An Investigation into Machine Learning through the Simulation of Human Survival

Computer Science NEA

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1 Analysis

1.1 Statement of Investigation

I plan to investigate Machine Learning and Neural Networks by developing a Survival Simulation environment in which a character will be controlled by a Machine Learning algorithm.

The Machine Learning Algorithm I choose to implement will most likely require lots of Complex Maths, from prior knowledge I know that Matrices and Calculus are heavily used within Neural Networks. Most of this Maths I will have covered in my Maths and Further Maths Lessons, but some will require independant research on my Part.

The survival simulation will be procedurally generated and present multiple challenges towards this character in order to provide a complex problem for it to solve. The procedural generation will be based upon a seed, and will generate Terrain which the character has to explore and navigate. The challenges could be things like collecting items, or having to avoid/kill enemies which are actively tracking the character and trying to hinder it's progress.

The key question I aim to answer with this investigation is:

Can I develop a Machine Learning Algorithm to survive in a pseudorandom, open-world environment?

This question is rather broad and allows me to experiment with varying levels of complexity when it comes to the simulation. As long as I can implement a Machine Learning Algorithm which is complex enough to solve the provided challenges.

1.2 Background

I am investigating Machine Learning because I've been wanting to try my hand at it for a while, this Project will allow me to gain a broad understanding of Neural Networks and their applications, along with an understanding of procedural generation.
I am investigating this area of Computer Science because I've been interesting in attempting a form of Machine Learning for a while now but havent had a reason to dive into it. Machine Learning is an evolving field, with mere infinite applications such as Image Recognition, Chat Bots, Self Driving Cars, etc. I feel as though my project will be sufficiently advanced enough to expand my knowledge of the subject. It will require lots of research, planning, and design work in order to successfully fulfil my Technical Solution.

1.3 Expert

For my expert I approached one of my friends, Shaun, who has prior experience with Machine Learning. He has created his own Hand Written Digit Recognition Network before, along with using Python Libraries such as *PyTorch* to train an agent to play the game *Flappy Bird*, among other ML projects. He has a much better understanding of Machine Learning than me currently, so hopefully he will be a good resource as I develop my project.

1.4   Initial Research

1.4.1   First Interview

As part of my Investigation I approached my friend Shaun, who has Experience with Machine Learning. I formed a list of questions to ask him, the responses are paraphrased for clarity. I mainly wanted to gain an idea of what Machine Learning algorithm would suit my project the best. So I targetted my questions towards this.

1. What are your first impressions of my project?

   "Your project is definitely very complex and if finished will tick alot of the boxes needed for Full Marks. There are lots of layers of complexity along with room for good Object Orientated Design."

2. What Machine Learning Algorithms do you think would be relevant to my project?

   "Without pushing your complexity too far I think you should look into Deep Reinforcement Learning, I believe it has the possibility of solving your problem if not too complex. Because of that you may way want to keep your simulation as minimal as possible in order to give your Agent a chance. If you wanted to go further you could implement a Convolutional Neural Network, but this will add to the Complexity and take more time to program."

3. Would User Defined Parameters be helpful?

   "The ability to dynamically change the parameters through a json file or similar would be very useful. Epecially to users who have little to no experience with it before hand. The ability to change things like the Procedural Generation, Enemy Counts, Network Structure etc would be the perfect addition to your project."

4. What Procedural Generation method would be best for my Project?

   "I only have experience with Perlin Noise but I think that it would be a great fit for your Project. It uses simple vector Maths to calculate Gradient Noise, and is relatively simple to understand and Program. There are other Procedural Generation Methods I'm aware of like Diamond Square or Simplex Noise, but both of those are much more complicated to my understanding."

5. How complex should I make my Simulation?

   "I would stick to a relatively simple simulation at first, and then if your agent is successful at solving it, you can add more to test the limits of your network after. Dynamic threats like Enemies which follow the Agent which it can attack would provide a base complex problem to start off with. Other problems could be collecting items or a simple Food Collection system with a Hunger Meter."

6. How should I determine if my project is successful?

   "You could log a graph of Loss compared to Time, and in theory if your agent is learning it will successfully reduce the average Loss the more training it receives. You could use this graphed data as supporting evidence in your Evaluation."

7. What should I focus my Initial Research on?

"It would be benefical to you to research the Maths behind Neural Networks, specifically for Forward Propagation and Back Propagation. The Maths behind it can get very complicated, along with being very hard to debug if a small error is made. They both heavily rely on Matrix Operations, so if you're not familiar with those you should get up to speed."

1.4.2 Existing Investigations

Crafter

In my research on the Internet I discovered a project called *Crafter*.

https://github.com/danijar/crafter

Crafter is described to be *"Benchmarking the Spectrum of Agent Capabilities"*, and is utlised in conjunction with Machine Learning Algoriths such as *DreamerV2*, *PPO* and *Rainbow*. Crafter poses significant challenge towards its Player, requiring high levels of generalisation, long-term reasoning, and complex problem solving. If the machine Learning algorithm in question fails to achieve one of these aspects it will struggle to full "Solve" the simulation.

High levels of generalisation are required when training a Machine Learning algorithm, if this is not achieved then your network will only lend itself to a single Dataset/Problem. An example of this would be training a network used to recognise hand written digits on only one way of writing 4's, if presented with an input for a different type of 4 it may not recognise it and identify it incorrectly.

Long-Term reasoning is a complex problem to solve in the context of Machine Learning, current Machine Learning models struggle to deal with this problem. This is dealt with by using algorithms built to mimic "memory". A common implementation of this is Experience Replay which stores states in a queue, and relearns from it after every N ammount of steps.

A complex reward and action system may take time for an algorithm to learn but it certainly is possible with current Machine Learning Models. Crafter utilises a complex action system with a flow chart determining which Action can be taken given the current state of the simulation. Below is shown the Complex Flow Chart of Actions:

(a) Success Rate of Algorithms   (b) Comparison Against Human Data
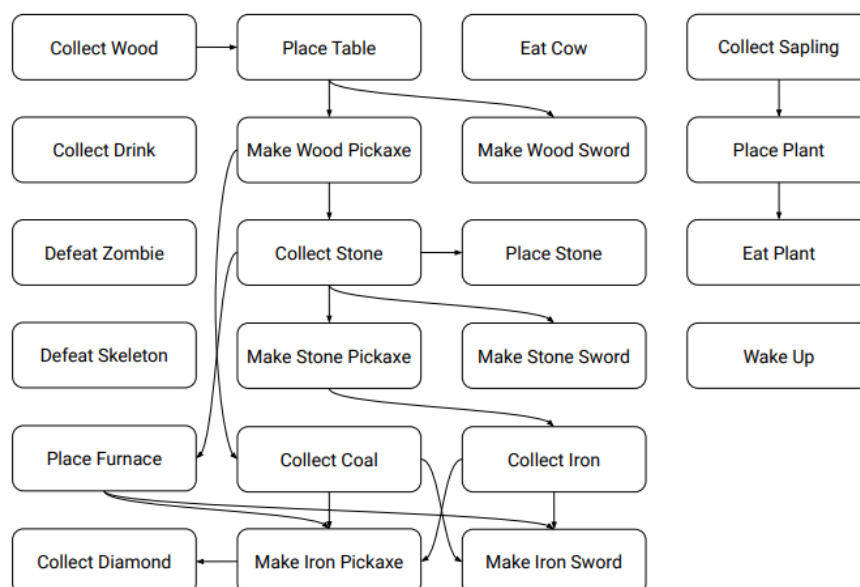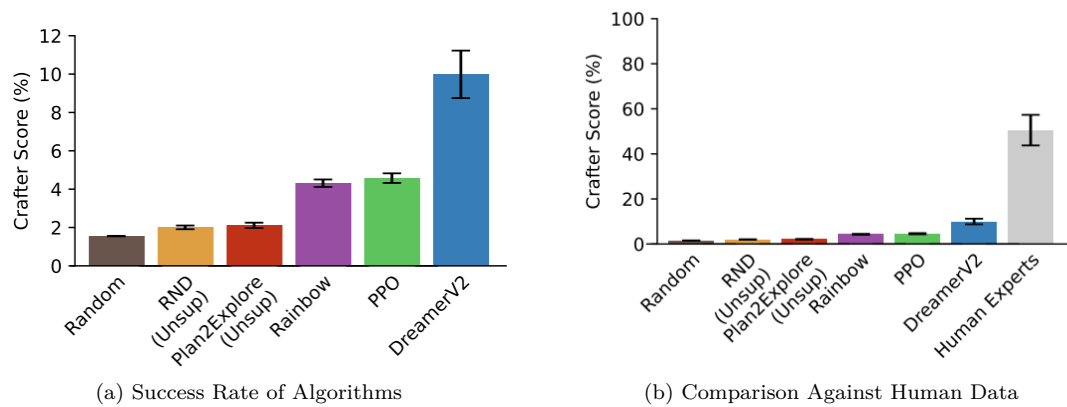
Complex action system as shown in the Paper "Benchmarking the Spectrum of Agent Capabilities"

Crafter manages to achieve quite high success rates with various Algorithms, but they still fail to overcome, or even match human standards. This is likely due to the complexity of the problem, and in theory will be solvable within the near future as Machine Learning advances over the next few years. This is why I plan to create a simpler simulation which the Agent will be more likely to be able to solve. Below is shown the Success Rate Data for both Algorithms and Human Experts.

While I would love to create a simulation similar to crafter, it is very complex and would take a long time to develop. Yet would not net many marks in the process. Overall I feel like Crafter is a good example that my project is possible, but will require a complex Machine Learning Model in order to achieve reliable results from my Investigation.

Minecraft

Minecraft is a *very* popular Game. It's a sandbox game, meaning that the player can do almost anything they want. The game is formed from blocks which can be broken or placed, along with a plethora of items, enemies, passive animals and more. It has infinite terrain generation, and explicity uses Perlin Noise, and is generated from a seed. The seed determines all the terrain generation, loot tables, random structures, caves, etc.

First it starts off on a very broad level, painting a basic topographical map of the world. It uses Perlin Noise to sample a height value for each chunk, where chunks are 16x16 areas of blocks. Then within these chunks the game uses the Diamond Square algorithm to interpolate between it and the chunks around it, creating blocks where the terrain should be. This produces an entirely deterministic results based upon the seed.

Secondly, the Caves are generated using Perlin Worms, which travel in deterministic directions based on their starting position. These worms dig through the terrain carving out caves which can then be traversed by the player. Within these Caves spawn water sources, pools of lava, useful ores. All of these are deterministically generated by the original seed.

Example of Minecraft's terrain generation in a Swamp Biome

Example of a Sunken Pirate Ship Structure

Minecraft itself is too complex and dynamic to be solved by current Machine Learning algorithms, along with there is no quantifiable metric for performance due to it's sandbox nature. There exist data sets for Minecraft, in the form of captured gameplay footage, but there has been little to no success of quantifiably good solutions to solving Machine Learning problems within Minecraft.

Overall I feel like it would be good to borrow elements from Minecraft's terrain generation, such as its utilisation of Perlin Noise. But the majority of the games systems are way too complex for a Machine Learning algorithm to solve.

Conway's Game of Life

Conway's Game of Life is whats called a Cellular Automaton, which is a discrete computation model formed from a grid of cells along with a ruleset. Conway's is commonly referred to a Zero Player Game, where the input for the Automaton is defined at the start, with no further adjustment needed for it to run. The game is fully Turing complete and can simulate a Universal Constructor.

The rules of Conway's are such that:

1. Any live cell with fewer than two live neighbours dies, as if by underpopulation.
2. Any live cell with two or three live neighbours lives on to the next generation.
3. Any live cell with more than three live neighbours dies, as if by overpopulation.
4. Any dead cell with exactly three live neighbours becomes a live cell.

It is rather interesting that such complicated Machines can be formed from such a simple ruleset, as an example here is a Turing Machine formed from 34 Thousand Cells:
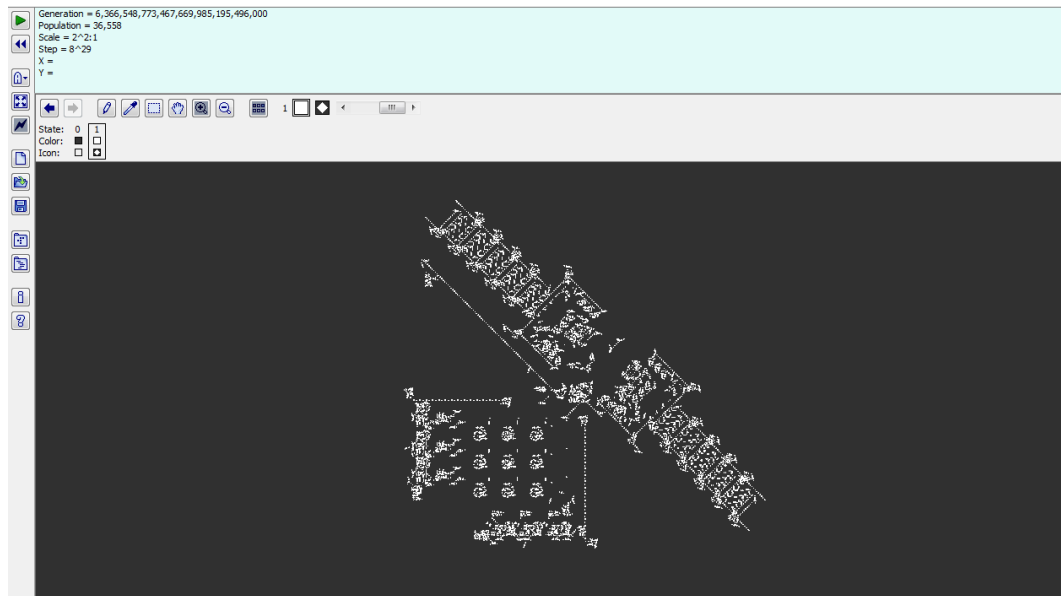
Overall, I think this shows that my simulation doesnt need to have complex rules in order to achieve interesting results. Conway's is formed from 4 simple rules, and yet is Turing complete.

1.4.3   Algorithms and Potential Data Types

Neural Network and Matrices
As part of developing a Machine Learning Algorithm, I will need to implement a Matrix class in order to implement a Neural Network. Matrices are commonly used to represent individual layers of a network. Along with making calculations much easier, condensing them into performing operations on matrices, rather than nested using nested for loops and lists. As part of my Initial Research I have taken the time to understand how a Neural Network functions, it turns out I have already learned most of the Maths needed to understand how it works in my A Level Maths and Further Maths courses.

A Neural Network functions as a series mathematical equations used to recognise relationships between inputs and desired outputs. They take in a Vector of Input Data, and output a Vector of Output Data. They can be in simple terms as a function: $N(x)$ where: $\{x \in V, N(x) \in V\}$. The functions name in this case is Forward Propagation.

We form a Neural Network with multiple layers of Nodes, the layers being referred to as the Input Layer, Hidden Layer/s and Output Layer. In this case each Node is connected to every Node in the previous layer and the following layer. In the below image is represented a Neural Network with a layer structure of $[3, 5, 2]$.
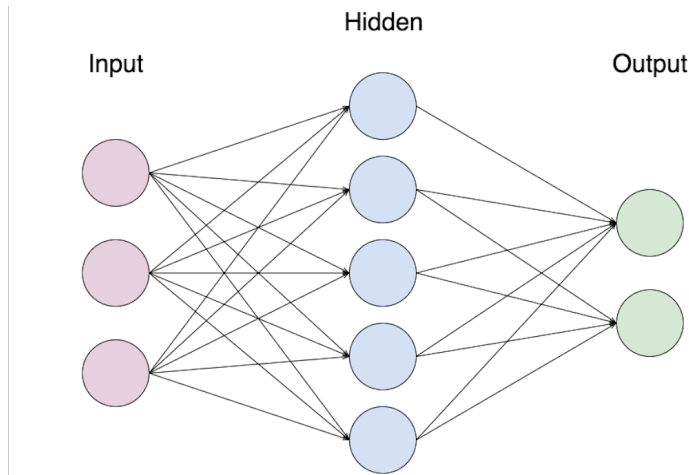
Each connection, otherwise known as an Arc or Edge, has an associated weight. Along with every output of a layer having an associated Bias. These are used to compute the outcome of a network.

Forward Propagation is used to compute the outcome of a network, it has a general form and uses Matrix Multiplication and Addition to achieve this.

$$
S^{(L)} = \begin{bmatrix} s_0^{(L)} \\ s_1^{(L)} \\ \vdots \\ s_n^{(L)} \end{bmatrix} = \begin{bmatrix} w_{0,0}^{(L-1)} & w_{0,1}^{(L-1)} & \cdots & w_{0,m}^{(L-1)} \\ w_{1,0}^{(L-1)} & w_{1,1}^{(L-1)} & \cdots & w_{1,m}^{(L-1)} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n,0}^{(L-1)} & w_{n,1}^{(L-1)} & \cdots & w_{n,m}^{(L-1)} \end{bmatrix} \begin{bmatrix} a_0^{(L-1)} \\ a_1^{(L-1)} \\ \vdots \\ a_n^{(L-1)} \end{bmatrix} + \begin{bmatrix} b_0^{(L)} \\ b_1^{(L)} \\ \vdots \\ b_n^{(L)} \end{bmatrix}
$$

$$
\sigma(S^{(L)}) = \sigma\left(\begin{bmatrix} s_0^{(L)} \\ s_1^{(L)} \\ \vdots \\ s_n^{(L)} \end{bmatrix}\right) = \begin{bmatrix} \sigma(s_0^{(L)}) \\ \sigma(s_1^{(L)}) \\ \vdots \\ \sigma(s_n^{(L)}) \end{bmatrix}
$$

We then apply an activation function as shown above, in this case we will apply the Sigmoid function: $\sigma(x)$ to $S^{(L)}$. The Sigmoid function is a Mathematical Function which *squishes* values between 0 and 1. Shown Below:
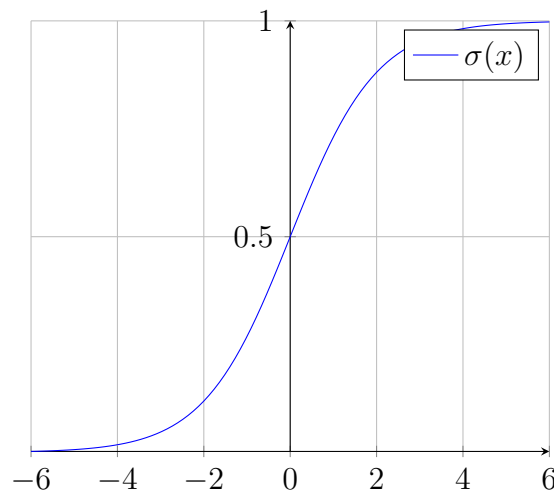
Matrices can be used for all parts of a Neural Network implementation, and will prove very useful in my Technical Solution.

Procedural Generation

For my project I am going to have to procedurally generate 2d terrain, while researching this I came across a few algorithms which seemed to be able to do this pretty well. I will compare two algorithms I discovered below.

Post-Processing Algorithms	Perlin Noise
I discovered two post processing algorithms often used for simple 2d terrain generation. 1 Averages squares around the selected square, and the other pulls it up or down the gradient its currently on. I find these interesting because they're relatively simple, and I'm not quite sure whether they will produce good results or not. So it would be interesting to test out implementing these in my prototype.	Perlin Noise is an algorithm developed by Ken Perlin for use in the digital generation of noise. This noise can be combined to create *realistic* looking height maps for world generation. Perlin Noise retains continuity and is seeded so the generation can be entirely controlled. By "retains continuity" I mean that you can sample the same point and retrieve the same value. If I was to implement Perlin noise it would take longer, but also might end up with a better result due to it being more widely used. It's a trade-off between time to implement and desired result.

I also discovered an algorithm called Poisson Disc Sampling, this can be used to sample random points in N dimensional space. It takes in 2 values, the R and K value, these values determine the output of the function. The R values is the minimum distance a point has to be from another, randomly placed point which hasn't been selected yet. If the distance between any existing points is less than R, the point will be rejected and another will be selected. The K value determines how many rejected are needed before the algorithm will stop attempting to choose a new point.

Proposed Programming Language and Associated Libraries

When selecting a Programming Language and associated Graphical Libraries I took into consideration a few options. Below I have weighed up 3 options for Programming Language, along with 2 graphical libraries per language

Proposed Solution	Benefits and Downsides of Proposed Solution

Python		Python is the first thought which comes to mind when I think about programming, it is my favourite language and I'm yet to find anything which I prefer. Its very versatile and great for rapid prototyping, the dynamic typing makes It great for coding quickly without worrying too much about whether you're using a *float32 or float64*. It also has hundreds of libraries and is very well supported by its developers and the community.
Python Graphical Libraries	Pygame	Pygame is a highly customizable and well developed binding of *Simple DirectMedia Layer* (SDL) Library. It has a full set of 2d drawing tools, along with keyboard and audio capabilities. I have lots of experience with Pygame so I already have code which I can take from, which will speed up development when dealing with the Pygame library.
	Tkinter	Tkinter provides an interface to the standard *Tcl/Tk GUI Toolkit*, which is available for most platforms, this makes it highly versatile. Though as my project is not intended as a software package I dont see this as being an incredibly big selling point. Tkinter will serve mostly the same purpose as Pygame but give me easier options for Graphical Input, I dont currently plan to add GUI so this feature isnt neccesary.
C#		C# is my second favourite language, I have plenty of experience with it from developing games with Unity. It's faster than Python and is less abstracted, but this speed isn't necessarily required for my project. With C# I could utilise the *Unity Game Engine* for my project, but then I might end-up relying on builtin types and functions rather than developing my own.

Proposed Solution	Benefits and Downsides of Proposed Solution	
C# Graphical Libraries	Windows Forms	Windows Forms is a relatively simple drag drop interface for designing your own applications. I've never used it before but I could utilise it with C# to create my project. I belive it might be a bit overkill for my needs though, as it includes many, many UI features which I will have no use for.
	WPF	WPF or *Windows Presentation Foundation* is a versatile development platform for desktop applications. It is relatively versatile in its uses and utilises XAML and is the UI Language of Windows Platforms. XAML would be a new language for me to learn but I have experience with HTML so I dont believe it would be too difficult. The platform would provide a stable base to my project.
Rust	Rust is low level language designed for speed and efficiency, I started using it recently as a side hobby and would like to use it more in future projects of mine. Though I feel like it may be a bit overkill for a Computer Science NEA, with it often being used for server side applications rather than general purpose applications.	
Rust Graphical Libraries	Piston2d	Piston2d is a feature complete 2d graphics library which utilises OpenGl, I've worked with it briefly before and I believe it would be a good option over Pixels if I needed more complex drawing methods.
	Pixels	Pixels is a lightweight 2d graphics library designed to simply push pixels to the screen, Its relatively simple and i've used it for making a simple *Falling Sand Game* before, could be a good little option if I wanted to develop a lightweight solution.

1.5 Prototype

1.5.1 Prototype Objectives

Before starting my Prototype I had to decide upon a short list of objectives I wanted to complete/investigate as part of it. These boiled down to a few things:

1. Terrain Generation

2. Displaying the Generated Terrain using a Graphics Library

3. Matrix and Vector implementation

For my Prototype, I first created a GitHub Repository, available here:

https://github.com/TheTacBanana/CompSciNEAPrototype

I had created a hierarchy of importance for development in my head, visualized using this flow diagram:
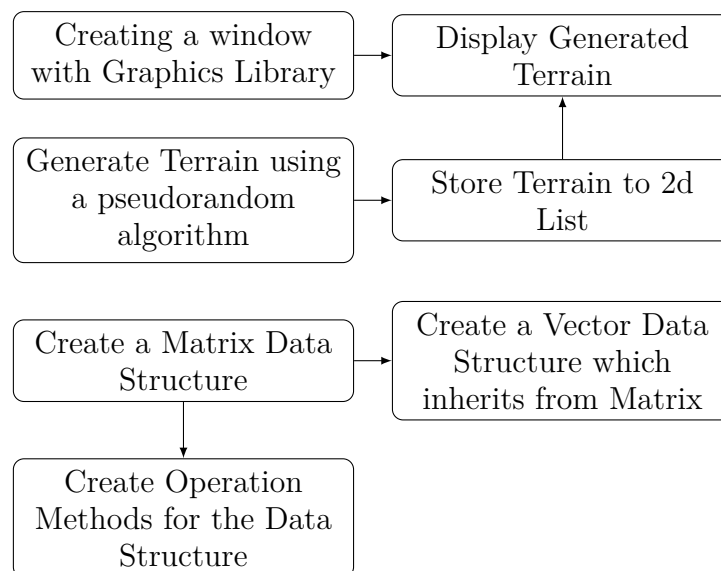
I decided to use Python for developing my Prototype, this seemed like a good fit due to me having lots of experience with the language. Python is a Dynamically Typed and Interpretted language which makes it versatile for protyping and fast, iterative development.

1.5.2 Terrain Generation and Displaying to Window

Starting from the begining of my hierarchy I installed Pygame using *pip* and started creating a window. This was a relatively simple task only taking a few lines:

```python
import pygame

simSize = 128
gridSize = 2

window = pygame.display.set_mode((simSize*gridSize, simSize*gridSize))
pygame.display.set_caption("Procedural Generation")

running = True
while running == True:
```

```
11      for event in pygame.event.get():
12        if event.type == pygame.QUIT:
13          running = False
```

This creates a window like this:
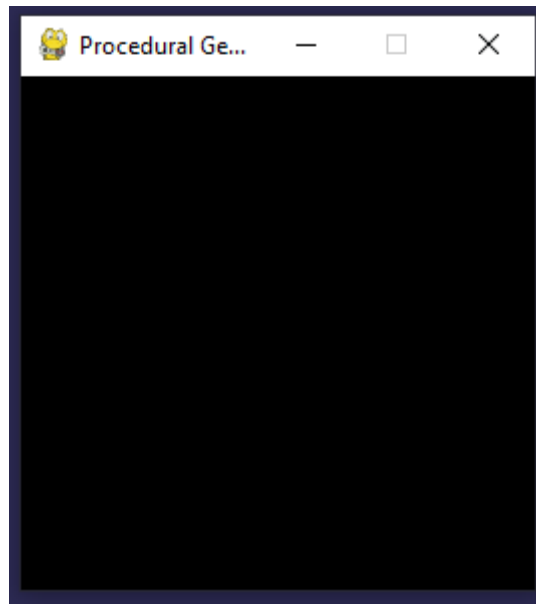
Following the hierarchy I then added noise generation by generating random numbers and assigning them to a 2d List. Shown here:

```
1   def GenerateMap(self, seed):
2       random.seed(seed)
3       for y in range(0, self.arraySize):
4           for x in range(0, self.arraySize):
5               self.heightArray[x][y] = round(random.random(),2)
```

After creating some code to draw squares based upon the random value, I ended up with this random array of Black-White squares:

This was a good start, but didnt really look like terrain yet. As part of my research I came

across simple algorithms to turn random noise into usable 2d terrain. I decided to implement these algorithms. They are relatively short and didnt take too much time to implement. I've named the two algorithms UpDownNeutralGen and Average.

