a route to follow while perpetually responding to changes in the environment.

This traffic simulation is also made in Unity and contains many agents which populate an environment and have a set of behaviours to follow. This project has a lot of similar mechanics, as it is also simulating multiple agents in an environment which have a set of behaviours and have interactions.

### Irish Crime Data Visualisation by Max Curtis.

A system to allow for the visualization of Ireland’s crime statistics. This data is an untapped resource in its current state. This project is an application that helps users understand a mountain of data using data visualisation techniques.

This data visualisation application has some similar concepts to this project, the main one being that the application helps users develop a greater understand of the available data. There is a vast amount of data available online about Coronavirus and its transmission but having a good visualisation can help users truly comprehend what the data implies.

## 2.6. Conclusions

In this chapter, the research done for the project was shown and presented. This research included similar existing systems, technologies related to the simulation, Coronavirus transmission research, and data visualisation research. Finally, two similar existing fourth year projects were discussed. When the project was being planned, these technologies were researched and reviewed thoroughly to determine what would be used.

# 3. Experiment Design

## 3.1 Introduction

In this chapter the design of the project and simulation are discussed. First the methodology used in this project will be outlined and following this a discussion of the technical architecture will be presented. The front-end design of the system will be presented next, showing the key screens of the simulation. The back-end is also discussed with Class Diagrams to show the design of the objects.

## 3.2. Software Methodology

Agile software methodologies focus on continuous delivery of valuable software, and the primary measure of progress is working software. (18)

The software methodology this project uses is agile scrum. Agile scrum focuses on dividing the project into sprints, which are short-timed periods in which an amount of work is set to complete, generally focusing on a specific feature of the project. Before each sprint, it is planned what work will be delivered from the sprint, and how that work will be achieved. One feature of the scrum methodology is regularly reflecting on work done and learning from it, in turn becoming more efficient as behaviour is adjusted accordingly. (19)

Scrum works well for projects with many important features, so it is perfect for this project. This project contains numerous important features which can be developed and implemented during these sprints, and then further improved with future iterations. This approach allows for many core features to be implemented successfully with some complexity, and then they can be improved and fleshed out later with less important features.

The waterfall model is a good example of a software methodology that would not work with this project. The waterfall model entails running through the entire project in a single iteration, never going back and making modifications or changes. This would not work as features of this project need to be iteratively designed, with a simple design working first, and then after some testing, reflecting, and further development, they can be revisited with a greater understanding of requirements and design.

## 3.3. Project Management

GitHub was chosen to be used for project management and keeping track of development. It is very straightforward to use, having a simple GUI program and well as a console interface. Every step of development was saved in a commit and pushed to the project, allowing for effortless version control and for making sure that no work is lost. There were multiple times during development where the project had numerous errors which were easily fixed by reverting to a previous version. GitHub also has a task board feature, allowing you to separate out the various features to be developed with tags denoting their importance and what section of the project they belong too. This was invaluable for keeping track of features during the different development stages.

## 3.4. Overview of System

### 3.4.1. Technical Architecture

As this project is entirely in Unity and C#, it’s technical architecture is a standalone system.



Figure - Architecture

### 3.4.2. System Diagram



Figure – System Diagram

## 3.5. Front-End

### 3.5.1. Key Screens

The project contains 3 main key screens. One of which being the actual game view of the 3D simulation. With this, the user will able to watch in real time as the agents walk around the environment, possibly being exposed to transmission of the virus.



Figure – View of simulation

The second key screen of the project is the interactive GUI in which the user can adjust various parameters of the simulation. This screen is filled with buttons and sliders which adjust the actual parameters used in the simulation.



Figure - GUI

### 3.5.2 Use Cases

Below, a simple use case for this system is shown. The users primary goal would be to run the simulation and observe the results, altering parameters and noticing how they affect the output.