UpDownNeutralGen Method

The UpDownNeutralGen method takes a tile, and considers every tile around it. It sums the tile which are greater than, less than, or within a certain range of the tile height. And then pulls the selected tile in the direction which has the highest precedence. As an example, here are some randomly generated values:

0.71	0.19	0.3
0.46	0.26	0.82
0.63	0.35	0.05

If we count the surrounding values into corresponding Higher, Lower and Neutral we get:

Higher	Lower	Neutral
4	1	3

This leads us to calculating the *pullValue*, respectively for each case:

$$Up-> pullValue = upTiles * 0.09$$
$$Down-> pullValue = upTiles * -0.08$$
$$Neutral-> pullValue = 0$$

$$Value[x][y] += pullValue$$

We then add the pullValue to the original square value, leaving us with the updated value. The code for this shown under the Prototype Code Header.

Average Method

The Average method takes a tile and considers every tile around it, this time instead of looking at the differences, it creates an average from the 8 surrounding tiles. It then sets the selected tile to this average value. As an example, here are some randomly generated values:

0.83	0.93	0.64
0.07	0.38	0.21
0.33	0.94	0.95

Summing these and dividing by the total grants us the average:

$$\frac{0.83 + 0.93 + 0.64 + 0.07 + 0.38 + 0.21 + 0.95 + 0.33 + 0.94}{9} = 0.586$$

$$Value[x][y] = 0.586$$

The code for this shown under the Prototype Code Header.

1.5.3   Finished Terrain Generation

Overall I am happy with the Terrain generation, though I feel as if it could be improved to look more realistic. The difference between the original random noise and the Colour Mapped Terrain looks so much better.
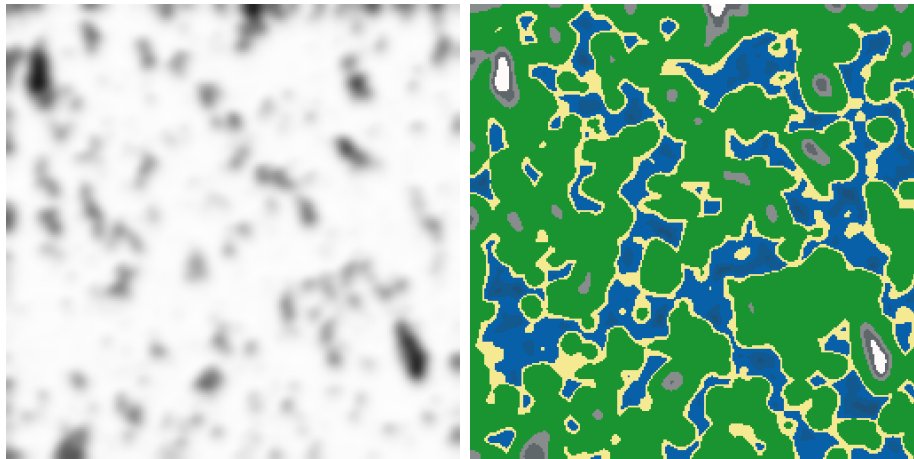
1.5.4   Matrix Data Structure

As part of my Matrix Class I made a list of operations which would be key to a Matrix Class, along with being useful for Machine Learning. A Matrix is an abstract data type, commonly used in Maths, but has practical uses in the world of Computer Science. It holds a 2d array of values such as:

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} \begin{pmatrix} a & b & c & d \\ e & f & g & h \end{pmatrix}$$

The values in a Matrix can be manipulated using common operations such as $+ - *$ as long as the orders of the 2 Matrices match up. Along with other, non-standard operations which have other purposes.

As part of my Matrix Class, I implemented the following operators:

1. Addition/Subtraction
   Implementing Addition didnt take too long, I utilised a nested for loop to iterate over every value in both Matrices. Adding the two values together into a temporary Matrix which the method then returned.

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} + \begin{pmatrix} e & f \\ g & h \end{pmatrix} = \begin{pmatrix} a+e & b+f \\ c+g & d+h \end{pmatrix}$$

2. Multiplication
   Multiplication of Matrices is slightly more complicated, it is of $O(n^3)$ complexity, utilising a triple nested for loop. It multiplies the row of a $M1$, by the column in $M2$. Summing the calculation into the element in the new Matrix $M3$.

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} * \begin{pmatrix} e & f \\ g & h \end{pmatrix} = \begin{pmatrix} a*e+b*g & a*f+b*h \\ c*e+d*g & c*f+d*h \end{pmatrix}$$

   There is also Scalar Multiplication which multiples each value of a Matrix by the Scalar.

$$k * \begin{pmatrix} a & b \\ c & d \end{pmatrix} = \begin{pmatrix} ka & kb \\ kc & kd \end{pmatrix}$$

3. Determinant
   Calculating the Determinant of an NxN Matrix is a recursive algorithm. With the base case being the Determinant of a 2x2 Matrix. When calculating the Determinant of a 3x3 Matrix you create a Matrix of Cofactors, and multiply each value by the corresponding value in the Sin Matrix (*Formed from repeating 1's and -1's*). Summing the values from a singular Row or Column will then give you the Determinant. For a 4x4 you simply calculate the Determinant of the corresponding 3x3's to get the Cofactors.

$$\begin{vmatrix} a & b \\ c & d \end{vmatrix} = a*d - b*c$$

$$\begin{vmatrix} a & b & c \\ d & e & f \\ g & h & i \end{vmatrix} = a * \begin{vmatrix} e & f \\ h & i \end{vmatrix} - b * \begin{vmatrix} d & f \\ g & i \end{vmatrix} + c * \begin{vmatrix} d & e \\ g & h \end{vmatrix}$$

4. Dot Product
   The Dot Product occurs between two vectors, and can be used to calculate the angle between them. Its a relatively simple operation only taking a few lines of code.

$$\begin{pmatrix} a \\ b \\ c \end{pmatrix} \cdot \begin{pmatrix} d \\ e \\ f \end{pmatrix} = a*d + b*e + c*f$$

1.5.5 Prototype Evaluation

Overall I am happy with my prototype, though I feel like some parts need to be improved. I did meet my objectives for my prototype but there were improvements which can me made when I create my Technical Solution. Namely the Terrain Generation along with the Matrix class. I feel that Perlin noise would be a better alternative to the two algorithms I used. In theory it should produce better results, and also provide more marks for complexity. My Matrix class could be rewritten to be more efficient, along with using operator overloading, which I didnt know Python could do at the time. I also feel like having Vector inherit from Matrix is relatively pointless, there is no need for it when I could just use 1 wide Matrices instead.

1.6   Second Interview

I asked a few more questions to my Expert regarding my project at this point. Receiving feedback on my Prototype and gaining a greater understanding of the Machine Learning Model I'm intending to use.

1. What are your thoughts on my prototype?

   "I think your prototype is good, but could be improved. The use of Operator Overloading would improve your Matrix Class, and optimising some of your algorithms would be useful. The Terrain generation looks good, but I think its a bit water heavy, this is where Perlin Noise might help you to achieve better results. Would also be more fine tunable to your liking."

2. Is a Dual Neural Network a good model to choose?

   "A Dual Neural Network should in theory be a complex enough Model for your project. The concern I have is whether your Network will be able to generalise enough in order to sufficiently 'solve' the simulation you design. There are some algorithms you could implement in order to tackle this though. You could do some research into these before finalising your design."

3. Which Activation Functions should I implement?

   "The most commonly used are Sigmoid, TanH, ReLu and SoftMax. They are relatively simple so wont take long to implement. Those would be a good starting point for testing your Neural Network."

4. What type of Reward system should I use?

   "As far as I'm aware there are two types of reward systems, Sparse and Dense. I think that Sparse would be better suited to your project. Sparse is where the reward given to the Agent is 0 for most actions. Compared to dense where reward is given for most most actions."

1.7   Objectives

Taking into account my Prototype and Interview, I have formed a list of objectives I feel to be most appropriate for my Investigation.

If all completed they will form a complete solution which will answer my Investigations question. Below is the list of objectives split into 6 key sections:

User Input

1. Read Parameters from a Json formatted file

2. Check Parameters fall within a certain range to prevent errors

3. Give user option to load Neural Network Training progress

Simulation

1. Utilise Perlin Noise to generate a 2d List of terrain heights

2. Store Terrain Heights in a Tile Data Type

3. Utilise Threading to generate Terrain Faster

4. Display terrain to a window

5. Map ranges of terrain heights to specific colour bands

6. Utilise Poisson Disc Sampling to generate objects for the Agent to interact with

7. Implement enemies which use basic pathfinding to traverse towards the player

8. Generate multiple enemies upon starting the simulation

9. Allow the enemies to attack the Agent

Agent

1. Implement Movement options for the Agent

2. Implement the ability to pick up the generated Objects

3. Implement the ability to attack the generated enemies

4. Create methods to sample the terrain around the Agent

5. Create methods to convert the sampled Tiles into a grayscale input vector for a neural network

6. Create reward methods to reward the agent given the terrain samples and action

Matrix Class

1. Implement a Dynamic Matrix Class with appropriate Operations such as:

    (a) Multiplication
    (b) Addition
    (c) Subtraction
    (d) Transpose
    (e) Sum
    (f) Select Row/Column

2. Create appropriate errors to throw when utilising methods the incorrect way

Deep Reinforcement Learning

1. Dynamically create a Dual Neural Network model based upon loaded parameters

2. Implement an Abstract Class for Activation Functions

3. Implement Activation Functions inheriting from the Abstract Class such as:

   (a) Sigmoid
   (b) TanH
   (c) ReLu
   (d) SoftMax

4. Create methods to Forward Propagate the neural network

5. Create methods to calculate the loss of the network using the Bellman Equation

6. Create methods to Back Propagate calculated error through the neural network

7. Create methods to update weights and biases within the network to converge on a well trained network

8. Utilise the outlined Matrix class to perform the mathematical operations in the specified methods

9. Implement Load and Save Methods to save progress in training

10. Implement a Double Ended Queue/Deque Data Type

11. Implement Experience Replay utilising the Deque Data Type to increase training accuracy

Data Logger

1. Be able to create a Data Logger class to log data points across training

2. Be able to create a Data Structure for the Data Logger

3. Allow multiple types specified types for a single parameter

4. When adding a new Data Point the Logger will check it to make sure it matches the given Data Structure

5. Implement a Heap Data Type

6. Implement a Heap sort using the Heap Data Type

7. Be able to sort by a parameter in the Data Structure

8. Be able to select a single parameter from the data points

9. Implement Load and Save Functions to save progress during training

1.8   Modelling of the Problem

In this section I will define and derive all the Mathematical Formulae relating to my Project. This includes all the Matrix Operations I plan to use and the General Forms of Forward Propagation and Back Propagation.

1.8.1   Matrices

Overview

Matrices are a Mathematical Data Structure, storing elements in the shape of a Rectangle. They are arranged Rows and Columns. An m x n Matrix will have m Rows and n Columns.

As part of defining the Matrix Operations, below is defined Matrix A and Matrix B and can be of any size.

$$A = \begin{bmatrix} a_{1,1} & a_{1,2} & \dots & a_{1,m} \\ a_{2,1} & a_{2,2} & \dots & a_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1} & a_{n,2} & \dots & a_{n,m} \end{bmatrix}$$

$$B = \begin{bmatrix} b_{1,1} & b_{1,2} & \dots & b_{1,m} \\ b_{2,1} & b_{2,2} & \dots & b_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n,1} & b_{n,2} & \dots & b_{n,m} \end{bmatrix}$$

Matrix Addition

Matrix Addition is the Operation of adding two Matrices by adding the Corresponding Elements together. Matrix Addition is Commutative. Below is A added to B.

$$A + B = \begin{bmatrix} a_{1,1} + b_{1,1} & a_{1,2} + b_{1,2} & \dots & a_{1,m} + b_{1,m} \\ a_{2,1} + b_{2,1} & a_{2,2} + b_{2,2} & \dots & a_{2,m} + b_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1} + b_{n,1} & a_{n,2} + b_{n,2} & \dots & a_{n,m} + b_{n,m} \end{bmatrix}$$

Matrix Subtraction

Matrix Subtraction is the Operation of subtracting two Matrices by adding the Corresponding Elements together, with the 2nd Matrix's element being Negated. Below is B Subtracted from A.

$$A - B = \begin{bmatrix} a_{1,1} - b_{1,1} & a_{1,2} - b_{1,2} & \dots & a_{1,m} - b_{1,m} \\ a_{2,1} - b_{2,1} & a_{2,2} - b_{2,2} & \dots & a_{2,m} - b_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1} - b_{n,1} & a_{n,2} - b_{n,2} & \dots & a_{n,m} - b_{n,m} \end{bmatrix}$$

Matrix Multiplication

Matrix Multiplication calculates the Dot Product between the Rows in Matrix A and Columns in Matrix B. The Dot Product is a Vector Operation which takes two equal-length series of Numbers and returns a single Number. Each element in the 1st series of Numbers is Multiplied with the opposing element in the 2nd series, these are then summed to find the Dot Product.

$$AB = \begin{bmatrix} c_{1,1} & c_{1,2} & \dots & c_{1,m} \\ c_{2,1} & c_{2,2} & \dots & c_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ c_{n,1} & c_{n,2} & \dots & c_{n,m} \end{bmatrix}$$

Such that

$$c_{i,j} = a_{i,1}b_{1,j} + a_{i,2}b_{2,j} + \ldots + a_{i,n}b_{n,j} = \sum_{k=1}^{n} a_{i,k}b_{k,j}$$

Matrix Scalar Multiplication

Scalar Multiplication Multiplies each element by a single Scalar, in this case k.

$$k * A = \begin{bmatrix} ka_{1,1} & ka_{1,2} & \ldots & ka_{1,m} \\ ka_{2,1} & ka_{2,2} & \ldots & ka_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ ka_{n,1} & ka_{n,2} & \ldots & ka_{n,m} \end{bmatrix}$$

Matrix Hadamard Product

The Hadamard Product calculates the element-wise product between two equally sized Matrices.

$$A \odot B = \begin{bmatrix} a_{1,1}b_{1,1} & a_{1,2}b_{1,2} & \ldots & a_{1,m}b_{1,m} \\ a_{2,1}b_{2,1} & a_{2,2}b_{2,2} & \ldots & a_{2,m}b_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1}b_{n,1} & a_{n,2}b_{n,2} & \ldots & a_{n,m}b_{n,m} \end{bmatrix}$$

Matrix Transpose

The Transpose of a Matrix flips the given Matrix over the Diagonal, effectively Rows become Columns.

$$B^T = \begin{bmatrix} b_{1,1} & b_{2,1} & \ldots & b_{n,1} \\ b_{1,2} & b_{2,2} & \ldots & b_{n,2} \\ \vdots & \vdots & \ddots & \vdots \\ b_{1,m} & b_{2,m} & \ldots & b_{n,m} \end{bmatrix}$$

1.8.2   Forward Propagation

Overview

Forward Propgation is used in a Neural Network to calculate the output of the Network. It feeds Input Data through each Layer, leaving each Node with its resultant Activation Value. This is completed in two processes: Pre-Activation and Activation.

The Standard Notation I will be using to describe the Calculations:

$a_i^{(L)}$ = The Activation Value for the ith Node in the Lth Layer
$z_i^{(L)}$ = The Pre-Activation Value for the ith Node in the Lth Layer
$w_{m,n}^{(L)}$ = The Weight between node $n \to m$ from the Lth to the $(L+1)^{th}$
$b_i^{(L)}$ = The Bias Value for the ith Node in the Lth Layer

Pre-Activation

The Pre-Activation Value for the ith Node is the Sum of the Preceding Layers Activation Values, Multiplied by the Weight value between them. This then has the Bias Value added. M is the size the Layer $(L-1)$.

$$z_i^{(L)} = \sum_{k=1}^{M} (a_i^{(L-1)} \times w_{k,i}^{(L-1)}) + b_i^{(L)}$$

This can also be represented in its Matrix Form rather easily. You take the Vector of Activation Values from $(L-1)$ and multiply it by the Weight Matrix from $(L-1)$. You then add the Vector of Bias Values and that leaves you with the Pre-Activation for Layer L.

$$Z^{(L)} = W^{(L-1)} \times A^{(L-1)} + B^{(L)}$$

$$Z^{(L)} = \begin{bmatrix} z_0^{(L)} \\ z_1^{(L)} \\ \vdots \\ z_n^{(L)} \end{bmatrix} = \begin{bmatrix} w_{0,0}^{(L-1)} & w_{0,1}^{(L-1)} & \cdots & w_{0,m}^{(L-1)} \\ w_{1,0}^{(L-1)} & w_{1,1}^{(L-1)} & \cdots & w_{1,m}^{(L-1)} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n,0}^{(L-1)} & w_{n,1}^{(L-1)} & \cdots & w_{n,m}^{(L-1)} \end{bmatrix} \begin{bmatrix} a_0^{(L-1)} \\ a_1^{(L-1)} \\ \vdots \\ a_n^{(L-1)} \end{bmatrix} + \begin{bmatrix} b_0^{(L)} \\ b_1^{(L)} \\ \vdots \\ b_n^{(L)} \end{bmatrix}$$

Activation

Activation Functions are usually an abstraction representing the rate of "Action Potential" firing in the Node. The most Common Activations for Neural Networks are the following 3 Activations:

ReLu

$$\text{ReLu}(x) = \begin{cases} x < 0 & 0 \\ x > 0 & x \end{cases}$$
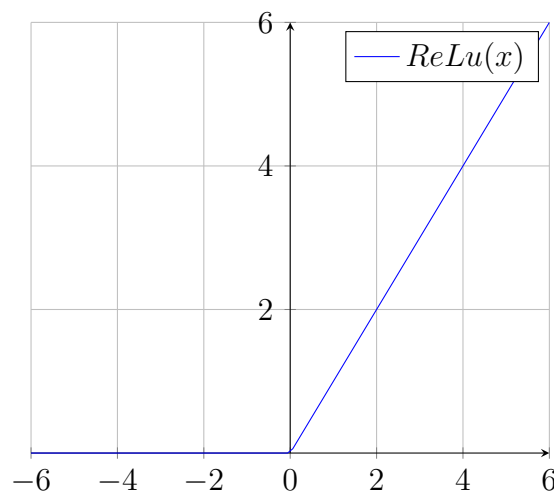
Sigmoid

$$\text{Sigmoid}(x) = \frac{1}{1+e^{-x}}$$
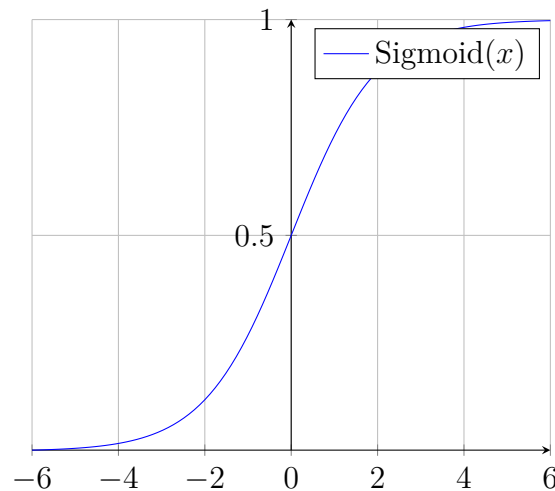
TanH

$$\text{TanH}(x) = \frac{\sinh(x)}{\cosh(x)} = \frac{e^x - e^{-x}}{e^x + e^{-x}}$$
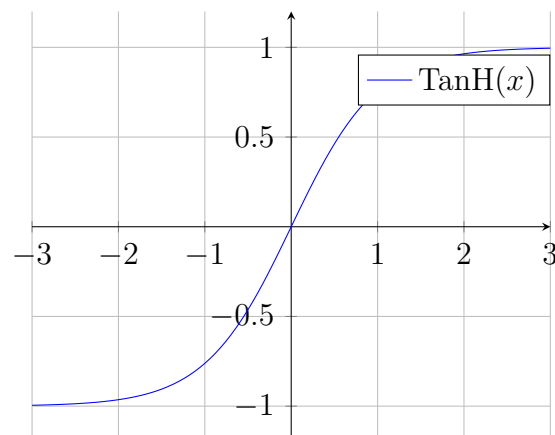
SoftMax

SoftMax is an exception to the Activation Functions and is a Generalisation of Sigmoid to Multiple Dimensions. It takes in a Vector $\mathbf{z}$ of K Real Numbers, and normalises it into a probability distribution which Sums to 1.

$$\text{SoftMax}(\mathbf{z})_i = \frac{e^{z_i}}{\sum_{j=1}^{K} e^{z_j}}$$

For $i = 1, \ldots, K$ And $\mathbf{z} = (z_1, \ldots, z_K)$

1.8.3   Differentiation

Differentiation from First Principles

Differentiation is the process of finding the Gradient of a Function at a specific point. In the case of a Neural Network, this can be used to measure the sensitivity of the Function Output, in respect to the Input. This derivative is known as said Functions' Gradient Function.

With a simple straight line graph we can find the gradient as $\frac{\Delta y}{\Delta x}$, Δ (Delta) is used to represent a fininite increment.

When find the Derivative of a more Complex Function we can use Two Points. Point $P : (x, f(x))$ and Point $Q : (x + h, f(x + h))$. The variable h tends towards 0, so Points Q will eventually be ontop of point P. This is called Differentiation from First Principles.

$$\begin{aligned} \frac{\Delta y}{\Delta x} &= \lim_{h \to 0} \left(\frac{f(x + h) - f(x)}{(x + h) - x} \right) \\ &= \lim_{h \to 0} \left(\frac{f(x + h) - f(x)}{h} \right) \end{aligned}$$

Derivatives are more commonly represented as $f'(x)$ or $\frac{dy}{dx}$

Standard Differentiation Rules

Instead of manually using Smaller and Smaller Values of h manually, there are standard Differentiation Rules. These are as follows:

$$\begin{aligned} y = x^k &\rightarrow \frac{dy}{dx} = kx^{k-1} \\ y = k &\rightarrow \frac{dy}{dx} = 0 \\ y = e^{kx} &\rightarrow \frac{dy}{dx} = ke^{kx} \\ y = f(x)g(x) &\rightarrow f(x)g'(x) + f'(x)g(x) \\ f(x) = \frac{g(x)}{h(x)} &\rightarrow f'(x) = \frac{g'(x)h(x) - g(x)h'(x)}{h(x)^2} \end{aligned}$$

These rules are applied to each component of the Function to find the Derivative.

Chain Rule

The Chain Rule is used to compute the derivative of Nested Functions such as $f(x) = g(h(x))$. The derivative of this Function can be expressed as:

$$f'(x) = g'(h(x))h'(x)$$

This can be applied to an infinite number of Functions, where $f(x) = g_1(g_2(\ldots (g_n(x))))$. By this rule we can represent the derivative as a Series of Derivatives Multiplied together:

$$\frac{df}{dx} = \frac{df}{df_1} \frac{df_1}{df_2} \frac{df_2}{df_3} \ldots \frac{df_n}{df_x}$$

Partial Derivatives

Partial Derivatives are used when the Function in question contains Multiple Variables. They utilise the same rules, except the Variables which aren't being derived get treated as constants. The Derivative of $f(x, y)$ with respect to x is expressed as $f'_x(x, y)$ or $\frac{\partial f}{\partial x}$.

1.8.4 Back Propagation

Overview

Back Propagation is the algorithm used to adjust Weights and Bias' in a Neural Network. Through using this algorithm you can successfully "train" the Network to recognise certain patterns in data. The Input Data gets propagated through the Network using Forward Propagation, and then the output is passed into the Loss Function.

The Bellman Equation

The Bellman Equation is a method of optimisation, and is used for dynamic programming. In the context of Machine Learning we can utilise it to reinforce good behaviour and negate bad behaviour. By writing the relationships between two states in the form of an action, we can optimise this by choosing the best action when given a state. If we let s_t be the current state, we can define all the possible actions from that state as $a_t \in \Gamma(s_t)$. Where $\Gamma(s_t)$ represents all given actions from a state. We can also define the State Transition from $s_t \to s_{t+1}$ as $T(s_t, a)$ when action a has been taken. The Reward from this is given as $R(s_t, a)$. A Discount Factor $0 < \gamma < 1$ is also defined to assume impatience, compounding the effects of γ the further in the future the Reward is.

With these definitions, an infinite-horizon problem is formed:

$$V(s_0) = \max_{\{a_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \gamma^t \cdot R(s_t, a_t)$$

We can form this into another Equation which uses the Principle of Optimality, such that:

An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision. - Richard E. Bellman

We will consider the first decision seperately to all future reward, and then collect the future decisions within the brackets, which the infinite-horizon problem above is equivalent too.

$$\max_{a_0} \left\{ R(s_0, a_0) + \gamma \cdot \left[\max_{\{a_t\}_{t=1}^{\infty}} \sum_{t=1}^{\infty} \gamma^{t-1} \cdot R(s_t, a_t) \right] \right\}$$

This at first glance has only made the problem uglier but infact has made our lives easier. It can be condensed further into a Recursively Defined Function:

$$V(s_0) = \max_{a_0} \{ R(s_0, a_0) + \gamma \cdot V(x_1) \}$$

When subjected to: $x_1 = T(s_0, a_0)$

Loss Function

The Loss Function of a Network represents how well a Neural Network is performing. The aim of the Back Propagation is to minimise this Functions output. When using a standard Neural Network and you're training on a labelled data set, you can be certain about the Expected Output. The standard Loss Function is as follows:

$$
\begin{aligned}
Loss_i &= \frac{1}{2} \cdot (ExpectedOutput_i - ActualOutput_i)^2 \\
&= \frac{1}{2} \cdot (y_i - \hat{y}_i)^2
\end{aligned}
$$

This is whats called the Half Square Difference. This Differentiates nicely which is why it is commonly used.

To finally use Bellman Equation as a Loss Function we need to convert it into a Loss Function:

$$
Q(s_t, a_t) = R(s_t, a_t) + \gamma \cdot \max_{a_{t+1}} Q(s_{t+1}, a_{t+1})
$$

$$
Loss = \left(R(s_t, a_t) + \gamma \cdot \max_{a_{t+1}} Q(s_{t+1}, a_{t+1}) - Q(s_t, a_t) \right)^2
$$

Gradient Descent

To minimise the Loss Function, the Weights and Bias' in the Network need to be algorithmically adjusted to converge towards the expected outputs. You can calculate these adjustments by using Partial Derivatives. You can take the Derivative of every Weight and Bias with respect to the Loss Function. The Derivatives of each weight can vary, such as one weight being 0.5 and the other being 3, the Second Weight affects the Loss Function $10\times$ as much. This process is known as Gradient Descent.

Differentiating Activation Functions

As part of Back Propgation we need to derive all the Activation Functions we use within our Layer structure. The Derivatives are shown below.

The ReLu Derivative:

$$
\text{ReLu}(x) = \begin{cases} 0 & x < 0 \\ x & x > 0 \end{cases}
$$

$$
\text{Relu'}(x) = \begin{cases} 0 & x < 0 \\ 1 & x > 0 \end{cases}
$$
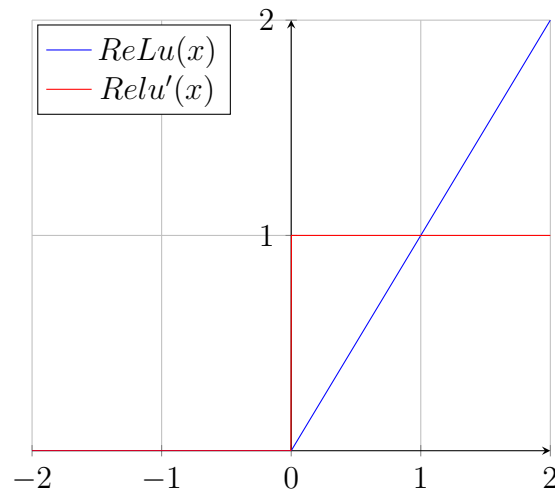
The Sigmoid Function Derivative:

$$
\begin{aligned}
\text{Sigmoid}(x) &= \frac{1}{1+e^{-x}} \\
&= (1+e^{-x})^{-1} \\
\frac{d\sigma(x)}{dx} &= -1 \cdot (1+e^{-x})^{-2} \cdot -e^{-x} \\
&= \frac{e^{-x}}{(1+e^{-x})^2} \\
&= \frac{e^{-x}}{1+e^{-x}} \cdot \frac{1}{1+e^{-x}} \\
&= \frac{e^{-x}+1-1}{1+e^{-x}} \cdot \frac{1}{1+e^{-x}} \\
&= \left(\frac{1+e^{-x}}{1+e^{-x}} - \frac{1}{1+e^{-x}} \right) \cdot \frac{1}{1+e^{-x}} \\
&= \text{Sigmoid}(x) \cdot (1 - \text{Sigmoid}(x))
\end{aligned}
$$
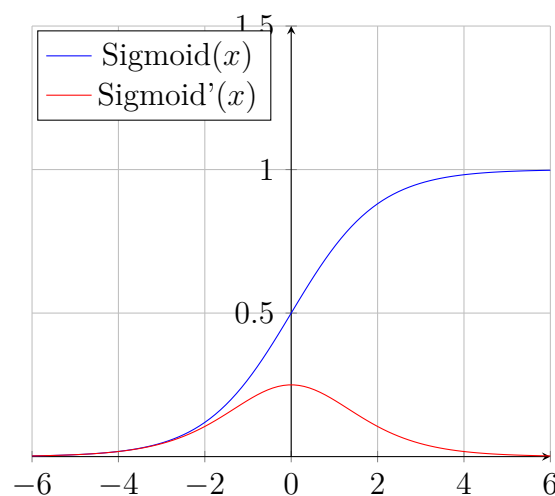
The TanH Derivative:

$$
\begin{aligned}
\mathrm{TanH}(x) &= \frac{\sinh(x)}{\cosh(x)} \\
&= \frac{e^x - e^{-x}}{e^x + e^{-x}} \\
\mathrm{TanH'}(x) &= \frac{(e^x + e^{-x})(e^x + e^{-x}) - (e^x - e^{-x})(e^x - e^{-x})}{(e^x + e^{-x})^2} \\
&= \frac{(e^x + e^{-x})^2}{(e^x + e^{-x})^2} - \frac{(e^x - e^{-x})^2}{(e^x + e^{-x})^2} \\
&= 1 - \mathrm{TanH}^2(x)
\end{aligned}
$$
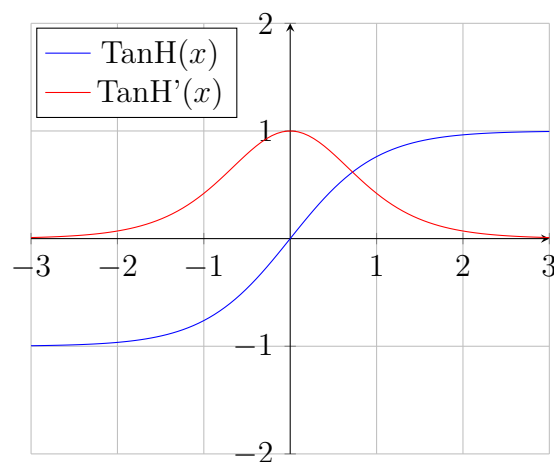
Simple Network

We can apply Back Propagation to this simple Neural Network:
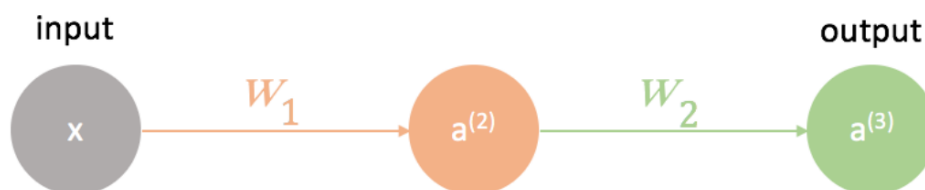
For this Network we need to calculate the derivative of each weight with respect to the cost function. With the use of the chain rule w_1 can be expressed as:

$$
\frac{\partial c}{\partial w_2} = \frac{\partial c}{\partial a_3} \frac{\partial a_3}{\partial z_3} \frac{\partial z_3}{\partial w_2}
$$

This means we need to find each derivative in the chain. The first derivative is given as $\dfrac{\partial c}{\partial a_3}$.

$$c = \frac{1}{2} \cdot (y - a_3)^2$$

$$\frac{\partial c}{\partial a_3} = y - a_3$$

Next we find $\frac{\partial a_3}{\partial z_3}$, here we will use TanH for our activation function.

$$a_3 = \frac{e^{z_3} - e^{-z_3}}{e^{z_3} + e^{-z_3}}$$

$$= \tanh(z_3)$$

$$\frac{\partial a_3}{\partial z_3} = 1 - \tanh^2(a_3)$$

Next we find the final derivative $\frac{\partial z_3}{\partial w_2}$

$$z_3 = a_2 \cdot w_2$$

$$\frac{\partial z_3}{\partial w_2} = a_2$$

We then combine this all together to find $\frac{\partial c}{\partial w_2}$

$$\frac{\partial c}{\partial w_2} = = (y - a_3) \cdot (1 - \tanh^2(a_3)) \cdot a_2$$

When calculating the derivatives of w_1 it's slightly more complicated, it requires us to *extend* the chain of derivatives.

$$\frac{\partial c}{\partial w_1} = \frac{\partial c}{\partial a_3} \frac{\partial a_3}{\partial z_3} \frac{\partial z_3}{\partial a_2} \frac{\partial a_2}{\partial z_2} \frac{\partial z_2}{\partial w_1}$$

It is however similar to our original chain, the only new derivative is $\frac{\partial z_3}{\partial a_2}$. Which is simply w_2, leaving us with the following derivative:

$$\frac{\partial c}{\partial w_1} = (y - a_3) \cdot (1 - \tanh^2(a_3)) \cdot w_2 \cdot a_2 \cdot (1 - \tanh^2(a_2)) \cdot a_1$$

We can generalise this into the form below for layers $1, 2, \ldots, n$:

$$\frac{\partial c}{\partial w_l} = a_l \cdot \sigma'(z_{l+1}) \cdot \frac{\partial c}{\partial a_{l+1}}$$

$$\frac{\partial c}{\partial a_l} = \begin{cases} y - \hat{y} & l = n \\ w_l \cdot \sigma'(z_{l+1}) \cdot \frac{\partial c}{\partial a_{l+1}} & Else \end{cases}$$

Complex Network
For a Complex Network, with multiple Neurons per layer, it is quite similar. An example of this is shown below:
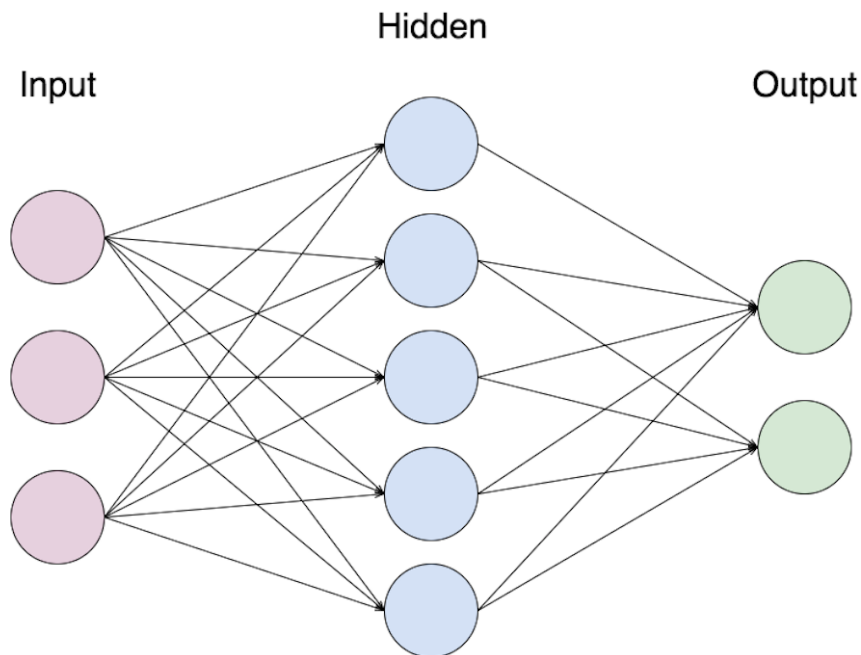
When deriving an Activation value we instead need to consider all weight derivatives connected to the next layer. We can generalise this into the weight update form for layers $1, 2, \ldots, n$:

$$\Delta w_{i \to j} = -\eta \delta_j z_i$$

$$\delta_i = \begin{cases} \sigma'(z_i) \cdot (y_i - \hat{y}_i) & \text{Node } i \text{ in Final Layer} \\ \sigma'(z_i) \sum_{k \in \text{outs}(i)} \delta_k w_{i \to k} & \textit{Else} \end{cases}$$

This should be all that is needed to perform Back Propagation.

2   Design

2.1   System Flow Charts

Below is shown the Flow Chart Overview of my Entire Project. This flowchart is very abstracted without going into the fine detail of each Process.
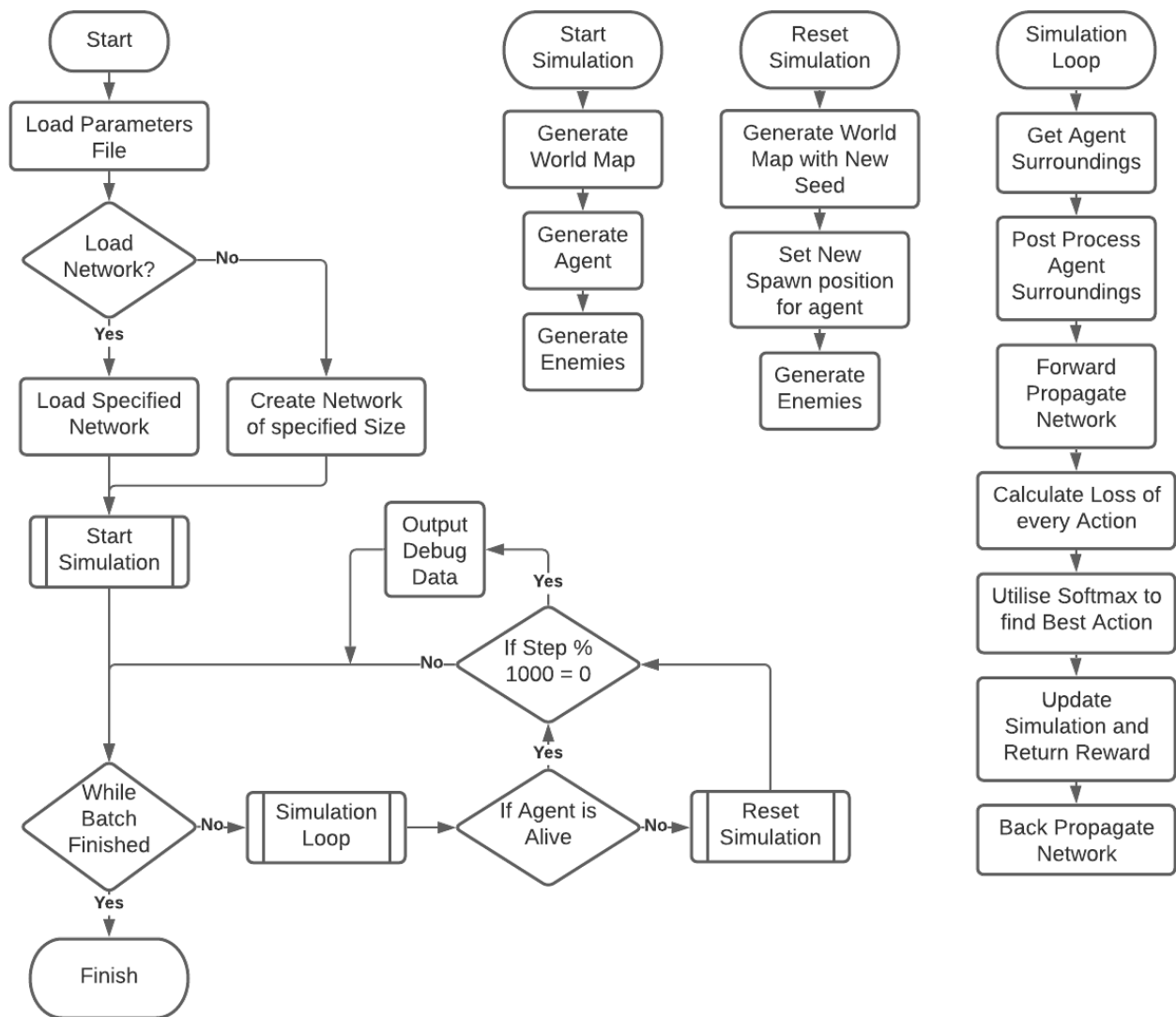
Below is shown the Action and Reward Tree for the Agent. Any Reward is added to a Total Reward Buffer and returned as part of the Function.

2.2   Class Diagrams

Below is shown the Class Diagram of the entire Technical Solution. The Data Logger is listed seperately for clarity, as in practice multiple sections of the Program will aggregate with it.

Enemy

+ parametersDictionary : Dictionary
+ location : Tuple (int, int)
+ alive : Bool = True

+ CommitAction(agent : Agent, worldMap : WorldMap)

+ SpawnPosition(enemyList : List<Enemy>, worldMap : WorldMap) : Tuple (Int, Int)

Simulation

+ paramDictionary : Dictionary
+ worldMap : WorldMap
+ network : Dual Network
+ agent : Agent
+ enemyList : List<Enemy>
+ step : Int

+ Simulation(params : Dictionary)

+ TimeStep()
+ UpdateEnemies()
+ InitiateSimulation()
+ CreateWorld(seed: Int = 0)
+ CreateDeepQNetwork(layers : List<Int> = [ ])
+ CreateAgent()
+ SpawnEnemies(number : Int = 0)
+ ResetOnDeath()
+ RenderToCanvas(window : Surface)

+ LoadParameters(fileName : String) : Dictionary
+ CheckParameters(params : Dictionary, fileName : String) : Bool

Agent

+ parametersDictionary : Dictionary
+ location : Tuple (int, int)
+ alive : Bool = True
+ inventory : Dictionary

+ Agent(location: Tuple (int, int), params : Dictionary)

+ GetTileVector(worldMap : WorldMap, enemyList : List<Enemy>) : Matrix
+ TileVectorPostProcess(tileVector : Matrix) : (Matrix, Matrix)
+ ColourToGrayscale(colourTuple: Tuple (int, int, int)) : Float
+ CommitAction(action : Int, tileVector : Matrix, worldMap: WorldMap, enemyList : List<Enemy>)
+ Move(direction : Int, worldMap : WorldMap)
+ CheckIfValidStandTile(location : Tuple (int, int), worldMap : WorldMap) : Bool
+ PickupItem(worldMap : WorldMap)
+ Attack(enemyList : List<Enemy>)

+ GetReward(action : Int, tileObjVec : Matrix) : Float
+ MoveReward(tile : Tile) : Float
+ CombatReward(tileVector : Matrix) : Float
+ GetRewardVector(tileVector : Matrix, outputs : Matrix) : Float
+ MaxQ(tileVector : Matrix) : Float
+ Reset(worldMap : WorldMap)

+ SpawnPosition(worldMap : WorldMap)

DoubleNeuralNet

+ parametersDictionary : Dictionary
+ MainNetwork : NeuralNet
+ TargetNetwork : NeuralNet
+ ExperienceReplay : Deque<Experience>
+ epsilon : Float
+ step : Int
+ cumReward : Float
+ layerActivation : Activation
+ finalLayerActivation : Activation
+ fileName : String
+ activations : Tuple (Activation, Activation)

+ DoubleNeuralNet(layers : List, params : Dictionary)

+ TakeStep(agent : Agent, worldMap : WorldMap, enemyList : List<Enemy>)
+ SampleExperienceReplay(agent : Agent)
+ LossFunction(output : Matrix, experience : Experience, agent : Agent)
+ SaveState(fileName : String)

+ LoadState(fileName : String) : DoubleNeuralNet

Sigmoid   TanH   SoftMax   Relu

<<interface>>
Activation

+ Activation(input : Matrix) : Matrix
+ Derivative(input : Matrix) : Matrix

Deque

+ length : Int
+ queue : List<Experience>
+ frontPointer : Int
+ backPointer : Int

+ Deque(length : Int)

+ PushFront(item : Experience)
+ Full() : Bool
+ First() : Experience
+ Last() : Experience
+ Sample(count : Int) : List<Experience>

NeuralNet

+ parametersDictionary : Dictionary
+ layers : List<Layer>

+ NeuralNet(layersIn : List<Layer>, params : Dictionary)

+ ForwardPropagation(inputVector : Matrix, activations : Tuple (Activation, Activation))
+ BackPropagation(activations : Tuple (Activation, Activation))
+ UpdateWeightsAndBiases()

WorldMap

+ mapSize : Int
+ tileWidth : Int
+ seed : Int
+ tileBorder : Int
+ tileArray : List<List<Tile>>
+ paramDictionary : Dictionary
+ renderedMap : Surface
+ renderedInteractables : Surface

+ WorldMap(seed : Int, params : Dictionary)

+ GenerateMap()
+ GenerateThreaded()
+ ThreadedChild(quadrant : List<List<Tile>>)
+ GenerateTreeArea()
+ PoissonDiscSampling(pointList : List) : List
+ PoissonCheckPoint(point : Tuple (int, int), pickedPoints : List
+ RenderMap() : Surface
+ RenderInteractables() : Surface
+ DrawMap() : Surface
+ Clamp(value : Float, low : Float, high : Float) : Float

Experience

+ state : Matrix
+ action : Int
+ reward : Matrix
+ stateNew : Matrix

Layer

+ parametersDictionary : Dictionary
+ weightMatrix : Matrix
+ biasVector : Matrix
+ weightUpdates : Matrix
+ biasUpdates : Matrix
+ errSignal : Matrix
+ sVector : Matrix
+ outputVector : Matrix

+ Layer(prevSize : Int, size : Int)

+ ForwardPropagation(prevLayer : Layer, activations : Tuple (Activation, Activation))
+ BackPropagation(prevLayer : Layer, activations : Tuple (Activation, Activation))
+ UpdateWeightsAndBiases(epochCount : Int)

Matrix

+ matrixVals: List<List<Type>>
+ order: Tuple (int, int)

+ Matrix(order : Tuple (int, int))
+ Matrix(order : Tuple (int, int), identity : Bool)
+ Matrix(order : Tuple (int, int), random : Bool)
+ Matrix(values : List<List<Type>>)

+ operator +(M1 : Matrix, M2 : Matrix) : Matrix
+ operator -(M1 : Matrix, M2 : Matrix) : Matrix
+ operator *(M1 : Matrix, M2 : Matrix) : Matrix
+ operator *(M1 : Matrix, Scalar : Float) : Matrix
+ operator ^(M1 : Matrix) : Matrix

+ ToString() : String
+ Transpose() : Matrix
+ SelectColumn(Col:Int) : List
+ SelectRow(Row:Int) : List
+ Sum() : Float
+ Max() : Float
+ Clear()

Perlin Noise

+ OctaveNoise() : Float
+ Noise() : Float
+ Gradient() : Float
+ LinearInterpolate() : Float
+ Fade() : Float

Tile

+ tileHeight : Float
+ tileType : Int
+ tileColour : Tuple (int, int, int)
+ explored : Bool = False
+ hasObject : Bool = False
+ hasEnemy: Bool = False

DataLogger

+ name : String
+ dataStructure : List
+ dataPoints : List

+ DataLogger(name : String, dataStructure : List, loadDataPoints : Bool = True)

+ LogDataPointBatch(dataPoints : List)
+ LogDataPoint(dataPoint : List)
+ CheckMatchStructure(dataPoint : List) : Bool
+ HeapSort(parameterIndex : Int) : List
+ Select(searchIndex : Int, searchContents : List)

+ SaveDataPoints(fileName : String)
+ LoadDataPoints(fileName : String) : List

Heap

+ elements : List
+ index : List

+ Heap(elements : List, indexIn : int)

+ AddElement(element : List)
+ SiftUp(elementIndex: Int)
+ SiftDown(elementIndex: Int)
+ RemoveTop() : List
+ Peek() : List
+ Length() : Int
+ Heapify()

2.3   Individual Classes

Below is shown a simplified Class Diagram, and the Individual Classes with Descriptions as to their Role in the Program.