Figure – Use Case

## 3.6. Back-End

### 3.6.1 Class Diagrams

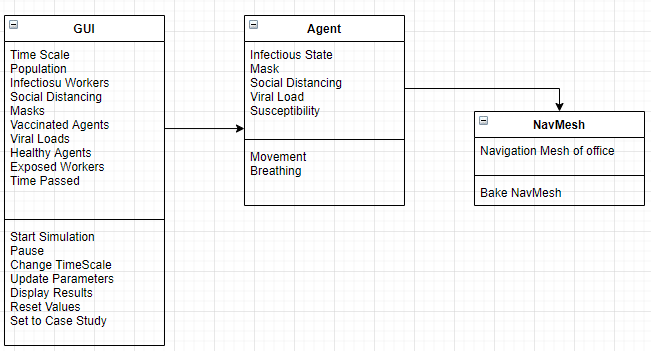


Figure – Class Diagram

## 3.7. Conclusions

In this chapter, the design of the simulation system was presented. First, the agile scrum methodology was discussed as the approach to be used in this project. Following this, the technical architecture of the system was presented.

The front-end design of the system was presented next, showing the 2 key screens of the simulation. The back-end was also discussed with a class diagram to show the design of the objects.

### 

Requirements table.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **ID** | **Name** | **Description** | **Priority** | **Version** |
| 1 | Real Time Simulation | The user can watch the simulation run in real time and observe the virus spreading between agents. | High | 1.0 |
| 2 | Change Variables | The user can adjust certain variables that alter the results of the simulation via the GUI. | High | 1.1 |
| 3 | Utilize Unity’s Navigation Mesh System | The autonomous agents in this simulation will be able to path find through the building with the help of the navigation mesh. | High | 1.0 |
| 4 | Autonomous Agents | The agents follow certain behaviours as they path find throughout the building following various feasible paths. | High | 1.0 |
| 5 | Use Data from Medical Papers | The methods of transmission and exposure will make use of statistics taken from medical papers/journals | High | 1.2 |
| 6 | Display Results | The user can see statistics about the number of agents exposed to the virus as the simulation runs. | High | 1.1 |
| 7 | Utilize Unity’s Particle System | The infected agents will be emitting infected particles from their mouths with the use of Unity’s particle system. | High | 1.3 |
| 8 | GUI with sliders | A GUI will be displayed to the user containing sliders to alter variables and display some real time results. | Low | 1.1 |
| 9 | Time Scale | The user can alter the time scale via the GUI to have the simulation run faster or slower depending on their preferences. | High | 1.4 |
| 10 | Infectious agents | Agents will either be healthy, infectious or exposed. Most spawn as healthy and can become exposed if they come in contact with the virus. | High | 1.1 |
| 11 | Simulated environment | The project takes place in a simulated environment of a location in which transmission would occur. | High | 1.0 |
| 12 | Utilize Entity Component System | The entity component system is a data-oriented way of programming which significantly increase performance. | Low | 1.5 |
| 13 | Utilize C# Job System | The C# Job System would allow for Scripts and certain processes to be multithreaded. | Low | 1.5 |

# 4. Experiment Development

## 4.1. Introduction

In this chapter the entire development process will be outlines and discussed. The chapter will begin with setting up the environment and the beginning of the development leading to the prototype, and then go through the feature-based development cycle discussing the underlying technologies of each feature and the issues faced during the implementation of these features.

## 4.2. Environment Setup

Before development began, a GitHub repository was created and a Unity project and a “.gitignore” file were added. The “.gitignore” file was for making sure certain unnecessary files were not uploaded every time a commit was made. The Unity project was set up using Unity 2019.4.14f1, which is the 2019 long term support version. This version was chosen as it was the newest LTS release which are known to be more stable than other versions. A task board and Google Doc were also set up as a way to keep track of development.

## 4.3. Entity Component System

Due to the simulation having to have numerous calculations and behaviours run at real time, performance was sure to be important. The Entity Component System (ECS) would be a solution to this, as it is a great way to optimize importance due its data orientated design and multithreading capabilities.