The Simulation Class is used to compose the 3 Main Sections of the Program into a Single Interface Class, it contains all the Setup, Display and Forward Methods.

```
                    ┌─────────────────────────────────────────────────┐
                    │                   Simulation                    │
                    ├─────────────────────────────────────────────────┤
                    │ + paramDictionary : Dictionary                  │
                    │ + worldMap : WorldMap                           │
                    │ + network : Dual Network                        │
                    │ + agent : Agent                                 │
                    │ + enemyList  : List<Enemy>                      │
                    │ + step : Int                                    │
                    ├─────────────────────────────────────────────────┤
                    │ + Simulation(params : Dictionary)               │
                    │                                                 │
                    │ + TimeStep()                                    │
                    │ + UpdateEnemies()                               │
                    │ + InitiateSimulation()                          │
                    │ + CreateWorld(seed: Int = 0)                    │
                    │ + CreateDeepQNetwork(layers : List<Int> = [ ])  │
                    │ + CreateAgent()                                 │
                    │ + SpawnEnemies(number : Int = 0)                │
                    │ + ResetOnDeath()                                │
                    │ + RenderToCanvas(window : Surface)              │
                    │                                                 │
                    │ + LoadParameters(fileName : String) : Dictionary│
                    │ + CheckParameters(params : Dictionary, fileName : String) : Bool│
                    └─────────────────────────────────────────────────┘
```
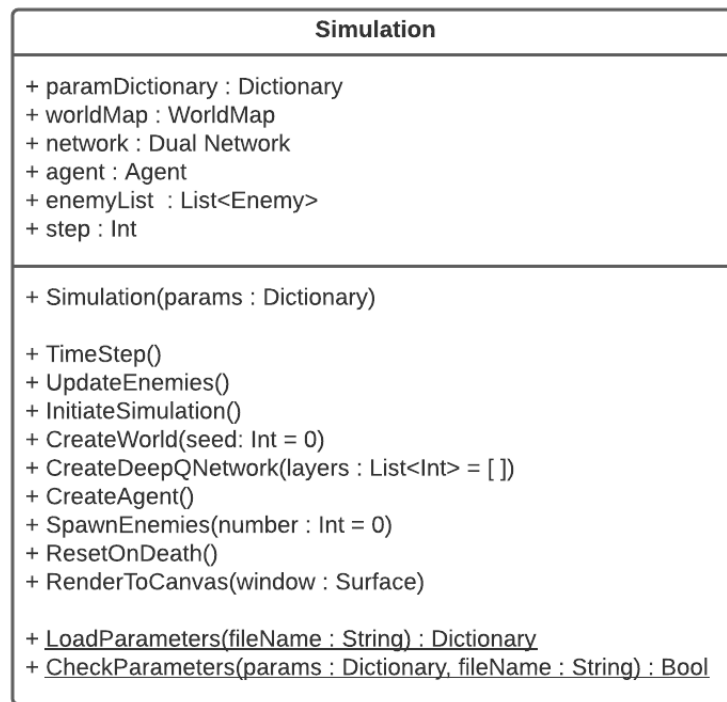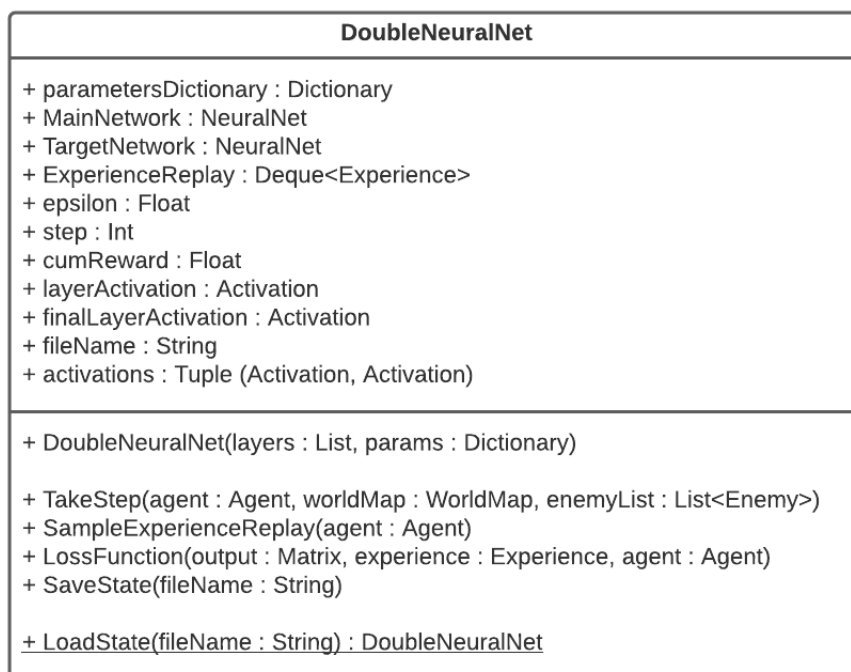
The DoubleNeuralNet Class combines together two Neural Networks to create a more complex Machine Learning Model.

```
          ┌─────────────────────────────────────────────────────────┐
          │                    DoubleNeuralNet                      │
          ├─────────────────────────────────────────────────────────┤
          │ + parametersDictionary : Dictionary                     │
          │ + MainNetwork : NeuralNet                               │
          │ + TargetNetwork : NeuralNet                             │
          │ + ExperienceReplay : Deque<Experience>                  │
          │ + epsilon : Float                                       │
          │ + step : Int                                            │
          │ + cumReward : Float                                     │
          │ + layerActivation : Activation                          │
          │ + finalLayerActivation : Activation                     │
          │ + fileName : String                                     │
          │ + activations : Tuple (Activation, Activation)          │
          ├─────────────────────────────────────────────────────────┤
          │ + DoubleNeuralNet(layers : List, params : Dictionary)   │
          │                                                         │
          │ + TakeStep(agent : Agent, worldMap : WorldMap, enemyList : List<Enemy>)│
          │ + SampleExperienceReplay(agent : Agent)                 │
          │ + LossFunction(output : Matrix, experience : Experience, agent : Agent)│
          │ + SaveState(fileName : String)                          │
          │                                                         │
          │ + LoadState(fileName : String) : DoubleNeuralNet        │
          └─────────────────────────────────────────────────────────┘
```

The NeuralNet Class contains all the methods needed for a Functional Neural Network.

```
┌─────────────────────────────────────────────────────────────────────┐
│                              NeuralNet                                │
├─────────────────────────────────────────────────────────────────────┤
│ + parametersDictionary : Dictionary                                   │
│ + layers : List<Layer>                                                │
├─────────────────────────────────────────────────────────────────────┤
│ + NeuralNet(layersIn : List<Layer>, params : Dictionary)             │
│                                                                       │
│ + ForwardPropagation(inputVector : Matrix, activations : Tuple (Activation, Activation)) │
│ + BackPropagation(activations : Tuple (Activation, Activation))      │
│ + UpdateWeightsAndBiases()                                            │
└─────────────────────────────────────────────────────────────────────┘
```

The NeuralNetwork Class contains an Array of Layer objects. They are integral to the function of the Neural Network.

```
┌─────────────────────────────────────────────────────────────────────┐
│                                Layer                                  │
├─────────────────────────────────────────────────────────────────────┤
│ + parametersDictionary : Dictionary                                   │
│ + weightMatrix : Matrix                                               │
│ + biasVector : Matrix                                                 │
│ + weightUpdates : Matrix                                              │
│ + biasUpdates : Matrix                                                │
│ + errSignal : Matrix                                                  │
│ + sVector : Matrix                                                    │
│ + outputVector : Matrix                                               │
├─────────────────────────────────────────────────────────────────────┤
│ + Layer(prevSize : Int, size : Int)                                   │
│                                                                       │
│ + ForwardPropagation(prevLayer : Layer, activations : Tuple (Activation, Activation)) │
│ + BackPropagation(prevLayer : Layer, activations : Tuple (Activation, Activation)) │
│ + UpdateWeightsAndBiases(epochCount : Int)                            │
└─────────────────────────────────────────────────────────────────────┘
```

The Matrix Class is a key part of the Program, being used within the Neural Networks Logic.

```
┌─────────────────────────────────────────────────────────────────────┐
│                              Matrix                                   │
├─────────────────────────────────────────────────────────────────────┤
│ + matrixVals: List<List<Type>>                                        │
│ + order: Tuple (int, int)                                             │
├─────────────────────────────────────────────────────────────────────┤
│ + Matrix(order : Tuple (int, int))                                    │
│ + Matrix(order : Tuple (int, int), identity : Bool)                   │
│ + Matrix(order : Tuple (int, int), random : Bool)                     │
│ + Matrix(values : List<List<Type>>)                                   │
│                                                                       │
│ + operator +(M1 : Matrix, M2 : Matrix) : Matrix                       │
│ + operator -(M1 : Matrix, M2 : Matrix) : Matrix                       │
│ + operator *(M1 : Matrix, M2 : Matrix) : Matrix                       │
│ + operator *(M1 : Matrix, Scalar : Float) : Matrix                    │
│ + operator ^(M1 : Matrix) : Matrix                                    │
│                                                                       │
│ + ToString() : String                                                 │
│ + Transpose() : Matrix                                                │
│ + SelectColumn(Col:Int) : List                                        │
│ + SelectRow(Row:Int) : List                                           │
│ + Sum() : Float                                                        │
│ + Max() : Float                                                        │
│ + Clear()                                                             │
└─────────────────────────────────────────────────────────────────────┘
```
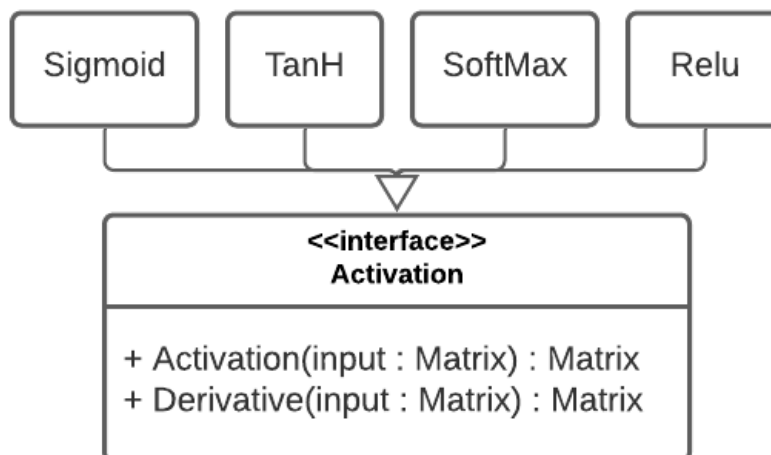
The Deque Class is used as part of the Experience Replay Algorithm.

```
                        Deque

        + length : Int
        + queue : List<Experience>
        + frontPointer : Int
        + backPointer : Int

        + Deque(length : Int)

        + PushFront(item : Experience)
        + Full() : Bool
        + First() : Experience
        + Last() : Experience
        + Sample(count : Int) : List<Experience>
```
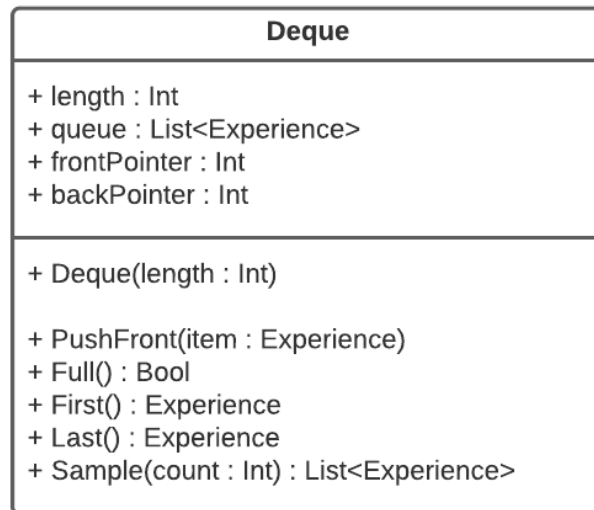
The Experience Class is stored within the Deque Object.

```
                Experience

        + state : Matrix
        + action : Int
        + reward : Matrix
        + stateNew : Matrix
```
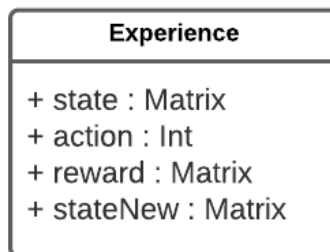
The Activation Class is an Abstract Base Class, in which the Neural Network Activations can inherit from, implementing their own definitions for Activation and Derivative.

```
  Sigmoid      TanH      SoftMax      Relu

                <<interface>>
                 Activation

        + Activation(input : Matrix) : Matrix
        + Derivative(input : Matrix) : Matrix
```

The Agent Class is used to store the Agents Location, along with implementing Action and Reward Methods.

```
┌─────────────────────────────────────────────────────────────┐
│                            Agent                              │
├─────────────────────────────────────────────────────────────┤
│ + parametersDictionary : Dictionary                          │
│ + location : Tuple (int, int)                                │
│ + alive : Bool = True                                        │
│ + inventory : Dictionary                                     │
├─────────────────────────────────────────────────────────────┤
│ + Agent(location: Tuple (int, int), params : Dictionary)     │
│                                                               │
│ + GetTileVector(worldMap : WorldMap, enemyList :             │
│ List<Enemy>) : Matrix                                        │
│ + TileVectorPostProcess(tileVector : Matrix) : (Matrix, Matrix)│
│ + ColourToGrayscale(colourTuple: Tuple (int, int, int)) : Float│
│ + CommitAction(action : Int, tileVector : Matrix, worldMap:  │
│ WorldMap, enemyList : List<Enemy>)                           │
│ + Move(direction : Int, worldMap : WorldMap)                 │
│ + CheckIfValidStandTile(location : Tuple (int, int), worldMap :│
│ WorldMap) : Bool                                             │
│ + PickupItem(worldMap : WorldMap)                            │
│ + Attack(enemyList : List<Enemy>)                            │
│                                                               │
│ + GetReward(action : Int, tileObjVec : Matrix) : Float       │
│ + MoveReward(tile : Tile) : Float                            │
│ + CombatReward(tileVector : Matrix) : Float                  │
│ + GetRewardVector(tileVector : Matrix, outputs : Matrix) : Float│
│ + MaxQ(tileVector : Matrix) : Float                          │
│ + Reset(worldMap : WorldMap)                                 │
│                                                               │
│ + SpawnPosition(worldMap : WorldMap)                         │
└─────────────────────────────────────────────────────────────┘
```

The Enemy Class inherits methods from Agent, Implementing its own CommitAction and SpawnPosition Methods.

```
┌─────────────────────────────────────────────────────────────┐
│                            Enemy                              │
├─────────────────────────────────────────────────────────────┤
│ + parametersDictionary : Dictionary                          │
│ + location : Tuple (int, int)                                │
│ + alive : Bool = True                                        │
├─────────────────────────────────────────────────────────────┤
│ + CommitAction(agent : Agent, worldMap : WorldMap)           │
│                                                               │
│ + SpawnPosition(enemyList : List<Enemy>, worldMap : WorldMap) : Tuple│
│ (Int, Int)                                                   │
└─────────────────────────────────────────────────────────────┘
```

The WorldMap Class generates and stores all Terrain Data for the current Simulation.

```
                        WorldMap
  ──────────────────────────────────────────────
  + mapSize : Int
  + tileWidth : Int
  + seed : Int
  + tileBorder : Int
  + tileArray : List<List<Tile>>
  + paramDictionary : Dictionary
  + renderedMap : Surface
  + renderedInteractables : Surface
  ──────────────────────────────────────────────
  + WorldMap(seed : Int, params : Dictionary)

  + GenerateMap()
  + GenerateThreaded()
  + ThreadedChild(quadrant : List<List<Tile>>)
  + GenerateTreeArea()
  + PoissonDiscSampling(pointList :  List) : List
  + PoissonCheckPoint(point : Tuple (int, int), pickedPoints : List
  + RenderMap() : Surface
  + RenderInteractables() : Surface
  + DrawMap() : Surface
  + Clamp(value : Float, low : Float, high : Float) : Float
```

The Perlin Noise Class contains only methods and is used to Sample Gradient Noise based on a Seed.

```
                    Perlin Noise
  ──────────────────────────────────────────
  + OctaveNoise() : Float
  + Noise() : Float
  + Gradient() : Float
  + LinearInterpolate() : Float
  + Fade() : Float
```
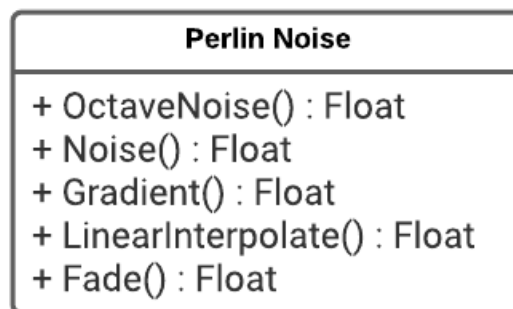
The Tile Class is used to Store and Manipulate Data per Tile.

```
                    Tile
  ──────────────────────────────────
  + tileHeight : Float
  + tileType : Int
  + tileColour : Tuple (int, int, int)
  + explored : Bool = False
  + hasObject : Bool = False
  + hasEnemy: Bool = False
```
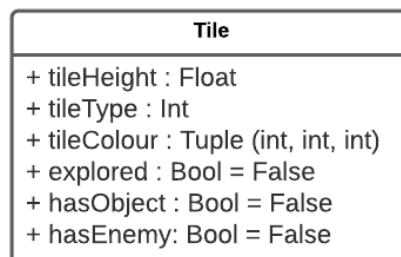
The DataLogger Class is used to log Data Points across the Program.

```
                          DataLogger
+ name : String
+ dataStructure : List
+ dataPoints : List
+ DataLogger(name : String, dataStructure : List, loadDataPoints : Bool = True)

+ LogDataPointBatch(dataPoints : List)
+ LogDataPoint(dataPoint : List)
+ CheckMatchStructure(dataPoint : List) : Bool
+ HeapSort(parameterIndex : Int) : List
+ Select(searchIndex : Int, searchContents : List)

+ SaveDataPoints(fileName : String)
+ LoadDataPoints(fileName : String) : List
```

The Heap Class is used as part of the Heap Sort implemented by the DataLogger.

```
                   Heap
+ elements : List
+ index : List

+ Heap(elements : List, indexIn : int)

+ AddElement(element : List)
+ SiftUp(elementIndex: Int)
+ SiftDown(elementIndex: Int)
+ RemoveTop() : List
+ Peek() : List
+ Length() : Int
+ Heapify()
```
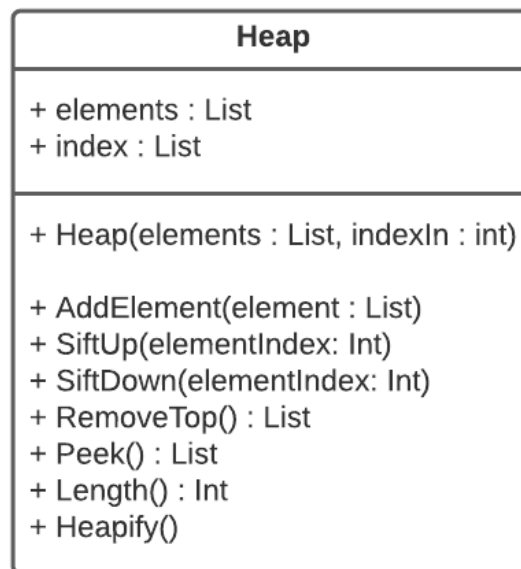
2.4   Choice of Programming Language and Libraries

During my Analysis I outlined a list of possible Programming Languages and Associated Libraries. I chose Python and Pygame as part of my prototype. I found this combination to be very easy to use and iteratively develop my prototype.

2.5   Description of Algorithms

In this section, I will describe the algorithms I intend to use in my Technical Solution. I will also include generalised Pseudocode as part of my description.

2.5.1   Matrix Addition

This algorithm is a Mathematical Operation to add 2 Matrices together. To Add together 2 Matrices their Orders must be the same. To perform the Operation you must Sum each element in Matrix A with the corresponding element in Matrix B, placing the result of each Sum in the resultant Matrix.

```
1   SUBROUTINE MatrixAddition(Matrix1, Matrix2)
2       TemporaryMatrix ← NEW Matrix(Matrix1.Order)
3       FOR Row ← 0 TO Matrix1.Order[0]
4           FOR Column ← 0 TO Matrix1.Order[1]
5               TemporaryMatrix[Row, Column] ← Matrix1[Row, Column] + Matrix2[Row, Column]
6           END FOR
7       END FOR
8       RETURN TemporaryMatrix
9   ENDSUBROUTINE
```

2.5.2 Matrix Subtraction

This algorithm is a Mathematical Operation to subtract 2 Matrices. To Subtract 2 Matrices their Orders must be the same. To perform the Operation you must Sum each element in Matrix A with the negative of the corresponding element in Matrix B, placing the result of each Sum in the resultant Matrix.

```
1   SUBROUTINE MatrixSubtraction(Matrix1, Matrix2)
2       TemporaryMatrix ← NEW Matrix(Matrix1.Order)
3       FOR Row ← 0 TO Matrix1.Order[0]
4           FOR Column ← 0 TO Matrix1.Order[1]
5               TemporaryMatrix[Row, Column] ← Matrix1[Row, Column] - Matrix2[Row, Column]
6           END FOR
7       END FOR
8       RETURN TemporaryMatrix
9   ENDSUBROUTINE
```

2.5.3 Matrix Multiplication

This algorithm is a Mathematical Operation to find the product of 2 Matrices. To Multiply 2 Matrices the number of Columns in the Matrix A must be equal to the number of Rows in Matrix B. Where Matrix A has dimensions of m x n and Matrix B has dimensions of j x k, the resultant Matrix will have dimensions of n x j. To Multiply two Matrices, the algorithm performs the Dot Product between the Row in Matrix A and the corresponding Column in Matrix B. The Dot Product is the Sum of the Products of corresponding elements.

```
1    SUBROUTINE MatrixMultiplication(Matrix1, Matrix2)
2        tempMatrix ← NEW Matrix((Matrix1.Order[0], Matrix2.Order[1]))
3        FOR i ← 0 TO Matrix1.Order[0]
4            FOR j ← 0 TO Matrix2.Order[1]
5                FOR l ← 0 TO Matrix.Order[1]
6                    tempMatrix[i, j] ← tempMatrix[i, j] + Matrix1[i, k] * Matrix2[k, j]
7                END FOR
8            END FOR
9        END FOR
10       RETURN tempMatrix
11   ENDSUBROUTINE
```

2.5.4 Matrix Scalar Multiplication

This algorithm is a Mathematical Operation to find the product between a Matrix and a Scalar. The result can be found by Multiplying each element of the Matrix by the Scalar Value to form the Resultant Matrix.

```
1   SUBROUTINE MatrixScalarMultiplication(Scalar, Matrix)
2       TemporaryMatrix ← NEW Matrix(Matrix.Order)
3       FOR Row ← 0 TO Matrix.Order[0]
4           FOR Column ← 0 TO Matrix.Order[1]
5               TemporaryMatrix[Row, Column] ← Scalar * Matrix[Row, Column]
6           END FOR
7       END FOR
8       RETURN TemporaryMatrix
9   ENDSUBROUTINE
```

2.5.5 Matrix Hadamard Product

This algorithm is a Mathematical Operation to another way to find the product between 2 Matrices. Instead of applying the Dot Product between Rows and Columns, you find the product between each element in Matrix A with the corresponding element in Matrix B, placing the result in the resultant Matrix.

```
1   SUBROUTINE MatrixHadamardProduct(Matrix1, Matrix2)
2       TemporaryMatrix ← NEW Matrix(Matrix1.Order)
3       FOR Row ← 0 TO Matrix1.Order[0]
4           FOR Column ← 0 TO Matrix1.Order[1]
5               TemporaryMatrix[Row, Column] ← Matrix1[Row, Column] * Matrix2[Row, Column]
6           END FOR
7       END FOR
8       RETURN TemporaryMatrix
9   ENDSUBROUTINE
```

2.5.6 Matrix Power

This algorithm is a Mathematical Operation to find the power of a Matrix. The given Matrix needs to have square dimensions. The result can be found by multiplying the given Matrix by itself n ammount of times where n is the given power.

```
1   SUBROUTINE MatrixHadamardProduct(Matrix, Power)
2       TemporaryMatrix ← CLONE Matrix
3       FOR Row ← 0 TO Power - 1
4           TemporaryMatrix ← TemporaryMatrix * Matrix
5       END FOR
6       RETURN TemporaryMatrix
7   ENDSUBROUTINE
```

2.5.7 Matrix Transpose

This algorithm is a Mathematical Operation used to Flip a Matrix across its Diagonal. The Transpose of any Matrix can be found by converting each Row of the Matrix into a Column. An m x n Matrix will turn into an n x m Matrix.

```
1   SUBROUTINE MatrixTranspose(Matrix)
2       TemporaryMatrix ← NEW Matrix(Matrix.Order)
3       FOR Row ← 0 TO Matrix.Order[0]
4           FOR Column ← 0 TO Matrix.Order[1]
5               TemporaryMatrix[Row, Column] ← Matrix[Column, Row]
```

```
6        END FOR
7      END FOR
8      RETURN temporaryMatrix
9  ENDSUBROUTINE
```

2.5.8 Activation Function SoftMax

This algorithm is a logistic function that creates a probability distribution from a set of points. This probability distribution sums to 1. It applies the standard Exponential Function to each element, then normalises this value by dividing by the sum of all these Exponentials.

```
1  SUBROUTINE Softmax(Input)
2      OutVector ← NEW Matrix(Input.Order)
3      ExpSum ← 0
4      FOR Row ← 0 TO Input.Order[0]
5          ExpSum ← ExpSum + Math.exp(Input[Row, 0])
6      END FOR
7      FOR Row ← 0 TO Input.Order[0]
8          OutVector[Row] ← Input[Row, 0] / ExpSum
9      END FOR
10     RETURN OutVector
11 ENDSUBROUTINE
```

2.5.9 Neural Network Forward Propagation

This algorithm is used to obtain the outputs of a Neural Network. It uses Matrix Multiplication to propagate the inputs of the network from Layer to Layer, eventually reaching the Output Layer. My Multiplying the Weight Matrix and the outputs of the previous Layer, and then adding the Bias. We can obtain the output of the layer.

```
1  SUBROUTINE Forward Propagation(PrevLayer, Activations, FinalLayer)
2      WeightValueProduct ← This.WeightMatrix * PrevLayer.OutputVector
3      This.SVector ← WeightValueProduct + This.BiasVector
4      IF NOT FinalLayer
5          This.OutputLayer ← Activations[0].Activation(SVector)
6      ELSE
7          This.OutputLayer ← Activations[1].Activation(SVector)
8      END IF
9  ENDSUBROUTINE
```

2.5.10 Neural Network Loss Function

The algorithm for to calculate the Loss of a Dual Neural Network can calculated by using a variation of the Bellman Equation. The Bellman Equation is neccesary for Mathematically Optimising in this case. It determines the Value of a decision at a certain point in time, in terms of the Payoff from the Inital Action and the Value of the Potential Payoff after taking that Initial Action.

2.5.11   Neural Network Backwards Propagation

This algorithm is used within a Neural Network to adjust its Weights and Biases, allowing it to more accurately predict the best outcome. In Reinforcement Learning, the Network is trained using an estimate for what is the best action given a situation. Using this estimate, we can train the Network to predict this outcome by converging the series of Weights and Biases towards a local minimum. This is done by calculating partial derivates for every weight and bias value with respect to the cost function. This derivative is then subtracted from the existing weight or bias, eventually converging on the best possible value.

2.5.12   Agent Get Tile Vector

This algorithm takes the current World Data of the simulation, and produces a Vector of Tile Data surrounding the Agent. This can be done using a nested For Loop rather simply.

```
1  SUBROUTINE GetTileVector(WorldMap)
2      Offset ← LoadFromParameters("DQLOffset")
3      SideLength ← 2 * Offset + 1
4      TileVector ← NEW Matrix((Math.pow(sideLength, 2), 1))
5      Num ← 0
6      FOR i ← Agent.Pos[1] - Offset TO Agent.Pos[1] + Offset + 1
7          FOR j ← Agent.Pos[0] - Offset TO Agent.Pos[1] + Offset + 1
8              TileVector[Num, 0] ← WorldMap[j, i]
9              Num ← Num + 1
10         END FOR
11     END FOR
12     RETURN TileVector
13 ENDSUBROUTINE
```

2.5.13   Agent Convert to Grayscale

This algorithm converts a given RGB Colour Value to the corresponding Gray Scale Value. The Red, Green and Blue elements of the colour value are multiplied by the specific values 0.299, 0.587 and 0.114. You then sum the results, and divide by 255.

```
1  SUBROUTINE RGBToGrayscale(RGBVal)
2      GrayscaleValue ← 0
3      GrayscaleValue ← GrayscaleValue + (0.299 * RGBVal[0])
4      GrayscaleValue ← GrayscaleValue + (0.587 * RGBVal[1])
5      GrayscaleValue ← GrayscaleValue + (0.114 * RGBVal[2])
6      RETURN GrayscaleValue / 255
7  ENDSUBROUTINE
```

2.5.14   Agent Post Process Tile Vector

This algorithm will convert the Tile Vector into a Vector of Grayscale values, which can be used as the input for the Neural Network.

```
1  SUBROUTINE GetTileVector(TileVector)
2      ProcessedVector ← NEW Matrix(TileVector.Order)
3      FOR Row ← 0 TO TileVector.Order[0]
4          ProcessedVector[Row, 0] ← RGBToGrayscale(TileVector[Row, 0].RGBValue)
5      END FOR
```

```
6        RETURN ProcessedVector
7    ENDSUBROUTINE
```

2.5.15   Agent Spawn Position

This algorithm will create a list of spawnable tiles for which the Agent could spawn on, and then randomnly select a specific tile as its spawn position.

```
1    SUBROUTINE AgentSpawnPosition(WorldMap)
2        SpawnList ← NEW List()
3        MapSize ← LoadFromParameters("MapSize")
4        FOR y ← 0 TO MapSize
5            FOR x ← 0 TO MapSize
6                IF WorldMap[x, y].TileType == 2
7                    SpawnList.Add([x, y])
8                END IF
9            END FOR
10       END FOR
11       SpawnList.Shuffle()
12       RETURN SpawnList[0]
13   ENDSUBROUTINE
```

2.5.16   Enemy Spawn Position

This algorithm will create a list of spawnable tiles for which Enemies can spawn on, then select tiles randomnly, if they dont already contain an enemy or the agent it will create an Enemy Object with that position. It will do this n ammount of times where n is the limit to how many enemies can spawn.

```
1    SUBROUTINE EnemySpawnPosition(WorldMap, EnemyList)
2        SpawnList ← NEW List()
3        EnemyLocationList ← NEW List()
4        MapSize ← LoadFromParameters("MapSize")
5        FOR y ← 0 TO MapSize
6            FOR x ← 0 TO MapSize
7                IF WorldMap[x, y].TileType == 2
8                    SpawnList.Add([x, y])
9                END IF
10           END FOR
11       END FOR
12       SpawnList.Shuffle()
13       IF SpawnList[0] IN EnemyLocationList
14           RETURN NONE
15       ELSE
16           RETURN SpawnList[0]
17       END IF
18       RETURN SpawnList[0]
19   ENDSUBROUTINE
```

2.5.17   Enemy Move

The algorithm I have designed for the Enemy Pathfinding is rather simple, and wont take up much runtime in my solution. First it calculates the distance between itself and the Agent in

both Axis. The Enemy will then converge upon the Agents position by moving in the direction with the greatest distance, effectively finding the nearest diagonal and following it.

```
1  SUBROUTINE EnemyMove(Agent, WorldMap)
2      XDifference ← Agent.Pos[0] - This.Pos[0]
3      YDifference ← Agent.Pos[1] - This.Pos[0]
4
5      IF XDifference == 0 AND YDifference == 0
6          Agent.Alive = False
7          RETURN
8      END IF
9
10     IF abs(XDifference) > abs(YDifference)
11         IF XDifference > 0
12             This.Pos[0] ← This.Pos[0] + 1
13         ELSE
14             This.Pos[0] ← This.Pos[0] - 1
15         END IF
16     ELSE IF abs(XDifference) < abs(YDifference)
17         IF YDifference > 0
18             This.Pos[1] ← This.Pos[1] + 1
19         ELSE
20             This.Pos[1] ← This.Pos[1] - 1
21         END IF
22     END IF
23  ENDSUBROUTINE
```

2.5.18   Poisson Disc Sampling

Poisson Disc Sampling is used to sample a set of points in N Dimensional Space. It takes two parameters, r and k, where r is the minimum distance a specified point must be from every other point, and k is the limit of samples to choose before rejection. It starts by creating an N Dimensional Grid which accelerates spacial searches. An initial sample is then chosen and inserted into the grid. It then chooses a random point, and determines if it is greater than r range from every other point in the grid. This can easily be acomplished using the previously defined Grid. If after k attempts, no point is found then the search is concluded.

```
1  SUBROUTINE PoissonDiscSampling(PointList)
2      KVal ← LoadFromParameters("PoissonKVal")
3      MapSize ← LoadFromParameters("MapSize")
4      PickedPoints ← NEW Grid(MapSize, MapSize)
5      SampleNum ← LoadFromParameters("MapSize")
6      WHILE SampleNum <= KVal
7          Sample ← PointList[RandomInt(0, PointList.Length - 1)]
8          Result ← CheckPointDistance(Sample, PickedPoints)
9          IF Result == True
10             PickedPoints[Sample[0], Sample[1]] ← True
11             SampleNum ← 0
12             CONTINUE
13         ELSE
14             SampleNum ← SampleNum + 1
15             CONTINUE
16         END IF
17     END WHILE
18     RETURN PickedPoints
19  ENDSUBROUTINE
```

2.5.19 Perlin Noise

Perlin Noise is a method of generating a procedural texture depending upon input parameters. It defines an n-dimensional grid of Vectors, each grid intersection contains a fixed, random unit vector. To sample Perlin Noise, the grid cell which the point lies in must be found. The Vectors between the sampled point, and the corners of the cell. We then take the Dot Product between these new Vectors, and the Vectors applied to the intersections. In 2d Space this leaves us with 4 Values. We then use an Interpolation function to Interpolate between the 4 Values.

```
1   PermTable ← [1 → 255].Shuffle() * 2
2
3   SUBROUTINE PerlinNoise(X, Y)
4       XFloor ← Math.floor(X)
5       YFloor ← Math.floor(Y)
6
7       G1 ← PermTable[PermTable[XFloor] + YFloor]
8       G2 ← PermTable[PermTable[XFloor + 1] + YFloor]
9       G3 ← PermTable[PermTable[XFloor] + YFloor + 1]
10      G4 ← PermTable[PermTable[XFloor + 1] + YFloor + 1]
11
12      XExact ← X - XFloor
13      YExact ← Y - YFloor
14
15      D1 ← Grad(G1, XFloor, YFloor)
16      D2 ← Grad(G2, XFloor - 1, YFloor)
17      D3 ← Grad(G3, XFloor, YFloor - 1)
18      D4 ← Grad(G4, XFloor - 1, YFloor - 1)
19
20      U ← Fade(XFloor)
21      V ← Fade(YFloor)
22
23      XInterpolated ← Lerp(U, D1, D2)
24      YInterpolated ← Lerp(U, D3, D4)
25
26      RETURN Lerp(V, XInterpolated, YInterpolated)
27  ENDSUBROUTINE
28
29  SUBROUTINE Grad(Hash, X, Y)
30      Temp ← Hash BITWISEAND 3
31      IF Temp == 0
32          RETURN X + Y
33      ELSE IF Temp == 1
34          RETURN -X + Y
35      ELSE IF Temp == 2
36          RETURN X - Y
37      ELSE IF Temp == 3
38          RETURN -X - Y
39      ELSE
40          RETURN 0
41      END IF
42  ENDSUBROUTINE
43
44  SUBROUTINE Lerp(Ammount, Left, Right)
45      RETURN ((1 - Ammount) * Left + Ammount * Right)
46  ENDSUBROUTINE
47
48  SUBROUTINE Fade(T)
49      RETURN T * T * T * (T * (T * 6 - 15) + 10)
50  ENDSUBROUTINE
```

2.5.20 Octave Perlin Noise

Octave Perlin Noise takes the existing Perlin Noise algorithm, but adds rescaled clones of itself into itself, to create what is known as Fractal Noise. Creating this Fractal Noise is common practice because it reduces the sharp edges encountered with just the regular Perlin Noise Algorithm.

```
1  SUBROUTINE OctaveNoise(X, Y, Octaves, Persistence)
2      Total ← 0
3      Frequency ← 1
4      Amplitude ← 1
5      MaxValue ← 0
6
7      FOR i ← 0 TO Octaves
8          Total ← Total + (PerlinNoise(X * Frequency, Y * Frequency) * Amplitude
9
10         MaxValue ← MaxValue + Amplitude
11
12         Amplitude ← Amplitude * Persistence
13         Frequency ← Frequency * 2
14     END FOR
15
16     RETURN Total / MaxValue
17 ENDSUBROUTINE
```

2.5.21 Heap Heapify

The Heapify algorithm converts a Binary Tree of values into a valid Heap. The Heap Property is defined in Description of Data Structures below. This algorithm works by repeatedly performing Sift Down Operations for $\lfloor(N-1)/2\rfloor$ times. Where N is the Number of elements in the Tree. A Sift Down Operation will swap elements which don't conform to the Heap Property. This operation relys on the fact that Children of an Index are located at $2i + 1$ and $2i + 2$.

```
1  SUBROUTINE Heapify()
2      FOR i ← ⌊(HeapList.Length-1)/2⌋ TO 0 STEP -1
3          SiftDown(i)
4      END FOR
5  ENDSUBROUTINE
6
7  SUBROUTINE SiftDown(RootIndex)
8      IsHeap ← FALSE
9      End ← HeapList.Length - 1
10
11     WHILE (2 * RootIndex) + 1 <= End
12         ChildIndex = (RootIndex * 2) + 1
13         IF ChildIndex <= End AND HeapList[ChildIndex] < HeapList[ChildIndex + 1]
14             ChildIndex ← ChildIndex + 1
15         END IF
16         IF HeapList[RootIndex] < HeapList[ChildIndex]
17             TempSwap ← HeapList[ChildIndex]
18             HeapList[ChildIndex] ← HeapList[RootIndex]
19             HeapList[RootIndex] ← TempSwap
20         ELSE
21             BREAK
22         END IF
23 ENDSUBROUTINE
```

2.5.22 Heap Extraction

This algorithm extracts the Root Element from a valid Heap. It does this by swapping the Root Element and Final Element, and then popping the new Final Element (Originally the Root) from the list.

```
1  SUBROUTINE RemoveTop()
2      TempSwap ← HeapList[-1]
3      HeapList[-1] ← HeapList[0]
4      HeapList[0] ← TempSwap
5      ReturnItem ← HeapList.Pop()
6
7      Heapify()
8
9      RETURN ReturnItem
10 ENDSUBROUTINE
```

2.5.23 Heap Sort

The Heap Sort algorithm relys on the prior two algorithms to fully order a list in Worst and Best case $O(nlog(n))$ Time Complexity. It is also $O(1)$ Space Complexity due to it being an In-Place Sorting algorithm. The sort will iteratively shrink the unsorted region by performing the following steps: Apply Heapify to the Unsorted Region, Extract the Root Element from the Heap, Insert the Extracted Element at the end of the Unsorted Region. This allows it to be In-Place because it never requires extra space.

```
1  SUBROUTINE HeapSort()
2      SortedList ← NEW List()
3      Heap ← NEW Heap(DataPoints)
4
5      WHILE Heap.Size() - 1 >= 0
6          SortedList.Append(Heap.RemoveTop)
7      END FOR
8
9      RETURN SortedList
10 ENDSUBROUTINE
```

2.6 Description of Data Structures

1. Matrices

   As part of developing a Neural Network, I will extensively use Matrices, as they are an integral part of the algorithms used for Machine Learning. After creating a prototype Matrix class as part of my prototype, I will represent it in the same format. A Matrix can be represented simply using a 2D Array, but they can have Mathematical Operations performed between them. Explanations and the formulae can be found in the Modelling of the Problem Analysis Section.

   To avoid repeating code in some places, Matrices will have multiple Constructors. The main Constructors are in the form of an (Int, Int) Tuple, or an pre-existing 2D Array. Other less used examples could be an Integer for creating a Vector of that length.

   Operator Overloading will be useful when implementing a Matrix Class, as it allows classes to have implementations for operators such as Multiplication, Addition,

Subtraction etc. This avoids the need to rely on Static Methods for Operator Implementations and makes code much more readable overall.

As part of a Neural Network Matrices are used heavily in the calculations. So it will be important to optimise the implemented algorithms to make sure their Algorithmic Time Complexity is minimised.

2. Double Ended Queue

   A Double Ended Queue (Commonly referred to as a **Deque**) is an Abstract Data Type, which is a generalisation of a Queue. Elements can be added to the Front/Head or Back/Tail. Deques are commonly implemented using an Array, and two pointers, one for Front and Back.

3. Tile

   A Tile is used to store specific location Data as part of the World Map. It can be initialised without values, and is then populated with the relevant information. Methods are attatched to this Class to Add/Remove Items and Enemies as needed. Allowing for the Agent when getting Tile data to get relevant and accurate information.

4. Experience

   An Experience is used to store data for Experience Replay. It is an Empty Class with no Methods. This includes the State, Action, NewState and Reward, all at the time of assignment. This is used in conjunction with the Experience Replay Algorithm, described above.

5. Heap

   A Heap is specialised Binary Tree which satisfies the **Heap Property**: such that for all nodes with Parents, the Parent has a greater value than the Child. A Heap is used as part of a Heap Sort, an $O(nlog(n))$ Sorting Algorithm. The highest priority element is always stored at the Root, with the tree of the structure being considered "Partialy Ordered". Heaps can be stored in an Array, with the Root element at Index 0. Children of an Index are located at **2i + 1** and **2i + 2**. The Parent of an Index is located at $\lfloor$**(i-1)/2**$\rfloor$.

2.7   File Structure

1. User Defined Parameters

   As part of my Technical Solution, the User will be able to modify the parameters which dynamically modifies the Simulation and the Structure of the Double Neural Network. The file is stored in a Json format (Java Script Object Notation). This allows the File to be Human Readable, and easily editable. Each parameter will also have a defined Range alongside it. The program will throw an error if the parameter is outside the specified range. Below is a table of the Parameters used in the Technical Solution, alongside their respective Ranges.

Name in Json	Data Type	Range	Description
EnterValues	Int	0 - 1	The program will ask you to enter values if this is 1

GenerateThreaded	Int	0 - 1	The program will generate the Terrain using Multiple Threads
EnableEnemies	Int	0 - 1	Toggled Enable Enemies Option.
SaveWeights	Int	0 - 1	Toggled Save Network Weights Option.
StepDelay	Float	0 - ∞	The time delay each step.
Debug	Int	0 - 1	Toggled Debug Option.
DebugScale	Int	1 - 4	The scale of the Debug side extension.
WorldSize	Int	16 - 1024	The size the of the World in Tiles. Must be a Multiple of 2.
TileWidth	Int	1 - 8	The Width and Height of each Tile.
TileBorder	Int	0 - 3	The Pixel Border surrounding Tiles.
OctavesTerrain	Int	1 - 20	The Perlin Noise Octave Value for World Generation.
PersistenceTerrain	Float	0 - 1	The Perlin Noise Persistence Value for World Generation.
WorldScale	Float	0.1 - 10	The Perlin Noise Scale Value for World Generation.
OctavesTrees	Int	1 - 20	The Perlin Noise Octave Value for Trees
PersistenceTrees	Float	0 - 1	The Perlin Noise Persistence Value for generating the Trees.
PoissonKVal	Int	0 - ∞	The K Value for Poisson Disc Sampling.
TreeSeedOffset	Int	0 - ∞	The Seed offset for generating the Trees.
TreeHeight	Float	0 - 1	The difference between Min Tree spawning height and Max Tree spawning height.
InteractableTileBorder	Int	0 - 3	The Pixel Border surrounding Interactables.
TreeBeachOffset	Float	0 - 1	The height difference from Beaches which Trees will Spawn.
Grayscale	Int	0 - 1	Toggled Grayscale Terrain Option.
Water	Float	0 - 1	The cuttoff values for Water.
Coast	Float	0 - 1	The cuttoff values for Coast.
Grass	Float	0 - 1	The cuttoff values for Grass.
Mountain	Float	0 - 1	The cuttoff values for Mountains.
TreeType	String	0 - 1	The internally used Inventory name for collected Trees.
StartEnemyCount	Int	0 - ∞	The maximum count of Enemies to Spawn upon the creation of a new Map.
ColourWater	[Int, Int, Int]	0 - 255	The display Colour of Water.
ColourCoast	[Int, Int, Int]	0 - 255	The display Colour of Coast.
ColourGrass	[Int, Int, Int]	0 - 255	The display Colour of Grass.
ColourMountain	[Int, Int, Int]	0 - 255	The display Colour of Mountains.
ColourTree	[Int, Int, Int]	0 - 255	The display Colour of Trees.
ColourPlayer	[Int, Int, Int]	0 - 255	The display Colour of the Agent.
ColourEnemy	[Int, Int, Int]	0 - 255	The display Colour of Enemies.
MoveReward	Float	-1 - 1	The Reward Gained when the Agent Moves.
CollectItemReward	Float	-1 - 1	The Reward Gained when the Agent collects an Item.
DeathReward	Float	-1 - 1	The Reward Gained when the Agent Dies through any means.
ExploreReward	Float	-1 - 1	The Reward Gained when the Agent moves into a Tile which hasnt been Visited yet.
AttackReward	Float	-1 - 1	The Reward Gained when the Agent successfully Attacks an Enemy.
AttackFailedReward	Float	-1 - 1	The Reward Gained when the Null Action is chosen.
NoopReward	Float	-1 - 1	The Reward Gained when the Null Action is chosen.
TargetReplaceRate	Int	5 - 300	Replace Rate for Target Neural Network.
EREnabled	Int	0 - 1	Wether Experience Replay is Enabled or Disabled.
ERBuffer	Int	1k - 10k	The size of the Experience Replay Buffer.
ERSampleRate	Int	1 - 100	The ammount of steps between each Experience Replay sample.

ERSampleSize	Int	10 - 1000	The ammount of samples taken from the Experience Replay Buffer.
DeepQLearningLayers	[Int, ..., Int]	0 - 256	List of Integers defining the size of each Layer in the Neural Network.
DQLEpoch	Int	10 - 1000	The ammount of steps per Weight and Bias Update, along with Network Saving and Debug Output
DQLearningMaxSteps	Int	1000 - ∞	Maximum steps the Simulation will run for.
DQLOffset	Int	1 - 10	The square radius around the agent which is sampled for the Input vector, must be the root of the Input Layers size.
DQLEpsilon	Float	0 - 1	The initial Probability that the Agent will favour a Random Action over the predicted Action
DQLEpsilonRegression	Float	0 - 1	The rate at which Epsilon will decrease, Epsilon is multiplied every step by this number
DQLLearningRate	Float	0 - 1	The Learning Rate of the Neural Network. Higher values will cause more drastic changes during Back Propagation.
DQLGamma	Float	0 - 1	The Discount for future gained Reward

2. .dqn Files

DQN Files are used to store all Data relating to the Dual Neural Network. It is a Binary File. It contains all Layer Data, along with Experience Replay Data, the activations being used, and other important data.

3. .data Files

Data Files are used to store all data points created by the Data Loggers. They are Binary Files and are individually created per Data Logger.

3 Testing

3.1 Testing Table

3.1.1 Targetted Testing Areas

As part of testing my NEA, I identified the key areas of my project which needed testing. My testing targets these areas from different angles to ensure they work correctly. These areas are:

1. User Input and Program Output

    (a) Parameter Loading
    (b) Neural Network Loading
    (c) Graphical Output
    (d) Console Output

2. Matrix Implementation

    (a) Constructor Cases
    (b) Matrix Operations
    (c) Thrown Exceptions

3. Deep Q Learning Algorithm

    (a) Forward Propagation
    (b) Loss Function
    (c) Back Propagation
    (d) Double Ended Queue Data Type

4. Data Logger

    (a) Data Structure Matching
    (b) Heap Data Structure
    (c) Heap Sort Implementation

5. Simulation

    (a) Generation of 2d Terrain
    (b) Continuity of Generation
    (c) ML Agent
    (d) Reward Methods

Below is included an NEA Testing video used for some parts of Testing Evidence

https://thisisalink.com/youtotallybelieveme/

3.1.2   User Input and Program Output Tests

Test No.	Test Name	Input Data / Description	Expected Output	Pass / Fail	Testing Evidence
1	Loading Parameters File	Input "Default.json" file which contains the loadable values	Loads parameters into the Parameters Dictionary variable	Pass	1.1
2	Parameters within range	Input Loaded Parameters Dictionary	Prints to console "Parameters within Specified Ranges"	Pass	1.2
3	Below Range Parameter	Input "Default.json" file with a below range parameters	Raises an exception detailing the Parameter, Value of Parameters, and the given Range Required	Pass	1.3
4	Above Range Parameter	Input "Default.json" file with an above range parameters	Raises an exception detailing the Parameter, Value of Parameters, and the given Range Required	Pass	1.4
5	Network Saved Data Loading	When Prompted to load network data type "Y", and type the file name of network data to load	Network Data is loaded successfully, training position stored	Pass	1.5
6	Window Opening	Run Program, enter setup info as normal	Window opens and is of the correct size/resolution	Pass	1.6
7	Window Displays correct debug information	Run Program, enter setup info as normal, with "Debug" = 1 in parameters file	Debug Layer output info displayed on Right side of Window	Pass	1.7
8	Agent is displayed	Run Program, enter setup info as normal	Orange square displayed on screen	Pass	1.8
9	Enemies are displayed	Run Program, enter setup info as normal, with "StartEnemyCount" >= 1	Red Square/s are displayed on Screen	Pass	1.9
10	Console Messages Output	Run Program, enter setup info as normal	Console Messages Outputted per 100 Steps	Pass	1.10

3.1.3   Matrix Implementation Tests

Test No.	Test Name	Input Data / Description	Expected Output	Pass / Fail	Testing Evidence
1	Create Matrix with Tuple	A Tuple for the order of the Matrix	Matrix is created with an order the same as the Tuple	Pass	2.1

2	Create Matrix with 2d List	A 2d List, where the parent list holds a list for every row, each "row list" is of the same length	Matrix is created with the same values as the 2d List	Pass	2.2
3	Create Vector with List	A 1d List of any Values	Vector is created with the same values as the List	Pass	2.3
4	Print Matrix to Console	A valid Matrix of any size	Matrix Prints to the console with the correct formatting	Pass	2.4
5	Create Randomised Matrix	A Tuple for the order of the Matrix, and the the keyargument random=True	Matrix is created with randomised values between -0.5 and 0.5	Pass	2.5
6	Create Identity Matrix	A Tuple for the order of the Matrix, and the the keyargument identity=True	Matrix is created with all 0's and 1's down the diagonal	Pass	2.6
7	Matrix Addition Calculation	Two Matrices of the same order	Matrix Addition is performed to create a new Matrix with the added values	Pass	2.7
8	Matrix Subtraction Calculation	Two Matrices of the same order	Matrix Subtraction is performed to create a new Matrix with the subtracted values	Pass	2.8
9	Matrix Multiplication Calculation	Two Matrices where Width of $M1$ is equal to the height of $M2$	Matrix Multiplication is performed to create a new Matrix with the multiplied values	Pass	2.9
10	Matrix Scalar Multiplication Calculation	A $float/int$ as the scalar and any size Matrix	Matrix Scalar Multiplication is performed to create a new Matrix with the multiplied values	Pass	2.10
11	Vector Hadamard Product Calculation	Two Vectors with the same Order	Vector Hadamard Product is performed to create a new Vector with the multiplied values	Pass	2.11
12	Matrix Power Calulation	A Square Matrix with values stored in it	Matrix to the Power of is performed to create a new Matrix with the correct values	Pass	2.12
13	Matrix Transpose Calculation	A Matrix with values stored in it	New Matrix is created with values flipped across the diagonal	Pass	2.13
14	Matrix Select Column	A Matrix with values stored in it	Selects the indexed Column from the Matrix, returning as a list	Pass	2.14
15	Matrix Select Row	A Matrix with values stored in it	Selects the indexed Row from the Matrix, returning as a list	Pass	2.15
16	Vector Max in Vector	A Vector	Returns Largest value in Vector	Pass	2.16
17	Matrix Clear	A Matrix with values stored in it	Clears Matrix of any values	Pass	2.17
18	Combine Vectors	List of Vectors of the same Order	Combines the list of Vectors into a Matrix	Pass	2.18
19	Matrix Sum	-	Sums all values in the Matrix returning a $float/int$	Pass	2.19
20	Randomised Matrix Constructor Tests	Generator Constructor Parameters randomnly for 10000 Tests	All Tests Should produce a valid Matrix	Pass	2.16

21	Randomised Constructor Exception Tests	Generate Random Data to cause Exceptions within the Constructor for 10000 Tests	All Tests should trigger the Targetted Exception for that test	Pass	2.17
22	Randomised Operator Tests	Generator Random Data to test the Operator Methods for 10000 Tests	All Tests should produce the correct result	Pass	2.18
23	Randomised Operator Exception Tests	Generate Random Data to cause Exceptions within the Operators for 10000 Tests	All Tests should trigger the Targetted Exception for that test	Pass	2.19

3.1.4   Deep Reinforcement Learning Algorithm Tests

Test No.	Test Name	Input Data / Description	Expected Output	Pass / Fail	Testing Evidence
1	Networks are Created	Run Program, enter setup info, denying the loading of weights	A Dual Neural Network is created after Program Start	Pass	3.1
2	Networks conforms to Parameters	Run Program, enter setup info, denying the loading of weights	The created Dual Neural Network conforms to the specified structure in the parameter "DeepQLearningLayers"	Pass	3.2
3	Forward Propagation Test	Where L is the Current Layer, Forward Propagation requires: $OutputVector^{L-1}$, $WeightMatrix^{L-1}$, $BiasVector^{L}$	The output of the Layer	-	-
4	Forward Propagation Multi Layer Test	Same as Entry Above	-	-	-
5	Loss Function Bellman Equation	-	-	-	-
6	Back Propagation Test	-	-	-	-
7	Back Propagation Multi Layer Test	-	-	-	-
8	Deque Push Front	A value to push to the Deque	Item is pushed to front of Deque	Pass	3.8
9	Deque First/Last	Call the .First() or .Last() Method for a Deque Object	Returns item at Front/Last index of Deque	Pass	3.9
10	Deque Sample N Ammount of Items	Call the .Sample(int N) Method, with a parameter of N items, for a Deque Object	Returns N number of random samples from Deque	Pass	3.10
11	Experience Replay Sampling	-	Back Propagation is performed on the sampled Deque Items	-	-
12	Activation Outputs Unit Test	Input Value Vector to the Activation Function	Returns a Vector of values, where the Activation has been applied to them	-	-
13	Activation Derivatives Output Unit Test	Input Value Vector to the Activation Derivative Function	Returns a Vector of values, where the Activation Deivative has been applied to them	-	-