Development began with getting some simple ECS systems working. Some online tutorials were followed to achieve this, and although they were generally unrelated to the project, they were invaluable for achieving a greater understanding of the scope of ECS and whether it would be a viable option for this project. The ECS preview packages needed to be imported into Unity for the project to work.

These tutorials comprised of getting objects to hover and spin and have a player be able to move around and collect them, having a stats counter be constantly displayed. Traditionally in Unity this could be achieved by attaching scripts to a couple game objects, but with ECS rather than game objects there were some entities in the scene with corresponding data components, and separate systems which acted as the behaviours and could be multithreaded using the C# job system. This data-oriented design over the usual object-oriented design results in the program running significantly better as it is a much more efficient method of doing things.

Even though this was a small-scale test project, many issues were encountered. The main issues being the volatile nature of ECS due it still being in beta. There were frequent updates which completely changed certain aspects of the system, making a vast amount of the available online material redundant. This was detrimental to development as it is a relatively new system and attempting to develop more complex behaviours with no material available would have would not have been possible during the length of this project. Another issue with ECS still being in beta was the fact that there were numerous bugs with every release, which could end up with certain not being possible or other features breaking with no feasible fixes.

Due to these issues, it was decided that the project would be developed in Unity without ECS, with the possibility of porting it over in future work.

## 4.3. SNAPS Tool and Navigation Mesh

After the decision to abandon ECS was made, a new project was created in the Unity 2019 LTS and added to the GitHub repository. This project was made with the standard render pipeline as graphics are not a focus. During research, an asset in the Unity Asset Store called “SNAPS” (x) which aids in the process of environment design was discovered. This tool contains themed asset packs containing accurately scaled prefab objects, and a script to allow for these objects to snap together on all three axis in the Unity scene editor, making environment design much more efficient. Each prototype pack follows a specific theme, and due to the fact that the simulation takes place in a workplace, the SNAPS Office asset pack was imported to the project.



Figure 5 – Sample assets

These prefab objects were placed in the scene and a simple office design was made. With an environment constructed, navigation mesh could now be implemented.



Figure 6 – Office environment

In Unity 2019, implementing a navigation mesh is relatively straight-forward once the scene is correctly set up. Any object that should be walkable by agents must be set to “navigation static”, and then they are all used in a process called “baking” which returns a map of all the walkable surfaces in the scene. This map can be shown in the Unity scene editor with Gizmos turned on.



Figure 7 - NavMesh

With a navigation mesh baked, objects with the “NavMesh Agent” component will be able to traverse the environment, finding the shortest paths to their destinations. To test this, a capsule was added to the scene with a NavMesh Agent component. A script was then written which takes the location clicked by the user by sending out a Raycast into the scene and sets it as the capsule’s destination. The update method is run every frame, so every frame the project was checking for any user input. This feature was presented in the prototype to show the navigation mesh working and soon removed.



Figure 9 – Movement Code

Another capsule was added to the scene with a separate movement script to allow the player to move around the office with keyboard controls, and the main camera was attached to this object. This script was also a placeholder script to show the office environment and would later be replaced by a more advanced script.

## 4.4. Simple path following and infection model

The next step of development was to have a simplistic prototype of the final project, with autonomous agents entering the office with a chance of becoming exposed to the virus. This was started off by adding more capsule objects with NavMesh Agent components to the scene and making a path following behaviour. Some random places in the office were added to a list of locations and a script was made which simply iterated through this list, setting these locations as destinations for the agents. This emulated the agents walking around the office and would soon be removed but was useful for the infection mechanics to take place.