3.1.5 Data Logger Tests

Test No.	Test Name	Input Data / Description	Expected Output	Pass / Fail	Testing Evidence
1	Heap Sort Decending	A randomnly generated input list	Sorts the list of items into Descending order	Pass	4.1
2	Add Point	A Data Point matching the data structure of the DataCollector	Point is added to Data Points list	Pass	4.2
3	Match Data Struture with Single	Data Structure contrains an index with a Single-Typed definition	No error thrown	Pass	4.3
4	Match Data Struture with Multi-Typed	Data Structure contrains an index with a Multi-Typed definition	No error thrown	Pass	4.4
5	Match Data Struture with List-Typed	Data Structure contrains an index with a List-Typed definition	No error thrown	Pass	4.5
6	Match Data Structure Error	Try match point with structure which does not match	Error is thrown with correct info	Pass	4.6
7	Select Query	Select from DataLogger with an Index and Search Contents	Returns a list of the selected column where the Search Contents Matches	Pass	4.7
8	Save Data Points	Invoke Save method on DataLogger Object	Saves Data Points to specified File	Pass	4.8
9	Load Data Points	Invoke Load method on DataLogger Object	Loads Data Points from specified File	Pass	4.9

3.1.6 Simulation Tests

Test No.	Test Name	Input Data / Description	Expected Output	Pass / Fail	Testing Evidence
1	Creation of Agent	Run progam as normal	Agent is created as an instance of the Agent Class	Pass	5.1
2	Creation of Enemies	Run program as normal with the "StartEnemyCount" Parameter >= 1	Up to the ammount of specified Enemies are created	Pass	5.2
3	Enemies Pathfind towards Agent	Run program as normal with "StartEnemyCount" Parameter >= 1	The spawned enemies pathfind towards the agent using the defined pathfinding algorithm	-	-
4	Getting Tile Data	Call .GetTileVector(worldMap, enemyList[]) with arguments for worldMap and the list of current Enemies	Returns a Vector of the surrounding tile objects	Pass	5.4
5	Convert Tile Data	Call .TileVectorPostProcess(tileVec) with argument of the result from the Test Above	Converts Tile Data into two vectors, Grayscale Colour and Tile Type	Pass	5.5

6	Reward System Test	-	Expected reward is given to agent	Pass	5.6
7	World Generates to an Acceptable Standard	Run program as normal	Generates 2d Terrain which roughly looks realistic	Pass	5.7
8	World Generation Conforms to Parameters	Utilise inputted parameters to identify the effect they have on the world Generation	Terrain changes depending on inputting Parameters	Pass	5.8
9	Perlin Noise retains Continuity	Generate two worlds with the same seed	Perlin Noise returns same value when using the same seed twice	Pass	5.9

3.2   Testing Evidence

3.2.1   User Input and Program Output Evidence

Evidence 1.1

The .json file which is being loaded


```
{
    "EnterValues": 1,
    "GenerateThreaded": 0,
    "EnableEnemies": 1,
    "SaveWeights": 1,
    "StepDelay": 0,
    "Debug": 0,
    "DebugScale": 1,

    "WorldSize": 64,
    "TileWidth": 8,
    "TileBorder": 0,

    "OctavesTerrain": 7,
    "PersistenceTerrain": 0.6,
    "WorldScale": 3.2,

    "OctavesTrees": 4,
    "PersistenceTrees": 0.95,
    "PoissonKVal": 20,
    "TreeSeedOffset": 1000,
    "TreeHeight": 0.15,
    "InteractableTileBorder": 0,
    "TreeBeachOffset": 0.05,

    "Grayscale": 0,
    "Water": 0.43,
    "Coast": 0.48,
    "Grass": 0.63,
    "Mountain": 1.0,

    "TreeType": "Wood",

    "StartEnemyCount": -13,
    "AgentAttackRange": 1,

    "ColourWater": [18, 89, 144],
    "ColourCoast": [245, 234, 146],
    "ColourGrass": [26, 148, 49],
    "ColourMountain": [136, 140, 141],
    "ColourTree": [13, 92, 28],
    "ColourPlayer": [233, 182, 14],
    "ColourEnemy": [207, 2, 2],

    "MoveReward": 0,
    "CollectItemReward": 0.1,
    "DeathReward": -0.1,
    "ExploreReward": 0.01,
    "AttackReward": 0.5,
    "AttackFailedReward": -0.1,
    "NoopReward": 0,

    "TargetReplaceRate": 5,
    "EREnabled": 1,
    "ERBuffer": 1000,
    "ERSampleRate": 100,
    "ERSampleSize": 10,

    "DeepQLearningLayers" : [49, 64, 32, 16, 7],
    "DQLEpoch": 100,
    "DQLearningMaxSteps": 10000,
    "DQLOffset": 3,
    "DQLEpsilon": 0.5,
    "DQLEpisonRegression": 0.99998,
    "DQLLearningRate": 0.75,
    "DQLGamma": 0.8
}
```

Printing the loaded Json File to console to Console to check the values match

{'EnterValues': 1, 'GenerateThreaded': 0, 'EnableEnemies': 1, 'SaveWeights': 1, 'StepDelay': 0, 'Debug': 0, 'DebugScale': 1, 'WorldSize': 64, 'TileWidth': 8, 'TileBorder': 0, 'OctavesTerrain': 7, 'PersistenceTerrain': 0.6, 'WorldScale': 3.2, 'OctavesTrees': 4, 'PersistenceTrees': 0.95, 'PoissonKVal': 20, 'TreeSeedOffset': 1000, 'TreeHeight': 0.15, 'InteractableTileBorder': 0, 'TreeBeachOffset': 0.05, 'Grayscale': 0, 'Water': 0.43, 'Coast': 0.48, 'Grass': 0.63, 'Mountain': 1.0, 'TreeType': 'Wood', 'StartEnemyCount': 5, 'AgentAttackRange': 1, 'ColourWater': [18, 89, 144], 'ColourCoast': [245, 234, 146], 'ColourGrass': [26, 148, 49], 'ColourMountain': [136, 140, 141], 'ColourTree': [13, 92, 28], 'ColourPlayer': [233, 182, 14], 'ColourEnemy': [207, 2, 2], 'MoveReward': 0, 'CollectItemReward': 0.1, 'DeathReward': -0.1, 'ExploreReward': 0.01, 'AttackReward': 0.5, 'AttackFailedReward': -0.1, 'NoopReward': 0, 'TargetReplaceRate': 5, 'EREnabled': 1, 'ERBuffer': 1000, 'ERSampleRate': 100, 'ERSampleSize': 10, 'DeepQLearningLayers': [49, 64, 32, 16, 7], 'DQLEpoch': 100, 'DQLearningMaxSteps': 10000, 'DQLOffset': 3, 'DQLEpsilon': 0.5, 'DQLEpisonRegression': 0.99998, 'DQLLearningRate': 0.75, 'DQLGamma': 0.8}

<div align="center">Evidence 1.2</div>

<div align="center">Console Output when parameters are within specified ranges</div>

<div align="center">A Screenshot of the .json file where the Ranges are defined</div>

<div align="center">Evidence 1.3</div>

<div align="center">The given out of range parameter - subceeding</div>

<div align="center">The specified range it should be within</div>

<div align="center">The Exception thrown when the program is run</div>

<div align="center">Evidence 1.4</div>

<div align="center">The given out of range parameter - exceeding</div>

<div align="center">The specified range it should be within</div>

```
"TreeBeachOffset": [0,1],
```

The Exception thrown when the program is run


```
Exception: 'TreeBeachOffset' of value 1.2, has exceeded the range: 0-1
```

Evidence 1.5

The Console prompt if the user wants to load Network Weights


```
Load weights (Y/N): Y
State file name: DQNetwork
```

The file the program is loading


```
∨ DQLearningData
  ⬚ DQNetwork.dqn  M
```

The testing step resumes at 400, underlined in Red


```
Load weights (Y/N): Y
State file name: DQNetwork
Created New World, Seed: 765802
Created New World, Seed: 274263
Created New World, Seed: 142187
Created New World, Seed: 613313
Created New World, Seed: 961492
Created New World, Seed: 493768
Created New World, Seed: 551641
Created New World, Seed: 133180
400 2.0499999999999966 0.49601591773672193
Created New World, Seed: 310069
```

Evidence 1.6

The width/height of the window


```
"WorldSize": 64,
```

The opened window, it is 64 wide and 64 tall
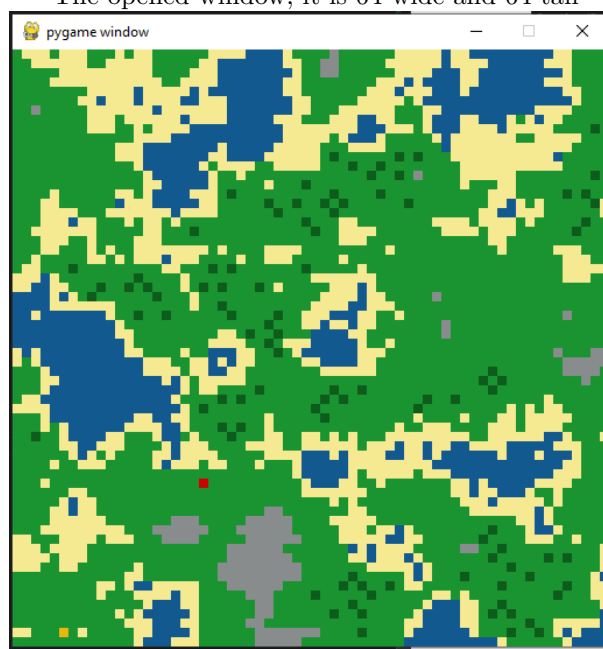
Evidence 1.7

Debug being set to 1 in the parameters file

The displayed debug information to the right of the Window
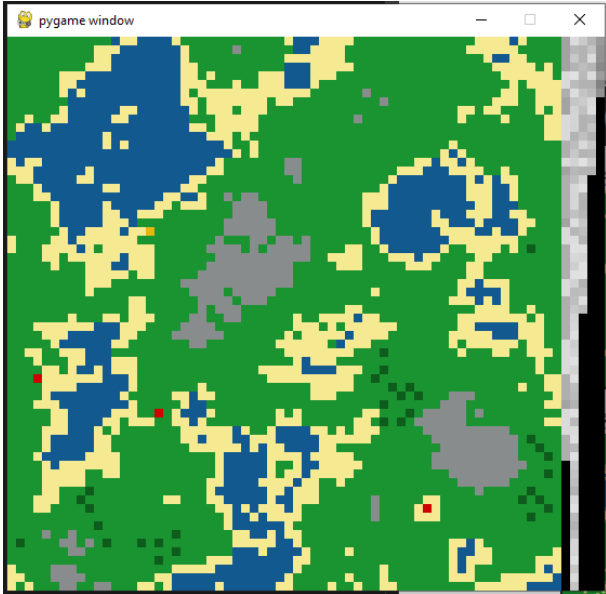
Evidence 1.8

The opened window, with the agent circled
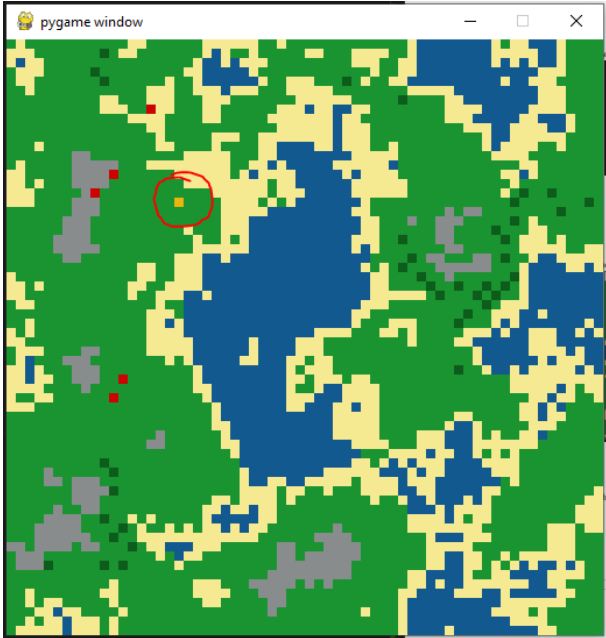
Evidence 1.9

The opened window, with the enemies circled
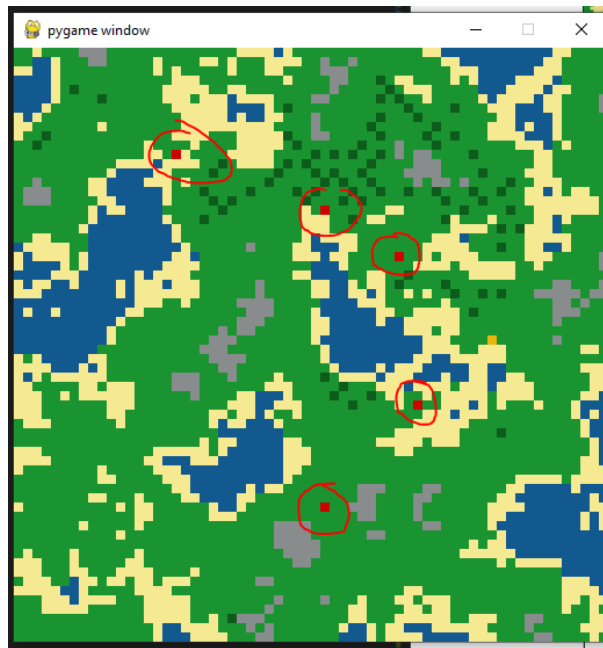
Evidence 1.10

The correctly displayed console outputs

3.2.2   Matrix Implementation Tests

Evidence 2.1

Creating a Matrix with a Tuple

```
1   matrix = Matrix((3, 4))
2   print(matrix)
```

The output of the above code:

```
['0', '0', '0', '0']
['0', '0', '0', '0']
['0', '0', '0', '0']
```

Evidence 2.2

Creating a Matrix with a 2d List

```
1   values = [[3, 4],
2           [1, 2]]
3   matrix = Matrix(values)
4   print(matrix)
```

The output of the above code:

```
['3', '4']
['1', '2']
```

Evidence 2.3

Creating a Matrix with a 1d List

```
1   values = [1, 2, 3, 4]
2   matrix = Matrix(values)
3   print(matrix)
```

The output of the above code:

```
['1']
['2']
['3']
['4']
```

Evidence 2.4

Printing a Matrix to the console

```
1   values = [[4, 3],
2           [2, 1]]
3   matrix = Matrix(values)
4   print(matrix)
```

The output of the above code:

```
['4', '3']
['2', '1']
```

Evidence 2.5

Creating a Randomised Matrix

```
1   matrix = Matrix((2, 2), random=True)
2   print(matrix)
```

The output of the above code:

```
['-0.20778786420611217', '-0.13982601523332772']
['0.19471852312767213', '-0.21125677633285878']
```

Evidence 2.6

Creating an Identity Matrix

```
1   matrix = Matrix((3, 3), identity=True)
2   print(matrix)
```

The output of the above code:

```
['1', '0', '0']
['0', '1', '0']
['0', '0', '1']
```

Evidence 2.7

Matrix Addition Calculation

```
1   values = [[4, 3],
2            [2, 1]]
3   matrix = Matrix(values)
4   values2 = [[3, 4],
5        [1, 2]]
6   matrix2 = Matrix(values2)
7
8   result = matrix + matrix2
9   print(result)
```

The output of the above code:

```
['7', '7']
['3', '3']
```

Evidence 2.8

Matrix Subtraction Calculation

```
1   values = [[4, 3],
2            [2, 1]]
3   matrix = Matrix(values)
4   values2 = [[3, 4],
5        [1, 2]]
6   matrix2 = Matrix(values2)
7
8   result = matrix - matrix2
9   print(result)
```

The output of the above code:

['1', '-1']
['1', '-1']

Evidence 2.9

Matrix Multiplication Calculation

```
1  values = [[4, 3],
2          [2, 1]]
3  matrix = Matrix(values)
4  values2 = [[3, 4],
5          [1, 2]]
6  matrix2 = Matrix(values2)
7
8  result = matrix * matrix2
9  print(result)
```

The output of the above code:

['15', '22']
['7', '10']

Evidence 2.10

Matrix Scalar Multiplication Calculation

```
1  values = [[4, 3],
2          [2, 1]]
3  matrix = Matrix(values)
4
5  result = matrix * 3
6  print(result)
```

The output of the above code:
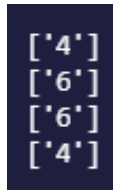
['12', '9']
['6', '3']

Evidence 2.11

Vector Hadamard Product Calculation

```
1  values = [1, 2, 3, 4]
2  vector = Matrix(values)
3
4  values = [4, 3, 2, 1]
5  vector2 = Matrix(values)
6
7  result = vector * vector2
8  print(result)
```

The output of the above code:
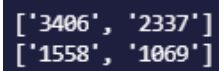
```
['4']
['6']
['6']
['4']
```

Evidence 2.12

Matrix Power Calculation

```
1   values = [[4, 3],
2            [2, 1]]
3   matrix = Matrix(values)
4
5   result = matrix ** 5
6   print(result)
```

The output of the above code:
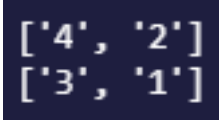
```
['3406', '2337']
['1558', '1069']
```

Evidence 2.13

Matrix Transpose Calculation

```
1   values = [[4, 3],
2            [2, 1]]
3   matrix = Matrix(values)
4
5   result = matrix.Transpose()
6   print(result)
```

The output of the above code:
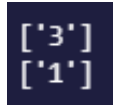
```
['4', '2']
['3', '1']
```

Evidence 2.14

Matrix Select Column

```
1   values = [[4, 3, 6],
2            [2, 1, 5]]
3   matrix = Matrix(values)
4
5   result = matrix.SelectColumn(1)
6   print(result)
```

The output of the above code:

```
['3']
['1']
```

Evidence 2.15

Matrix Select Row

```
1   values = [[4, 3, 6],
2            [2, 1, 5]]
3   matrix = Matrix(values)
4
5   result = matrix.SelectRow(0)
6   print(result)
```

The output of the above code:

[4, 3, 6]

Evidence 2.16

Vector Max

```
1   values = [4, 3, 6, 1, 2, 5]
2   vector = Matrix(values)
3
4   result = vector.MaxInVector()
5   print(result)
```

The output of the above code:
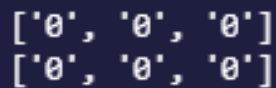
(6, 2)

Evidence 2.17

Matrix Clear

```
1   values = [[4, 3, 6],
2            [2, 1, 5]]
3   matrix = Matrix(values)
4
5   matrix.Clear()
6   print(matrix)
```

The output of the above code:

['0', '0', '0']
['0', '0', '0']

Evidence 2.18

Matrix Combine Vectors

```
1    values = [1, 2, 3, 4]
2    vector = Matrix(values)
3
4    values = [4, 3, 2, 1]
5    vector2 = Matrix(values)
6
7    vectorList = [vector, vector2]
8
9    result = Matrix.CombineVectorsHor(vectorList)
10   print(result)
```

The output of the above code:

```
['1', '4']
['2', '3']
['3', '2']
['4', '1']
```

Evidence 2.19

Matrix Sum

```python
values = [[4, 3, 6],
          [2, 1, 5]]
matrix = Matrix(values)

result = matrix.Sum()
print(result)
```

The output of the above code:

```
21
```

Evidence 2.20

Console Output, all Tests have passed with no failures

```
10000/10000 | CreateVectorFrom1DList
10000/10000 | CreateMatrixFrom2DList
10000/10000 | CreateMatrixFromTuple
10000/10000 | CreateIdentityMatrix
```

Evidence 2.21

Console Output, all Tests have passed with no failures

```
10000/10000 | NoMatchingInitCase
10000/10000 | UnableToCreateIdentityMat
```

Evidence 2.22

Console Output, all Tests have passed with no failures

```
10000/10000 | AdditionMatrix
10000/10000 | AdditionInteger
10000/10000 | SubtractionMatrix
10000/10000 | SubtractionInteger
10000/10000 | MultiplicationInteger
10000/10000 | MultiplicationHadamardVector
10000/10000 | MultiplicationMatrix
10000/10000 | Power
10000/10000 | Transpose
10000/10000 | SelectColumn
10000/10000 | SelectRow
10000/10000 | CombineVectorHorizontal
10000/10000 | Sum
10000/10000 | MaxInVector
10000/10000 | Clear
```

Evidence 2.23

Console Output, all Tests have passed with no failures

```
10000/10000 | NotOfTypeVector
10000/10000 | VectorsNotOfSameLength
10000/10000 | NoMatchingMultiplycase
10000/10000 | NoMatchingAdditionCase
10000/10000 | NoMatchingSubtractionCase
10000/10000 | NoMatchingPowerCase
10000/10000 | MismatchOrdersAdd
10000/10000 | MismatchOrdersSub
10000/10000 | MismatchOrdersMul
10000/10000 | SumOfMatrixReqNumericalVals
10000/10000 | ColumnOutOfRange
10000/10000 | ColumnMustBeInteger
10000/10000 | RowOutOfRange
10000/10000 | RowMustBeInteger
```

3.2.3   Deep Reinforcement Learning Algorithm Evidence

Evidence 3.1

The Neural Network objects in Memory

```
Load weights (Y/N): n
MainNetwork:  <deepqlearning.NeuralNet object at 0x000001FCE8C63D00>
TargetNetwork:  <deepqlearning.NeuralNet object at 0x000001FCE8D17A00>
```

Evidence 3.2

The layer sizes upon creating the Networks

```
Load weights (Y/N): n
Layer Size:  5
Layer Size:  5
```

The list of layer sizes in the parameters file

```
"DeepQLearningLayers" : [49, 64, 32, 16, 7],
```

Evidence 3.3

Evidence 3.4

Evidence 3.5

Evidence 3.6

Evidence 3.7

Evidence 3.8

Pushing items to the front of the Double Ended Queue

```
1   deque = Deque(10)
2   deque.PushFront(3)
3   print("Added 3:", deque.queue)
4   deque.PushFront(-5)
5   print("Added -1:", deque.queue)
6   deque.PushFront(9)
7   print("Added 9:", deque.queue)
```

The output of the above code:

```
Added 3: [3, None, None, None, None, None, None, None, None, None]
Added -1: [3, -5, None, None, None, None, None, None, None, None]
Added 9: [3, -5, 9, None, None, None, None, None, None, None]
```

Evidence 3.9

Creating a Double Ended Queue with a length of 4, add Push Items to it, and get the Items in First and Last

```
1    deque = Deque(4)
2    deque.PushFront(3)
3    deque.PushFront(-5)
4    deque.PushFront(9)
5    deque.PushFront(4)
6    deque.PushFront(-4)
7
8    print("First:", deque.First())
9    print("Last:", deque.Last())
10   print("Queue:", deque.queue)
```

The output of the above code:

```
First: -4
Last: -5
Queue: [-4, -5, 9, 4]
```

Evidence 3.10

Create a Double Ended Queue and Sample items from the Queue

```
1    deque = Deque(4)
2    deque.PushFront(3)
3    deque.PushFront(-5)
4    deque.PushFront(9)
5    deque.PushFront(4)
6    deque.PushFront(-4)
7
8    print("Sample 1:", deque.Sample(2))
9    print("Sample 2:", deque.Sample(2))
10   print(deque.queue)
```

The output of the above code:

```
Sample 1: [-5, 4]
Sample 2: [-5, 9]
[-4, -5, 9, 4]
```

3.2.4   Data Logger Evidence

<div align="center">Evidence 4.1</div>

<div align="center">Randomnly Generated Unsorted List, sorted by the 1st Element to form the Sorted List</div>

```python
inputList = [[random.randint(-10,10), random.randint(-10,10)] for i in range(5)]
print("Unsorted List:")
for item in inputList:
print(item)

dl = DataCollector("SortingTest", [int, int], False)

dl.LogDataPointBatch(inputList)

sortedList = dl.HeapSort(0)

print("Sorted List:")
for item in sortedList:
print(item)
```

<div align="center">The output of the above code:</div>

```
Unsorted List:
[0, 6]
[-6, -4]
[-3, -2]
[-2, 1]
[7, -1]
Sorted List:
[7, -1]
[0, 6]
[-2, 1]
[-3, -2]
[-6, -4]
```

<div align="center">Evidence 4.2</div>

<div align="center">Adding a single point: [5, 2] to DataLogger</div>

```python
dl = DataCollector("AddPointTest", [int, int], False)
print("Before: ", dl.dataPoints)

dl.LogDataPoint([5, 2])

print("After: ", dl.dataPoints)
```

<div align="center">The output of the above code:</div>

```
Before:  []
After:  [[5, 2]]
```

<div align="center">Evidence 4.3</div>

<div align="center">Test Data Point matches struture</div>

```python
dl = DataCollector("Match Single Types", [int, float], False)

print("Matches Structure: ", dl.CheckMatchStructure([-3, 2.2]))
```

<div align="center">The output of the above code:</div>

```
Matches Structure:   True
```

Evidence 4.4

Test Data Point matches structure

```
1   dl = DataCollector("Match Multi Typed", [bool, [float, int]], False)
2
3   print("Matches Structure: ", dl.CheckMatchStructure([False, 4.5]))
4   print("Matches Structure: ", dl.CheckMatchStructure([True, -9]))
```

The output of the above code:

```
Matches Structure:   True
Matches Structure:   True
```

Evidence 4.5

Test Data Point matches structure

```
1   dl = DataCollector("Match List Type", [bool, str], False)
2
3   print("Matches Structure: ", dl.CheckMatchStructure([True, ["Matt", "Isabel", "Tristan", "Chris"]]))
```

The output of the above code:

```
Matches Structure:   True
```

Evidence 4.6

Test error thrown when Data Point doesnt match the given structure

```
1   try:
2   dl = DataCollector("Match Data Structure Error", [str, int], False)
3
4   print("Matches Structure: ", dl.CheckMatchStructure(["Steve Preston", True]))
5   except Exception as x:
6   print(x)
```

The output of the above code:

```
Type: <class 'bool'> != Data Structure Type: <class 'int'>
 [<class 'str'>, <class 'int'>]
```

Evidence 4.7

Select Prime numbers in 1st index

```
1    inputList = [[random.randint(-10,10), random.randint(-10,10)] for i in range(5)]
2    print("Random List:")
3    for item in inputList:
4    print(item)
5
6    dl = DataCollector("Select List", [int, int], False)
7
8    dl.LogDataPointBatch(inputList)
9
10   sortedList = dl.Select(0, [1,2,3,5,7])
11
```

```
12    print("Selected List:")
13    for item in sortedList:
14    print(item)
```

The output of the above code:

```
Random List:
[9, -5]
[8, 3]
[1, -8]
[-1, 4]
[4, -10]
Selected List:
[1, -8]
```