With agents walking around the office, a simple infection model could be implemented. This was done using tags, with all but one of the agents being tagged as healthy and the final agent being tagged as infectious. Each agent had a capsule collider, so a simple script was made which changed the agents tag from healthy to exposed if anything tagged as infectious triggered their collider. Three corresponding materials were added to the project, with green representing healthy, yellow representing exposed and red representing infectious. The agents were set to their respective material and the script was modified so it would also change the agent’s material as well as their tag for visual clarity.

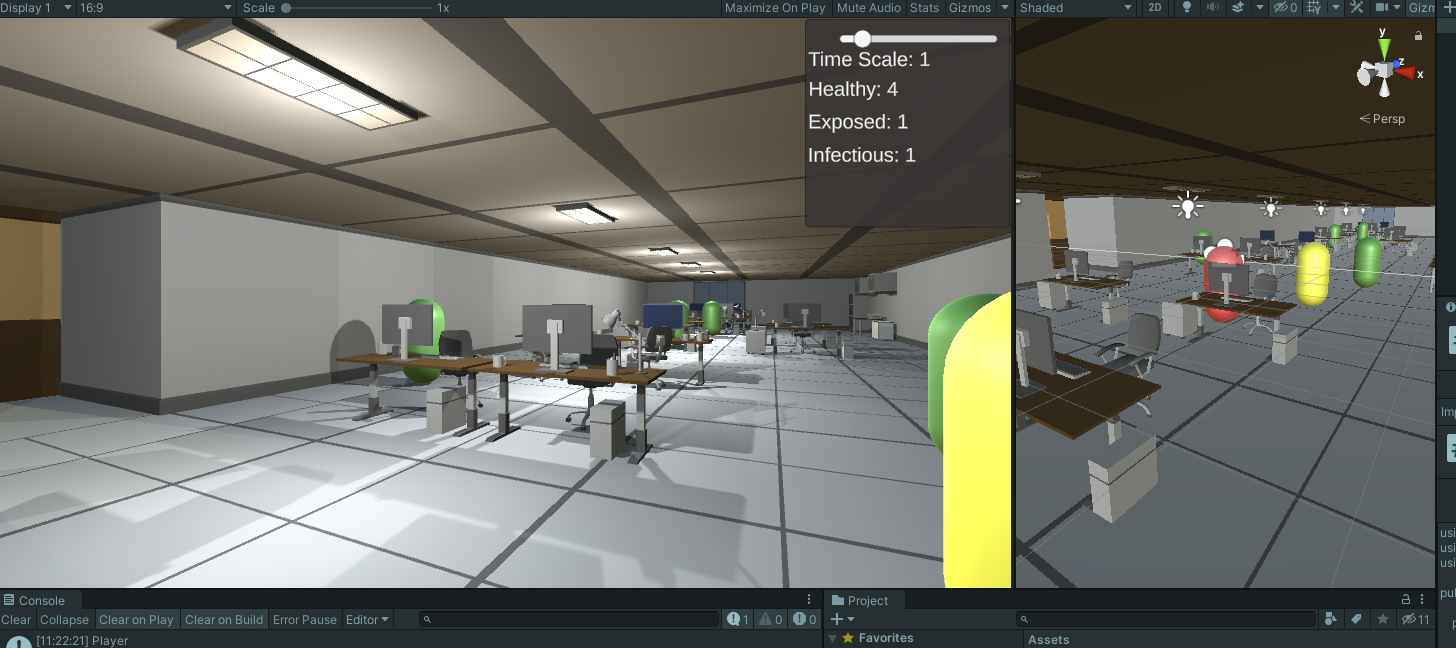


Figure x – Capsule agents

The office environment was also extended so the agents had more room to walk around the scene.

## 4.5. UI and Timescale

With a simple infection model working, some status counters which display statistics as the simulation is running were added to the corner of the screen.