Evidence 4.8

Test for saving a file

```
1    inputList = [[random.randint(-10,10), random.randint(-10,10)] for i in range(5)]
2    print("Saved List:")
3    for item in inputList:
4    print(item)
5
6    dl = DataCollector("Save-Load Test", [int, int], False)
7
8    dl.LogDataPointBatch(inputList)
9
10    dl.SaveDataPoints()
```
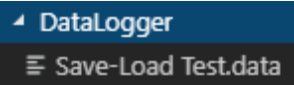
The saved Data Points

```
Saved List:
[8, 10]
[-7, -1]
[-1, -7]
[4, 1]
[5, -6]
```

The saved file "Save-Load Test.data"

```
⊿ DataLogger
≡ Save-Load Test.data
```

Evidence 4.9
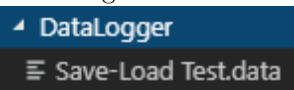
Test for loading a file

```
1    dl = DataCollector("Save-Load Test", [int, int], True)
2
3    print("Loaded List:")
4    for item in dl.dataPoints:
5    print(item)
```

The File we're loading from "Save-Load Test.data"

```
⊿ DataLogger
≡ Save-Load Test.data
```

The loaded Data Points

3.2.5   Simulation Evidence

Evidence 5.1

The Agent Object stored in Memory

Evidence 5.2

The Enemy Objects stored in Memory

Evidence 5.3

Video Evidence

Evidence 5.4

Tile Data Objects are returned in a Vector

Evidence 5.5

Grayscale Values in a Vector

Evidence 5.6

Reward on Left, and the chosen action on Right

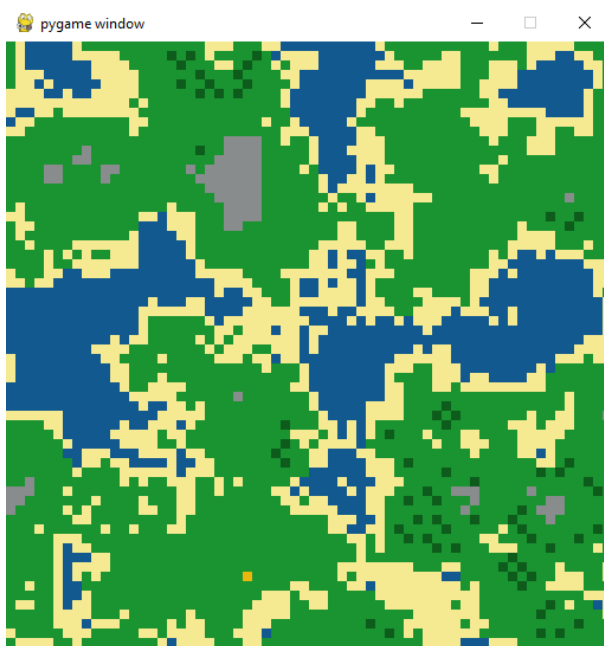Evidence 5.7

World Generated, is of an Acceptable Standard
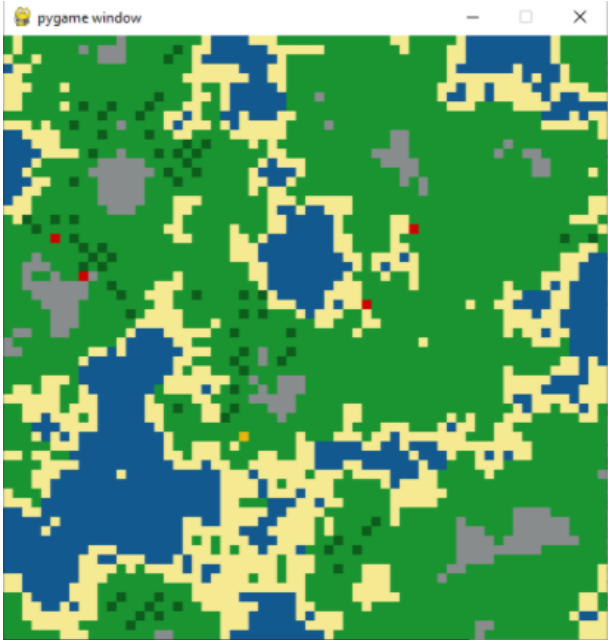
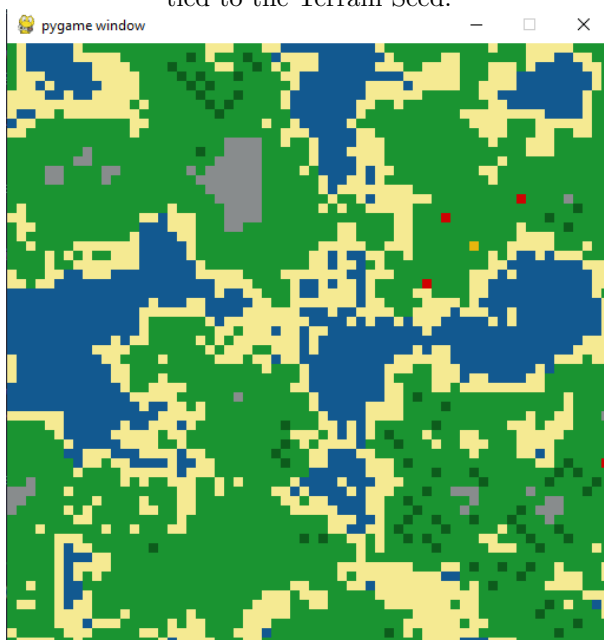
Evidence 5.8

Changed Water Value creates no Water and more Beach
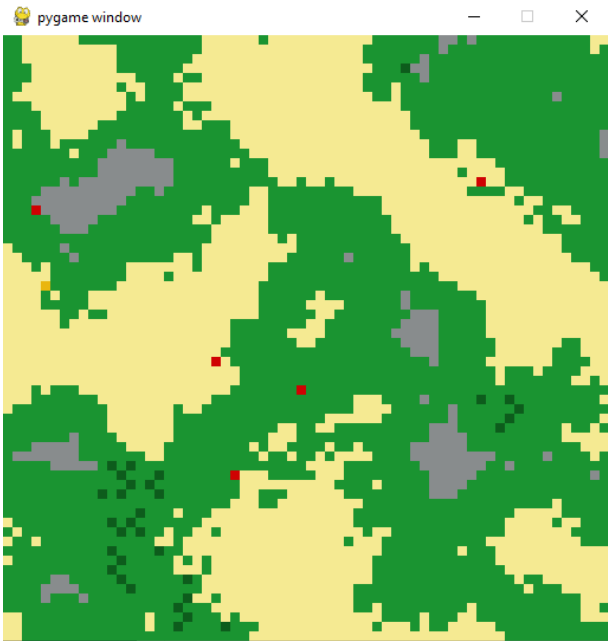
Evidence 5.9

Generated with seed 420

Generated again with the seed 420. Note different Trees, Enemy and Agent Positions, due to them not being tied to the Terrain Seed.

4 Evaluation

4.1 Evaluation of Objectives

In this section, I will evaluate my overarching objectives I set out to complete.

4.1.1 Reading user inputted data

The user can input the parameters through a json file, and these parameters are checked against a range file to check they are within the specified size. All of the parameters are read correctly and utilised within the Program.

The Machine Learning Data is read from .dqn files. The Learning is resumed from where it was saved from with all the Weights and Biases intact.

4.1.2 Generating the Environment

At the start of the program an instance of World Class is created and the Generate methods are invoked. These methods utilise Perlin Noise and Poisson Disc Sampling. The Terrain values are stored in a 2d list of Tile Objects which store the Height, Type and Colour data for each Tile. The Poisson Disc Sampling Generates a list of points which Trees are then generated at those positions. The Width of the world and Tile colours are determined by the Input Parameters.

4.1.3 Displaying the world to a Pygame Window

Upon generating the Map Data the Terrain is displayed in a grid to the Pygame Window, it is represented as a grid of tiles of the pixel width loaded in by the Inputted Parameters. The Agent and Enemies are Drawn at their according positions, taking up entire Tile. If Debug mode is enabled, a representation of the Neural Network will be displayed on the right hand side of the window.

4.1.4 Simple Agent with a set of Actions

An Agent can be created as an object and works along side the Dual Neural Network Object to enable interactions between the environment and the Network. The Agent can collect the surroundng Tile Data using the **GetTileVector** Method, this can then be converted into the Networks Input Vector using the **TileVectorPostProcess** Method. There exists Methods to Take a given Action, normally outputted by the Network. Along with Methods to Calculate Reward for an Action given a State, or the Maximum Possible Reward Given a State.

There also exists Methods to Reset the Agent to its default values. Along with Determining the Agents Spawn Position when given a WorldMap Object.

4.1.5 Matrix Class with Standard Operations

A Matrix can be created using 3 different methods. First using a Tuple of Integers, a new Matrix will be created of that size, with initialised 0 values. Second using a prexisting 2d list

of values, a new Matrix will be created with these dimensions and values. Thirdly a 1d list of values can be used to create a 1 wide Vector of values, where it reads each value into the 1st position of each row.

All standard operations for the Matrix Object are implemented using Operator Overloading to make code less bloated. All are written efficiently utilising minimum complexity algorithms. Addition can be carried out utilising the $+$ Operator. Subtraction can be carried out utilising the $-$ Operator. Multiplication and Scalar Multiplication are both carried out utilising the $*$ Operator. Power Operation is carried out utilising the $\hat{}$ operator. A Matrix can be converted to a Formatted String implicitly by using it in a string context.

All Matrice Operations have appropriate Exceptions with descriptive Error Messages. They will throw errors when incorrect Data is provided to the specified Operation.

4.1.6   Creation of a Reinforcement Learning Model

A Dual Neural Network can be created as an object, which stores two Neural Network Objects, Main and Target. The Dual Neural Network contains the Primary Method **Step** which invokes a Series of Lower Level Methods to perform a singular Time Step. The Neural Network Object store a List of Layers Objects which are dynamically created from the Input Parameters. Each Layer contains a Weight Matrix, Bias Vector, and Output Vector. The Lowest Level methods for Forward and Back Propagation are contained within the Layer Object.

First Forward Propagation occurs on the Main and Target Network. Then results of the Main Network are taken to choose the action for the Agent. Epsilon Greedy is implemented to determine whether to choose the random or predicted result. This Action is then fed to the Agent, along with calculating the reward for that Action. The Loss of the Main Network is then calculated using a modified Bellman Equation for Dual Neural Networks. This Loss is used for Back Propagating the Main Neural Network. The Main Networks Weights are copied to the Target Network every specified ammount of steps. Every specified ammount of steps, Experience Replay is performed to learn from past experiences again.

The combination of these steps form a functional Dual Neural Network utilising a Reinforcement Learning Model.

4.1.7   Creation of a Data Logger

A Data Logger Class can be used to Log and Store Data Points at various parts of the Program. Each Data Point is stored as a Tuple of Values as part of a .data file. These files are stored as Binary Files, and are Read into the Program upon launch.

As part of the Data Logger you can sort points utilising a Heap Sort to sort through Data.

4.2   Answering the Proposed Question

As part of my Machine Learning Investigation I proposed the Question:

Can I develop a Machine Learning Algorithm to survive in a pseudorandom, open-world environment?

I aimed to answer this question by designing and creating a Deep Reinforcement Learning Model utilising a Deep Neural Network, along with designing a Simple Simulation for a Machine Learning Agent to survive in.

With the Machine Learning Model I implemented, the Agent was unable to fully solve the simulation. After being trained to —- steps, the accuracy of the Network Improves in comparison to randomly taking actions, but fails to reach higher levels. I attempted to train the Network with varying parameters and Network Structures, but this yielded similar results. This follows suit with one of the Existing Investigations I researched. Crafter only manages to achieve 10% accuracy with the best algorithm, the rest achieving below 5%. In comparison to Human Experts which achieved near 60% accuracy, this is statistically little.

Below is shown the collected Data plotted to Graphs:

4.3   Expert Feedback

I went back to my Expert Shaun in order to collect feedback on my finalised Technical Solution. I asked him a few Questions about my project, paraphrased where neccesary.

1. What do you think of the Program?

   "Overall I think your project is incredibly visually interesting to look at, I could stare at the graphical output for hours just rooting for the Agent to better itself and kill the Generated Enemies. The User Inputted Parameters are easy to change through the json file, and it is helpful that they are locked between certain ranges to stop the User from crashing their Pc from allocating too much memory. The Terrain generation looks pretty good for just a 4 coloured map generated from Perlin Noise. The Neural Network works as intended, although it's a shame that the Machine Learning Model isn't advanced enough to 'Solve' the Simulation you've designed."

2. Does my Tehnical Solution achieve all of the Set Goals and Objectives?

   "The Program achieves all of the objectives you set out to complete, and it is clear alot of hard work went into completing your project. Lots of research needs to be carried out in order to understand the complexity behind Reinforcement Learning and all of its individual parts. Debugging this process also becomes increasingly difficult, due to the complex calculations, this demonstrates you have the ability to solve problems independently.

   You've also implemented an entire simulation ontop of the Dual Neural Network. Which uses more complex algorithms, this demonstrates you can develop multiple Vertical Slices of a project, and intertwine them together in order to create one bigger project. This takes planning skill and a good understanding of OOP in order to pull off."

3. What Criticisms/Improvements would you suggest?

   "Considering the scope of the project, youve carried out your completion of this task very well. The only suggestion I would have is to implement a Convolution, which might solve your Training Accuracy Problems. Otherwise a Description of your Project could be printed to console when the main file is run, or a 'ReadMe' text file included in the project files would useful to any users who have little to no experience with Reinforcement Learning."

4.4   Evaluation of Expert Feedback

I'm glad that my Expert likes my project. After putting so much work into it that is a relief. I think that his suggestions are valid, and in the future I might develop my project further to add a Convolution. This will hopefully boost the accuracy of my Network so I can achieve better training results. The ReadMe text file would also be a good addition, if I was to ever show my project publically.

Shaun has been a great use to me, such as helping me "Sanity Check" myself when my Back Propagation didn't work right off the bat. This help was incredibly valuable in completing my Technically Solution.

4.5   System Improvements

Overall I am happy with my Technical Solution. I achieved all the objectives I set out to complete in my Analyis. I have definitely achieved my primary goal of gaining a deeper understanding about the Maths and Logic behind how Neural Networks work. This has given me a Window into the field of Machine Learning and Artificial Intelligence, which I intend to pursue as part of my later Studies.

The Improvements I would like to make to my Technical Solution are:

1. The Implementation of a Convolutional Neural Network was something I came across in my Initial Research and was mentioned by my Expert. Convolution carries out Pre-Processing on the inputted data before it is even touched by the Neural Network. This in theory would increase the training accuracy of my Network leading to better Results.

2. The Optimisation of my Matrix Class by compiling it into C through the use of Cython would help speed up the training of the Neural Network. Due to Python being an interpretted language it is comparatively slow compared to the other programming languages I considered using. C is a compiled language so it is comparatively alot faster, about 45 times faster according to some sources online. This could provide an easy way to optimise my Program without having to convert my entire Codebase into a different Language.

3. An increase in complexity of my simulation would provide a greater challenge towards my Agent and Neural Network. I could add a basic crafting system to convert the collected Wood into a sword, or a Hunger Bar so the Agent has to collect food and water in order to survive. I feel as though the Network wouldnt be able to solve these problems effectively though without the implementation of my first improvement, a Convolutional Neural Network.

5 Technical Solution

5.1 main.py

```python
import pygame
from simulation import *
import time

params = Simulation.LoadParameters("Default") # Loads parameters
Simulation.CheckParameters(params, "Range") # Checks parameters

gameSim = Simulation(params) # Create and initiate simulation
gameSim.InitiateSimulation()

# Creates pygame window - includes side debug offset if needed
worldResolution = params["WorldSize"] * params["TileWidth"]
if params["Debug"]:
    debugOffset = (len(params["DeepQLearningLayers"]) * params["TileWidth"] * params["DebugScale"])
else:
    debugOffset = 0
window = pygame.display.set_mode((worldResolution + debugOffset, worldResolution))

stepDelay = params["StepDelay"] # Time step Delay

# Constant loop running
running = True
while running:
    for event in pygame.event.get():
        if event.type == pygame.QUIT: # If window exit than close end program
            running = False

        if event.type == pygame.KEYDOWN: # Key Down
            if event.key == pygame.K_F1: # Force Create new world
                gameSim.CreateWorld()
            if event.key == pygame.K_F2: # Force Kill agent
                gameSim.agent.alive = False

    if gameSim.step > params["DQLearningMaxSteps"]:
        running = False

    gameSim.TimeStep() # Perform a timestep
    time.sleep(stepDelay) # Sleep if needed

    gameSim.RenderToCanvas(window) # Draw to canvas

    pygame.display.update() # Update pygame window to display content
```

5.2 simulation.py

```python
from worldClass import *
from newAgent import *
from enemy import *
from deepqlearning import *
```

```python
5    import random, pygame, math
6
7    # Interface class between Main and Every other class
8    class Simulation():
9        def __init__(self, params): # Constructor for Simulation
10           self.paramDictionary = params
11
12           self.worldMap = None
13           self.network = None
14           self.agent = None
15
16           self.enemyList = []
17
18           self.step = 0
19
20   # Step forward network methods
21       def TimeStep(self): # Steps forward 1 cycle
22           if not self.agent.alive: # Resets Sim if Agent is dead
23               self.ResetOnDeath()
24
25           self.network.TakeStep(self.agent, self.worldMap, self.enemyList) # Take step with Deep Q Network
26
27           if self.paramDictionary["EnableEnemies"]: # If enemies enabled then update enemies
28               self.UpdateEnemies()
29
30           self.step += 1
31
32       def UpdateEnemies(self): # Updates Enemies
33           self.enemyList = [x for x in self.enemyList if x is not None] # Clears None type from list
34
35           for i in range(len(self.enemyList)): # Commits each Enemies actions and sets to None if they died in that
36               self.enemyList[i].CommitAction(self.agent, self.worldMap)
37
38               if not self.enemyList[i].alive: # Removes dead enemies from list
39                   self.enemyList[i] = None
40
41           self.enemyList = [x for x in self.enemyList if x is not None] # Clears None type from list
42
43   # Creation and Initialisation Methods
44       def InitiateSimulation(self): # Initialises Simulation
45           self.CreateWorld()
46           self.CreateAgent()
47
48           self.CreateDeepQNetwork()
49
50       def CreateWorld(self, seed = 0): # Creates new world with specified or random seed
51           if seed == 0: seed = random.randint(0, 999999)
52
53           if self.worldMap == None: # Creates a new world map if one does not exist - otherwise resets the seed
54               self.worldMap = WorldMap(seed, self.paramDictionary)
55           else:
56               self.worldMap.MAP_SEED = seed
57
58           if self.paramDictionary["GenerateThreaded"]: # Generates Terrain using 4 threads if specified
59               self.worldMap.GenerateThreadedParent()
```

```python
60             else:
61                 self.worldMap.GenerateMap()
62
63             self.worldMap.GenerateTreeArea() # Generates Tree Area
64
65             self.worldMap.RenderMap() # Renders Map and Renders Interactables
66             self.worldMap.RenderInteractables()
67
68             if self.paramDictionary["EnableEnemies"]: # Spawns Enemies if specified
69                 self.SpawnEnemies()
70
71             print("Created New World, Seed: {}".format(seed))
72
73     def CreateDeepQNetwork(self, layers = None): # Creates a Deep Q Network with the given Hyper Parameters
74             if layers == None:
75                 layers = self.paramDictionary["DeepQLearningLayers"]
76
77             if self.network == None: # Creates a Network if one doesnt already exist
78                 if self.paramDictionary["EnterValues"]:
79                     load = input("Load weights (Y/N): ")
80                     if load.upper() == "Y":
81                         fName = input("State file name: ")
82
83                         self.network = DoubleNeuralNet(layers, self.paramDictionary, load=True, loadName=fName)
84                     else:
85                         self.network = DoubleNeuralNet(layers, self.paramDictionary)
86                 else:
87                     self.network = DoubleNeuralNet(layers, self.paramDictionary)
88
89     def CreateAgent(self): # Creates an agent / Resets existing agent
90             if self.agent == None:
91                 self.agent = Agent(Agent.SpawnPosition(self.worldMap), self.paramDictionary)
92             else:
93                 self.agent.Reset(self.worldMap)
94
95     def SpawnEnemies(self, n = 0): # Spawns <= n enemies on call
96             if n == 0: n = self.paramDictionary["StartEnemyCount"]
97
98             for count in range(n): # Spawns enemies for count
99                 spawnLoc = Enemy.SpawnPosition(self.worldMap, self.enemyList)
100                if spawnLoc == None:
101                    continue
102                else:
103                    tempEnemy = Enemy(spawnLoc, self.paramDictionary)
104                    self.enemyList.append(tempEnemy)
105
106    def ResetOnDeath(self): # Resets Simulation if Agent Dies
107            self.CreateWorld()
108            self.CreateAgent()
109            self.enemyList = []
110
111            if self.paramDictionary["EnableEnemies"]: # Spawns Enemies if specified
112                self.SpawnEnemies()
113
114 # Render Methods
```

```python
115         def RenderToCanvas(self, window): # Render Content to Canvas
116             TW = self.paramDictionary["TileWidth"]
117             DS = self.paramDictionary["DebugScale"]
118
119             if self.paramDictionary["Debug"]: # Renders debug info for Neural Network if specified
120                 for i in range(len(self.network.MainNetwork.layers)):
121                     for k in range(self.network.MainNetwork.layers[i].outputVector.order[0]):
122                         value = self.network.MainNetwork.layers[i].outputVector.matrixVals[k][0]
123                         newVal = (math.tanh(value) + 1) / 2
124                         colourTuple = (255 * newVal, 255 * newVal, 255 * newVal)
125
126                         try: # Exceps if colour value out of range
127                             pygame.draw.rect(window, colourTuple, ((self.paramDictionary["WorldSize"] * TW + i * TW *
128                         except:
129                             print(newVal)
130
131             self.worldMap.DrawMap(window) # Draws Content to window
132
133             for i in range(len(self.enemyList)): # Draws enemies to window
134                 pygame.draw.rect(window, self.paramDictionary["ColourEnemy"], ((self.enemyList[i].location[0] * TW),
135
136             # Draws Player to window
137             pygame.draw.rect(window, self.paramDictionary["ColourPlayer"], ((self.agent.location[0] * TW), (self.agen
138
139     # Miscellaneous Methods
140         @staticmethod
141         def LoadParameters(fname): # Load Parameters from file and store them in a dictionary
142             file = open("Parameters\\{}.param".format(fname), "r")
143             params = json.loads(file.read())
144             file.close()
145             return params
146
147         @staticmethod
148         def CheckParameters(params, fname): # Checks every parameter against the range.parm file
149             file = open("Parameters\\{}.param".format(fname), "r") # Read range file
150             paramRanges = json.loads(file.read()) # Load with json module
151             file.close()
152
153             for param in params: # Checks if parameter is specified in range file - If specified than check against g
154                 if param in paramRanges:
155                     valRange = paramRanges[param]
156                     val = params[param]
157
158                     if valRange[1] == None: pass
159                     elif val > valRange[1]:
160                         raise Exception("'{}' of value {}, has exceeded the range: {}-{}".format(param, val, valRange
161
162                     if valRange[1] == None: pass
163                     elif val < valRange[0]:
164                         raise Exception("'{}' of value {}, has subceeded the range: {}-{}".format(param, val, valRang
165
166             print("Parameters within Specified Ranges")
```