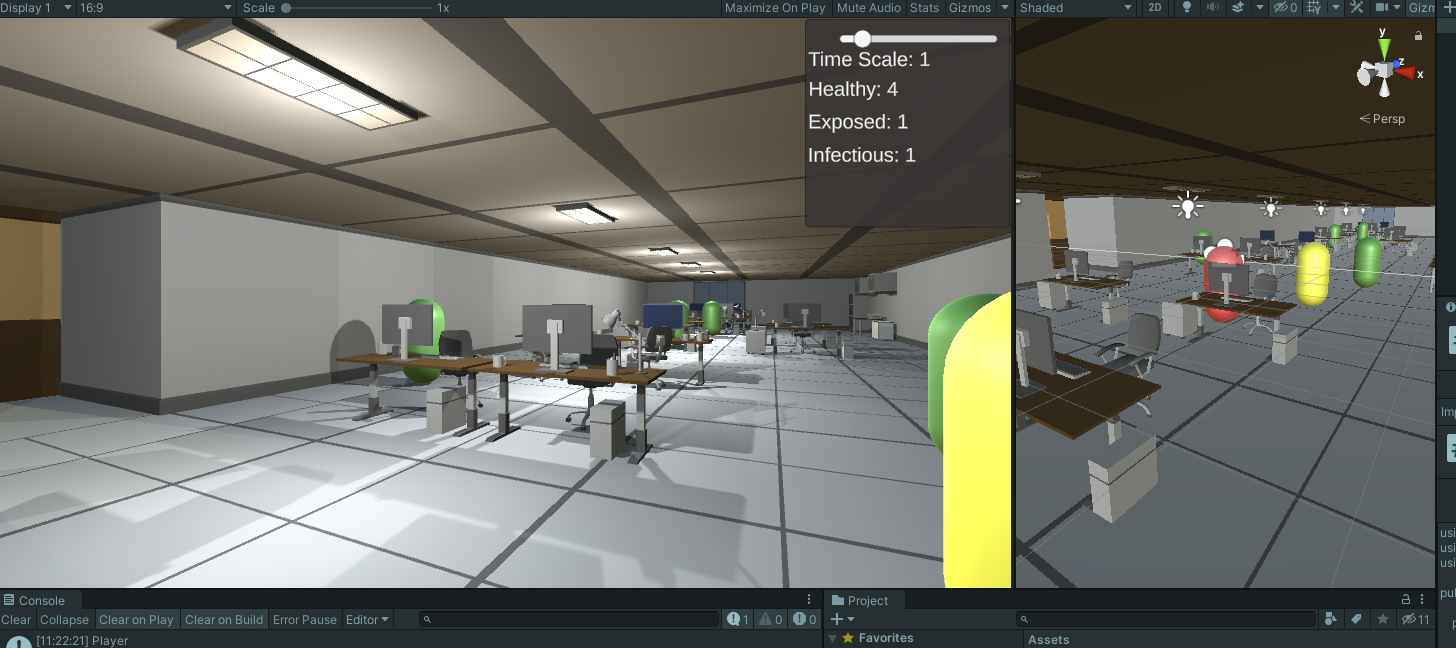


Figure x – Status counter displays

These counters display the current amount of healthy, exposed and infectious agents currently in the scene. This was done by making a list of all objects in the scene with their respective tag, and then displaying the length of each list.

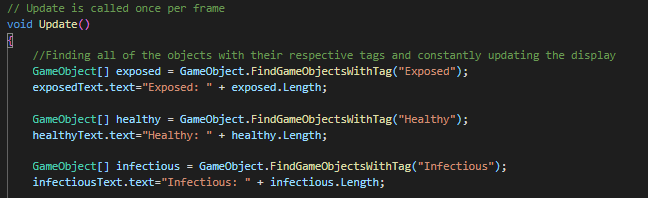


Figure x – Status counter code

The other element that was added to the screen was a timescale slider. This let the user change the speed at which the simulation runs at, so if they were to set the slider to 10, the simulation would run at times ten speed. This was done by multiplying the “Time.timescale” variable by the value of the slider. “Time.timescale” is a Unity varaible that controls the rate at which time passes.

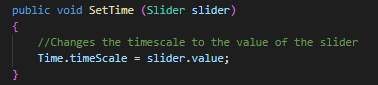


Figure x – Altering timescale

Finally, a simple start screen with a button was added which is on the screen before the simulation begins. Once the user clicks the button, the player movement, NavMesh agents and status counters are set to active. This was done by simply having them disabled by default, and having the buttons OnClick action set them to active.



Figure x – Start Button

## 4.6. Behaviour Trees

With the simulation having agents walking around, the virus spreading between them and status counters on the screen, behaviour trees were implemented and the path following behaviour was removed to make the agents follow set behaviours rather than just follow the same path.

The first step of implementing behaviour trees was to import the Panda BT asset from the Unity Asset Store. This asset contained a behaviour tree engine which allowed the creation of behaviour tree files which could be attached to agents to make them follow a set of logics written in the behaviour script.

A behaviour tree file and a behaviour script were both created after planning out and drawing a diagram of how the agents should behave. The simple plan was to have them enter the office and go to their desk, and after a set amount of time spent working, they would have a chance and leaving their desk to do a random desk in the office and then go back and continue working.

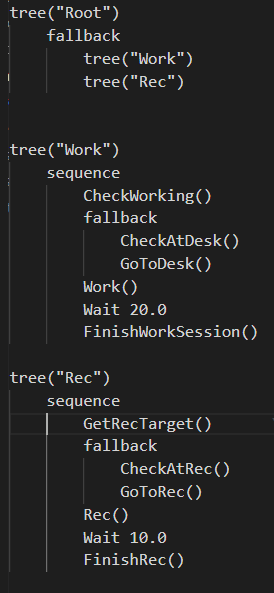


Figure x – Behaviour Tree

## 4.6. Conclusions

# 5. Testing and Evaluation

## 5.1. Introduction

## 5.2. System Testing

## 5.3. System Evaluation

## 5.4. Conclusions

# 6. Conclusions and Future Work

## 6.1. Introduction

## 6.2. Conclusions

## 6.3. Future Work

## Bibliography

1.

Fort J. Exploring new ways to simulate the coronavirus spreadUnity Simulation을 이용한 코로나바이러스 확산 시뮬레이션コロナウイルスの拡散をシミュレーションする新しい方法を探る - Unity Technologies Blog [Internet]. Unity Technologies Blog. 2020 [cited 2020 Dec 13]. Available from: <https://blogs.unity3d.com/2020/05/08/exploring-new-ways-to-simulate-the-coronavirus-spread/>

2.

Evershed N, Ball A. See how coronavirus can spread through a population, and how countries flatten the curve [Internet]. the Guardian. The Guardian; 2018 [cited 2020 Dec 14]. Available from: <https://www.theguardian.com/world/datablog/ng-interactive/2020/apr/22/see-how-coronavirus-can-spread-through-a-population-and-how-countries-flatten-the-curve>

3.

About — Godot Engine (stable) documentation in English [Internet]. Godotengine.org. 2020 [cited 2020 Dec 14]. Available from: <https://docs.godotengine.org/en/stable/about/index.html>

4.

Unity Essentials - Unity Learn [Internet]. Unity Learn. Unity Learn; 2020 [cited 2020 Dec 15]. Available from: <https://learn.unity.com/pathway/unity-essentials>

5.

Unity Technologies. Unity - Manual:  Render pipelines [Internet]. Unity3d.com. 2019 [cited 2020 Dec 15]. Available from: <https://docs.unity3d.com/Manual/render-pipelines.html>

6.

Unity Technologies. Unity - Manual: Building a NavMesh [Internet]. Unity3d.com. 2019 [cited 2020 Dec 15]. Available from: <https://docs.unity3d.com/Manual/nav-BuildingNavMesh.html>

7.

Unity Technologies. Unity - Scripting API: ParticleSystem [Internet]. Unity3d.com. 2019 [cited 2020 Dec 15]. Available from: <https://docs.unity3d.com/ScriptReference/ParticleSystem.html>

8.

Entity Component System | Entities | 0.16.0-preview.21 [Internet]. Unity3d.com. 2020 [cited 2020 Dec 15]. Available from: <https://docs.unity3d.com/Packages/com.unity.entities@0.16/manual/index.html>

9.

BillWagner. A Tour of C# - C# Guide [Internet]. Microsoft.com. 2020 [cited 2020 Dec 15]. Available from: <https://docs.microsoft.com/en-us/dotnet/csharp/tour-of-csharp/>

10.

Unity Technologies. Unity - Manual:  C# Job System Overview [Internet]. Unity3d.com. 2018 [cited 2020 Dec 15]. Available from: <https://docs.unity3d.com/2018.4/Documentation/Manual/JobSystemOverview.html>

11.

Tuite AR, Fisman DN, Greer AL. Mathematical modelling of COVID-19 transmission and mitigation strategies in the population of Ontario, Canada. Canadian Medical Association Journal [Internet]. 2020 Apr 8 [cited 2020 Dec 15];192(19):E497–505. Available from: <https://www.cmaj.ca/content/192/19/E497.full>

12.

Bourouiba L. A Sneeze. New England Journal of Medicine [Internet]. 2016 Aug 25 [cited 2020 Dec 15];375(8):e15. Available from: <https://www.nejm.org/doi/full/10.1056/NEJMicm1501197>

13.

Horne M. Coronavirus in Scotland: Vulnerable will receive vitamin D supplements [Internet]. Thetimes.co.uk. The Times; 2020 [cited 2020 Dec 15]. Available from: <https://www.thetimes.co.uk/article/coronavirus-in-scotland-vulnerable-will-receive-vitamin-d-supplements-zc8stdpkh>

14.

Nishiura H, Oshitani H, Kobayashi T, Saito T, Sunagawa T, Matsui T, et al. Closed environments facilitate secondary transmission of coronavirus disease 2019 (COVID-19). 2020 Mar 3 [cited 2020 Dec 15]; Available from: <https://www.medrxiv.org/content/10.1101/2020.02.28.20029272v2>

15.

Few S. Data Visualization - Past, Present, and Future [Internet]. 2007. Available from: <https://www.perceptualedge.com/articles/Whitepapers/Data_Visualization.pdf>

16.

Kiryakova G, Angelova N, Yordanova L. Gamification in education. Proceedings of 9th International Balkan Education and Science Conference.

17.

Snaps Prototype | Office [Internet]. @UnityAssetStore. Unity Asset Store; 2019 [cited 2020 Dec 15]. Available from: <https://assetstore.unity.com/packages/3d/environments/snaps-prototype-office-137490>

18.

Principles behind the Agile Manifesto [Internet]. Agilemanifesto.org. 2020 [cited 2020 Dec 16]. Available from: <http://agilemanifesto.org/principles.html>

19.

Atlassian. What is Scrum? [Internet]. Atlassian. 2018 [cited 2020 Dec 16]. Available from: <https://www.atlassian.com/agile/scrum>

20.

About Unity Test Framework | Test Framework | 1.1.20 [Internet]. Unity3d.com. 2019 [cited 2020 Dec 16]. Available from: <https://docs.unity3d.com/Packages/com.unity.test-framework@1.1/manual/index.html>

x.

Unity 2017 Game AI programming - Third Edition | Packt [Internet]. Packt. 2017 [cited 2021 Apr 4]. Available from: <https://www.packtpub.com/product/unity-2017-game-ai-programming-third-edition/9781788477901>

x.

Unity 2017 Game AI programming - Third Edition | Packt [Internet]. Packt. 2017 [cited 2021 Apr 4]. Available from: <https://www.packtpub.com/product/unity-2017-game-ai-programming-third-edition/9781788477901>