5.3   newAgent.py

```python
from worldClass import *
from random import shuffle
from matrix import Matrix

class Agent():
    def __init__(self, location, params):
        self.paramDictionary = params

        self.location = location

        self.alive = True

        self.emptyInventory = {"Wood": 0}
        self.inventory = self.emptyInventory

# Methods for tile vectors
    def GetTileVector(self, worldMap, enemyList): # Returns a Vector of Tile Datatype
        offset = self.paramDictionary["DQLOffset"]
        sideLength = 2 * offset + 1
        tileVec = Matrix((sideLength * sideLength, 1))

        blankOceanTile = Tile()
        blankOceanTile.InitValues(0, 0, self.paramDictionary["ColourWater"]) # Blank ocean tile for edge case

        enemyLocList = [enemyList[i].location for i in range(len(enemyList)) if enemyList[i] is not None]

        n = 0
        for y in range(self.location[1] - offset, self.location[1] + offset + 1): # Loop through Tiles in surroun
            for x in range(self.location[0] - offset, self.location[0] + offset + 1):
                if 0 <= x and x <= self.paramDictionary["WorldSize"] - 1 and 0 <= y and y <= self.paramDictionary
                    tileVec.matrixVals[n][0] = worldMap.tileArray[x][y]
                    if [x,y] in enemyLocList:
                        tileVec.matrixVals[n][0].WriteEnemy() # Writes enemies to tile if they exist
                else:
                    tileVec.matrixVals[n][0] = blankOceanTile # Write water tile when out of range of the world -
                n += 1
        return tileVec

    def TileVectorPostProcess(self, tileVec): # Returns 2 Vectors, 1 of tile types, 1 of grayscale values
        tileTypeVec = Matrix(tileVec.order)
        tileGrayscaleVec = Matrix(tileVec.order)

        for n in range(tileVec.order[0]): # Converts vector to grayscale and type vectors
            tileTypeVec.matrixVals[n][0] = tileVec.matrixVals[n][0].tileType

            if tileVec.matrixVals[n][0].hasEnemy: # Enemy will overwrite tile colour if they are within that tile
                tileGrayscaleVec.matrixVals[n][0] = self.ColourToGrayscale(self.paramDictionary["ColourEnemy"])
            else:
                tileGrayscaleVec.matrixVals[n][0] = self.ColourToGrayscale(tileVec.matrixVals[n][0].tileColour)

        return tileTypeVec, tileGrayscaleVec

    def ColourToGrayscale(self, colourTuple): # Converts colour value (255,255,255) to grayscale (0-1)
```

```python
54            grayscale = (0.299 * colourTuple[0] + 0.587 * colourTuple[1] + 0.114 * colourTuple[2]) / 255
55            return grayscale
56
57    # Action Methods
58        def CommitAction(self, action, tileObjVec, worldMap, enemyList): # Commits the given Action
59            offset = self.paramDictionary["DQLOffset"]
60            sideLength = 2 * offset + 1
61
62            if action == 0:
63                self.Move(action, worldMap) # Move Up
64
65            elif action == 1:
66                self.Move(action, worldMap) # Move Right
67
68            elif action == 2:
69                self.Move(action, worldMap) # Move Down
70
71            elif action == 3:
72                self.Move(action, worldMap) # Move Left
73
74            elif action == 4 and tileObjVec.matrixVals[(sideLength * offset) + offset][0].hasObject == True: # Pickup
75                self.PickupItem(worldMap)
76
77            elif action == 5: # Attack Surroundings
78                self.Attack(enemyList)
79
80            elif action == 6: # Noop/Null action
81                pass
82                #print("Noop")
83
84        def Move(self, direction, worldMap): # Moves agent in given Direction
85            if direction == 0: self.location = [self.location[0], self.location[1] - 1] # Move Up
86            elif direction == 1: self.location = [self.location[0] + 1, self.location[1]] # Move Right
87            elif direction == 2: self.location = [self.location[0], self.location[1] + 1] # Move Down
88            elif direction == 3: self.location = [self.location[0] - 1, self.location[1]] # Move Left
89
90            self.alive = self.CheckIfValidStandTile(self.location, worldMap)
91            if not self.alive: return
92
93            if worldMap.tileArray[self.location[0]][self.location[1]].explored == False: # Checks if tile is explored
94                worldMap.tileArray[self.location[0]][self.location[1]].explored = True
95
96        def CheckIfValidStandTile(self, location, worldMap): # Checks if tile will murder the agent
97            x = location[0]
98            y = location[1]
99            if 0 <= x and x <= self.paramDictionary["WorldSize"] - 1 and 0 <= y and y <= self.paramDictionary["WorldS
100           else:
101               return False
102
103           if worldMap.tileArray[x][y].tileType == 0: # Checks if tile is water
104               return False
105
106           return True
107
108       def PickupItem(self, worldMap): # Pickup Item in the same tile as Agent
```

```
109              if worldMap.tileArray[self.location[0]][self.location[1]].hasObject:
110                  self.inventory[worldMap.tileArray[self.location[0]][self.location[1]].objectType] += 1
111
112                  worldMap.tileArray[self.location[0]][self.location[1]].ClearObject()
113
114          def Attack(self, enemyList): # Attacks in a given Area surrounding Agent
115              enemyLocList = [enemyList[i].location for i in range(len(enemyList))]
116
117              for y in range(self.location[1] - 1, self.location[1] + 2): # Loop through Tiles in surrounding area
118                  for x in range(self.location[0] - 1, self.location[0] + 2):
119                      if [x,y] in enemyLocList:
120                          for i in range(len(enemyLocList)):
121                              if enemyLocList[i] == [x,y]:
122                                  enemyList[i] = None
123
124              enemyList = [x for x in enemyList if x is not None] # Clears enemy list of None type
125
126  # Reward Method
127          def GetReward(self, action, tileObjVec): # Gets reward given action and tile vector
128              offset = self.paramDictionary["DQLOffset"]
129              sideLength = 2 * offset + 1
130
131              cumReward = 0
132
133              if action == 0: # Move Up
134                  tile = tileObjVec.matrixVals[(sideLength * (offset - 1)) + offset][0]
135                  cumReward += self.MoveReward(tile)
136
137              elif action == 1: # Move Right
138                  tile = tileObjVec.matrixVals[(sideLength * offset) + offset + 1][0]
139                  cumReward += self.MoveReward(tile)
140
141              elif action == 2: # Move Down
142                  tile = tileObjVec.matrixVals[(sideLength * (offset + 1)) + offset][0]
143                  cumReward += self.MoveReward(tile)
144
145              elif action == 3: # Move Left
146                  tile = tileObjVec.matrixVals[(sideLength * offset) + offset - 1][0]
147                  cumReward += self.MoveReward(tile)
148
149              elif action == 4: # Pickup Item
150                  if tileObjVec.matrixVals[(sideLength * offset) + offset][0].hasObject:
151                      cumReward += self.paramDictionary["CollectItemReward"]
152                  else:
153                      cumReward += self.paramDictionary["NoopReward"]
154
155              elif action == 5: # Attack
156                  cumReward += self.CombatReward(tileObjVec)
157
158              elif action == 6: # No action/Noop/Idle
159                  cumReward += self.paramDictionary["NoopReward"]
160
161              return cumReward
162
163          def MoveReward(self, tileObj): # Gets Reward given Agent moving into a tile
```

```
164            reward = 0
165            if tileObj.tileType == 0 or tileObj.hasEnemy:   # Adds death reward if enemy or water
166                reward += self.paramDictionary["DeathReward"]
167            else:                                            # Else adds explore and move reward
168                if tileObj.explored == False:
169                    reward += self.paramDictionary["ExploreReward"]
170                reward += self.paramDictionary["MoveReward"]
171            return reward
172
173        def CombatReward(self, tileObjVec):
174            killReward = self.paramDictionary["AttackReward"]
175            offset = self.paramDictionary["DQLOffset"]
176            sideLength = 2 * offset + 1
177
178            reward = 0
179
180            # Checks tiles around agent for enemies, adding reward where neccesary
181            if tileObjVec.matrixVals[(sideLength * (offset - 1)) + offset - 1][0].hasEnemy: reward += killReward
182            if tileObjVec.matrixVals[(sideLength * (offset - 1)) + offset][0].hasEnemy:     reward += killReward
183            if tileObjVec.matrixVals[(sideLength * (offset - 1)) + offset + 1][0].hasEnemy: reward += killReward
184
185            if tileObjVec.matrixVals[(sideLength * offset) + offset - 1][0].hasEnemy:       reward += killReward
186            if tileObjVec.matrixVals[(sideLength * offset) + offset][0].hasEnemy:           reward += killReward
187            if tileObjVec.matrixVals[(sideLength * offset) + offset + 1][0].hasEnemy:       reward += killReward
188
189            if tileObjVec.matrixVals[(sideLength * (offset + 1)) + offset - 1][0].hasEnemy: reward += killReward
190            if tileObjVec.matrixVals[(sideLength * (offset + 1)) + offset][0].hasEnemy:     reward += killReward
191            if tileObjVec.matrixVals[(sideLength * (offset + 1)) + offset + 1][0].hasEnemy: reward += killReward
192
193            if reward > 0: return reward
194            else: return self.paramDictionary["AttackFailedReward"]
195
196        def GetRewardVector(self, tileObjVec, outputs): # Returns Vector of Reward Values Per action
197            returnVec = Matrix((outputs, 1))
198
199            for i in range(outputs):
200                returnVec.matrixVals[i][0] = self.GetReward(i, tileObjVec)
201
202            return returnVec
203
204        def MaxQ(self, rewardVec): # Used to get Max Reward from reward Vector
205            return max([rewardVec.matrixVals[i][0] for i in range(rewardVec.order[0])]) # Utilises List Comprehension
206
207    # Miscellaneous Methods
208        def Reset(self, worldMap): # Resets Inventory and Location of Agent
209            self.inventory = self.emptyInventory
210
211            self.location = Agent.SpawnPosition(worldMap)
212
213            self.alive = True
214
215        @staticmethod
216        def SpawnPosition(worldMap): # Returns a coord in which the Agent can spawn
217            spawnList = []
218
```

```
219             for y in range(0, worldMap.MAP_SIZE):
220                 for x in range(0, worldMap.MAP_SIZE):
221                     if worldMap.tileArray[x][y].tileType == 2:
222                         spawnList.append([x, y])
223
224             shuffle(spawnList)
225             return spawnList[0]
```

5.4   enemy.py

```
1   from newAgent import *
2   from random import randint
3
4   class Enemy(Agent): # Enemy inherits from Agent Class
5       def __init__(self, location, params): # Constructor for Enemy Class
6           self.paramDictionary = params
7
8           self.location = location
9
10          self.alive = True
11
12      def CommitAction(self, agent, worldMap): # Override of Agent Class method
13          xDif = agent.location[0] - self.location[0]
14          yDif = agent.location[1] - self.location[1]
15
16          if xDif == 0 and yDif == 0: # Checks if on Agent - If so -> Kill Agent
17              agent.alive = False
18              return
19
20          # Basic Path Finding for enemy
21          # Calculates difference between agent and player position, and moves in the greatest direction
22          if abs(xDif) > abs(yDif):  # X Dif > Y Dif
23              if xDif > 0:
24                  self.location[0] += 1
25              else:
26                  self.location[0] -= 1
27          elif abs(xDif) < abs(yDif): # Y Dif > X Dif
28              if yDif > 0:
29                  self.location[1] += 1
30              else:
31                  self.location[1] -= 1
32          else:                       # Move random direction when X Dif = Y Dif
33              if randint(0,1):
34                  if xDif > 0:
35                      self.location[0] += 1
36                  else:
37                      self.location[0] -= 1
38              else:
39                  if yDif > 0:
40                      self.location[1] += 1
41                  else:
42                      self.location[1] -= 1
43
44          self.alive = self.CheckIfValidStandTile(self.location, worldMap) # Checks if walked into water or not
```

```
45
46        @staticmethod
47        def SpawnPosition(worldMap, enemyList): # Generate spawn position for the enemy given worldMap and enemyList
48            spawnList = []
49            enemyLocList = [enemyList[i].location for i in range(len(enemyList))]
50
51            for y in range(0, worldMap.MAP_SIZE):
52                for x in range(0, worldMap.MAP_SIZE):
53                    if worldMap.tileArray[x][y].tileType == 2: # Checks if tile type is
54                        spawnList.append([x, y])
55
56            shuffle(spawnList)
57
58            if spawnList[0] in enemyLocList: # Select spawn if not already selected
59                return None
60            else:
61                return spawnList[0]
```

5.5   worldClass.py

```
1   import json, random, pygame, threading
2   import perlinNoise
3
4   # Class to store Individual Tile Data
5   class Tile():
6       def __init__(self): # Initialise Tile object
7           self.tileHeight = -1
8           self.tileType = 0
9           self.tileColour = (0,0,0)
10          self.explored = False
11          self.hasObject = False
12          self.hasEnemy = False
13
14      def InitValues(self, tileType, height, colour): # Set/Initialise Tile Vales
15          self.tileType = tileType
16          self.tileHeight = height
17          self.tileColour = colour
18
19      def AddObject(self, objectType, objectColour): # Adds an Object to the Tile Object
20          self.hasObject = True
21          self.objectType = objectType
22          self.objectColour = objectColour
23
24      def ClearObject(self): # Clears Object from the Tile Object
25          self.hasObject = False
26          self.objectType = ""
27          self.objectColour = (0,0,0)
28
29      def WriteEnemy(self): # Write Enemy to tile
30          self.hasEnemy = True
31
32  # Class to store world terrain and object data
33  class WorldMap():
34      def __init__(self, seed, params): # Initialise method for creating an instance of the world
```

```
35            self.MAP_SIZE = params["WorldSize"]
36            self.TILE_WIDTH = params["TileWidth"]
37            self.MAP_SEED = seed
38            self.TILE_BORDER = params["TileBorder"]
39
40            self.tileArray = [[Tile() for i in range(self.MAP_SIZE)] for j in range(self.MAP_SIZE)]
41
42            self.paramDictionary = params
43
44   # Non Threaded Terrain Generation
45       def GenerateMap(self): # Generates terrain - Not Threaded
46            for y in range(0, self.MAP_SIZE):
47                for x in range(0, self.MAP_SIZE):
48                    xCoord = x / self.MAP_SIZE * self.paramDictionary["WorldScale"]
49                    yCoord = y / self.MAP_SIZE * self.paramDictionary["WorldScale"]
50
51                    self.tileArray[x][y].tileHeight = perlinNoise.octaveNoise(self.MAP_SEED + xCoord, self.MAP_SEED +
52                                                      self.paramDictionary["OctavesTerrain"], self.paramDic
53
54   # Threaded Terrain Generation
55       def GenerateThreadedParent(self): # Generates terrain using 4 threads
56            threads = []
57
58            halfMap = int(self.MAP_SIZE / 2)
59            fullMap = self.MAP_SIZE
60
61            # Create 4 threads for threaded child functions
62            threads.append(threading.Thread(target=self.ThreadedChild, args=(0, halfMap, 0, halfMap)))
63            threads.append(threading.Thread(target=self.ThreadedChild, args=(halfMap, fullMap, 0, halfMap)))
64            threads.append(threading.Thread(target=self.ThreadedChild, args=(0, halfMap, halfMap, fullMap)))
65            threads.append(threading.Thread(target=self.ThreadedChild, args=(halfMap, fullMap, halfMap, fullMap)))
66
67
68            # Start all the threads
69            for t in threads:
70                t.start()
71
72            # While threads arent finished, pause
73            while threading.activeCount() > 1:
74                pass
75
76            self.RenderMap() # Render Map
77
78       def ThreadedChild(self, x1, x2, y1, y2): # Child Method to GenerateThreadedParent
79            for y in range(y1, y2):
80                for x in range(x1, x2):
81                    xCoord = (x / self.MAP_SIZE) * self.paramDictionary["WorldScale"]
82                    yCoord = (y / self.MAP_SIZE) * self.paramDictionary["WorldScale"]
83
84                    self.tileArray[x][y].tileHeight = perlinNoise.octaveNoise(self.MAP_SEED + xCoord + self.time, sel
85                                                      self.paramDictionary["OctavesTerrain"], self.paramDic
86
87   # Generate Tree Methods
88       def GenerateTreeArea(self): # Uses perlin noise to generate the areas for trees to spawn in
89            TSO = self.paramDictionary["TreeSeedOffset"]
```

```
 90
 91              treeList = []
 92
 93              for y in range(0, self.MAP_SIZE):
 94                  for x in range(0, self.MAP_SIZE):
 95                      xCoord = x / self.MAP_SIZE
 96                      yCoord = y / self.MAP_SIZE
 97
 98                      temp = perlinNoise.octaveNoise(self.MAP_SEED + xCoord + TSO, self.MAP_SEED + yCoord + TSO,
 99                              self.paramDictionary["OctavesTrees"], self.paramDictionary["PersistenceTrees"]) # Sam
100
101                      tileValue = self.Clamp(((self.tileArray[x][y].tileHeight / 2) + 0.5), 0.0, 1.0) # Clamp value
102
103                      if (temp > self.paramDictionary["TreeHeight"] and tileValue > self.paramDictionary["Coast"] + sel
104                                                  tileValue < self.paramDictionary["Grass"] - s
105                          treeList.append([x, y])
106
107              poissonArray = self.PoissonDiscSampling(treeList) # Get Poisson Disc Sampling values for poisson array
108
109              for y in range(0, self.MAP_SIZE):
110                  for x in range(0, self.MAP_SIZE):
111                      self.tileArray[x][y].ClearObject() # Clear Existing objects from tile map
112
113                      if poissonArray[x][y] == True:
114                          self.tileArray[x][y].AddObject(self.paramDictionary["TreeType"], self.paramDictionary["Colour
115
116          def PoissonDiscSampling(self, pointList): # A tweaked version of poisson disc sampling in 2 dimensions
117              k = self.paramDictionary["PoissonKVal"]
118
119              pickedPoints = [[False for i in range(self.MAP_SIZE)] for j in range(self.MAP_SIZE)] # Blank array of Fal
120
121              numPoints = len(pointList) - 1
122              if numPoints <= 0: # Catches if no points
123                  return pickedPoints
124
125              sampleNum = 0
126
127              while sampleNum <= k: # While sampled attempts is less than k
128                  sample = pointList[random.randint(0, numPoints)]
129
130                  result = self.PoissonCheckPoint(sample, pickedPoints) # Check points
131                  if result == True:
132                      pickedPoints[sample[0]][sample[1]] = True
133                      sampleNum = 0
134                      continue
135                  else:
136                      sampleNum += 1
137                      continue
138
139              return pickedPoints
140
141          def PoissonCheckPoint(self, point, pickedPoints): # Checks Specific points around a point for objects
142              if (1 <= point[0] and point[0] <= self.paramDictionary["WorldSize"] - 2 and
143                          1 <= point[1] and point[1] <= self.paramDictionary["WorldSize"] - 2):
144                  if pickedPoints[point[0]][point[1] - 1] == True: return False
```

```
145             elif pickedPoints[point[0] + 1][point[1]] == True: return False
146             elif pickedPoints[point[0]][point[1] + 1] == True: return False
147             elif pickedPoints[point[0] - 1][point[1]] == True: return False
148             elif pickedPoints[point[0]][point[1]] == True: return False
149             else: return True

151  # Render Methods
152      def RenderMap(self): # Renders terrain onto Pygame surface
153          resolution = self.MAP_SIZE * self.TILE_WIDTH
154          self.RenderedMap = pygame.Surface((resolution, resolution))
155          self.RenderedMap.set_colorkey((0,0,0))

157          if self.paramDictionary["Grayscale"] == 1: # Renders in grayscale if specified
158              for y in range(0, self.MAP_SIZE):
159                  for x in range(0, self.MAP_SIZE):
160                      value = self.tileArray[x][y].tileHeight
161                      value = (value / 2) + 0.5
162                      value = self.Clamp(value, 0.0, 1.0)

164                      pygame.draw.rect(self.RenderedMap, (255 * value, 255 * value, 255 * value), ((x * self.TILE_W
165                          (y * self.TILE_WIDTH + self.TILE_BORDER), self.TILE_WIDTH - (self.TILE_BORDER * 2), s

167          else:                                        # Else renders in Colour
168              for y in range(0, self.MAP_SIZE):
169                  for x in range(0, self.MAP_SIZE):
170                      value = self.tileArray[x][y].tileHeight
171                      value = (value / 2) + 0.5
172                      value = self.Clamp(value, 0.0, 1.0) # Clamps value between 0 and 1

174                      colour = None

176                      if value == 0: # Colour ramp for all available colours
177                          colour = (0,0,0)
178                      elif value < self.paramDictionary["Water"]:
179                          colour = tuple(self.paramDictionary["ColourWater"])
180                          self.tileArray[x][y].tileType = 0
181                          self.tileArray[x][y].tileColour = colour
182                      elif value < self.paramDictionary["Coast"]:
183                          colour = tuple(self.paramDictionary["ColourCoast"])
184                          self.tileArray[x][y].tileType = 1
185                          self.tileArray[x][y].tileColour = colour
186                      elif value < self.paramDictionary["Grass"]:
187                          colour = tuple(self.paramDictionary["ColourGrass"])
188                          self.tileArray[x][y].tileType = 2
189                          self.tileArray[x][y].tileColour = colour
190                      elif value < self.paramDictionary["Mountain"]:
191                          colour = tuple(self.paramDictionary["ColourMountain"])
192                          self.tileArray[x][y].tileType = 3
193                          self.tileArray[x][y].tileColour = colour

195                      # Draws correct colour pixel to rendered map - takes into account width and border
196                      pygame.draw.rect(self.RenderedMap, colour, ((x * self.TILE_WIDTH + self.TILE_BORDER),
197                          (y * self.TILE_WIDTH + self.TILE_BORDER), self.TILE_WIDTH - (self.TILE_BORDER * 2), s

199      def RenderInteractables(self): # Renders interactables onto pygame surface
```

```
200            resolution = self.MAP_SIZE * self.TILE_WIDTH
201            self.RenderedInteractables = pygame.Surface((resolution, resolution))
202            self.RenderedInteractables.set_colorkey((0,0,0))
203
204            ITB = self.paramDictionary["InteractableTileBorder"]
205
206            for y in range(0, self.MAP_SIZE): # Draw interactables to rendered image
207                for x in range(0, self.MAP_SIZE):
208                    if self.tileArray[x][y].hasObject == True:
209                        tile = self.tileArray[x][y]
210                        pygame.draw.rect(self.RenderedInteractables, tile.objectColour, ((x * self.TILE_WIDTH + ITB),
211                            (y * self.TILE_WIDTH + ITB), self.TILE_WIDTH - (ITB * 2), self.TILE_WIDTH - (ITB * 2)
212
213    def DrawMap(self, window): # Blits the rendered frames onto the passed through window
214        window.blit(self.RenderedMap, (0,0))
215        self.RenderInteractables()
216        window.blit(self.RenderedInteractables, (0,0))
217
218    # Miscellaneous Methods
219    def Clamp(self, val, low, high): # Simple function to clamp a value between two numbers - Used to make sure n
220        return low if val < low else high if val > high else val
```

5.6   perlinNoise.py

```
1   import random, math
2
3   p = [151,160,137,91,90,15,
4       131,13,201,95,96,53,194,233,7,225,140,36,103,30,69,142,8,99,37,240,21,10,23,
5       190, 6,148,247,120,234,75,0,26,197,62,94,252,219,203,117,35,11,32,57,177,33,
6       88,237,149,56,87,174,20,125,136,171,168, 68,175,74,165,71,134,139,48,27,166,
7       77,146,158,231,83,111,229,122,60,211,133,230,220,105,92,41,55,46,245,40,244,
8       102,143,54, 65,25,63,161, 1,216,80,73,209,76,132,187,208, 89,18,169,200,196,
9       135,130,116,188,159,86,164,100,109,198,173,186, 3,64,52,217,226,250,124,123,
10      5,202,38,147,118,126,255,82,85,212,207,206,59,227,47,16,58,17,182,189,28,42,
11      223,183,170,213,119,248,152, 2,44,154,163, 70,221,153,101,155,167, 43,172,9,
12      129,22,39,253, 19,98,108,110,79,113,224,232,178,185, 112,104,218,246,97,228,
13      251,34,242,193,238,210,144,12,191,179,162,241, 81,51,145,235,249,14,239,107,
14      49,192,214, 31,181,199,106,157,184, 84,204,176,115,121,50,45,127, 4,150,254,
15      138,236,205,93,222,114,67,29,24,72,243,141,128,195,78,66,215,61,156,180]
16  p = p + p
17
18  def octaveNoise(x, y, octaves, persistence): # Sums multiple levels of perlin noise
19      total = 0
20      frequency = 1
21      amplitude = 1
22      maxValue = 0
23
24      for i in range(octaves): # Combines Multiple octaves of perlin noise
25          total += ((noise(x * frequency, y * frequency)) * amplitude)
26
27          maxValue += amplitude
28
29          amplitude *= persistence
30          frequency *= 2
```

```
31
32        return total / maxValue
33
34   def noise(x, y): # Returns a value of the perlin noise function at (x, y) coordinate
35        xi = math.floor(x) % 255
36        yi = math.floor(y) % 255
37
38        g1 = p[p[xi] + yi]
39        g2 = p[p[xi + 1] + yi]
40        g3 = p[p[xi] + yi + 1]
41        g4 = p[p[xi + 1] + yi + 1]
42
43        xf = x - math.floor(x)
44        yf = y - math.floor(y)
45
46        d1 = grad(g1, xf, yf)
47        d2 = grad(g2, xf - 1, yf)
48        d3 = grad(g3, xf, yf - 1)
49        d4 = grad(g4, xf - 1, yf - 1)
50
51        u = fade(xf)
52        v = fade(yf)
53
54        x1Inter = lerp(u, d1, d2)
55        x2Inter = lerp(u, d3, d4)
56        yInter = lerp(v, x1Inter, x2Inter)
57
58        return yInter
59
60   def grad(hash, x, y): # Gradient Function defined as part of the algorithm
61        temp = hash & 3
62        if temp == 0:
63            return x + y
64        elif temp == 1:
65            return -x + y
66        elif temp == 2:
67            return x - y
68        elif temp == 3:
69            return -x - y
70        else:
71            return 0
72
73   def lerp(ammount, left, right): # Linear interpolation of values
74        return ((1 - ammount) * left + ammount * right)
75
76   def fade(t): # Fade Function defined as part of the algorithm
77        return t * t * t * (t * (t * 6 - 15) + 10)
```

5.7 deepqlearning.py

```
1   import random, pickle, math
2   from matrix import Matrix
3   import activations
4   from copy import copy
```

```python
5    from datalogger import *
6
7    class DoubleNeuralNet(): # Wraps a Main and Target Neural Network together
8        def __init__(self, layers, params, load=False, loadName="DQNetwork"): # Constructor for a Double Neural Netwo
9            self.paramDictionary = params
10
11           if not load: # Create brand new values
12               self.MainNetwork = NeuralNet(layers, params)
13               self.TargetNetwork = NeuralNet(layers, params)
14
15               self.ExperienceReplay = Deque(self.paramDictionary["ERBuffer"])
16
17               self.epsilon = self.paramDictionary["DQLEpsilon"]
18
19               self.step = 0
20               self.cumReward = 0.0
21
22               self.layerActivation = activations.TanH()
23               self.finalLayerActivation = activations.SoftMax()
24           else:
25               self.LoadState(loadName) # Load values from saved data
26
27           self.fileName = loadName
28
29           self.activations = (self.layerActivation, self.finalLayerActivation) # Tuple of activations
30
31           self.batchReward = 0
32           self.maxBatchReward = 0
33           self.batchLoss = 0
34           self.dataPoints = []
35
36                                                              # BatchReward, MaxBatchReward, PercentageDifference, Step
37           self.actionTracker = DataLogger("ActionTracker", [[float, int], [float, int], [float, int], int], False)
38
39       def TakeStep(self, agent, worldMap, enemyList): # Takes a step forward in time
40           self.step += 1
41
42           # Forward Propagation
43           agentSurround = agent.GetTileVector(worldMap, enemyList)
44           postProcessedSurround = agent.TileVectorPostProcess(agentSurround) # Retrieve Vector of State info from A
45           netInput = postProcessedSurround[1]
46
47           self.MainNetwork.ForwardPropagation(netInput, self.activations) # Forward Prop the Main Network
48
49           output = self.MainNetwork.layers[-1].outputVector
50           outputMax = output.MaxInVector()
51
52           # Action Taking and Reward
53           if random.random() < self.epsilon: # Epsilon slowly regresses, leaving a greater chance for a random acti
54               if type(self.finalLayerActivation) == activations.SoftMax: # Sum softmax distribution values and choo
55                   action = random.randint(0, 6)
56                   val = random.random()
57                   totalled = 0
58                   for i in range(output.order[0]):
59                       totalled += output.matrixVals[i][0]
```

```python
60                     if totalled >= val:
61                         action = i
62                         break
63                 else:
64                     action = random.randint(0, 6)
65             else:
66                 action = outputMax[1] # Choose best action
67
68             #action = random.randint(0, self.paramDictionary["DeepQLearningLayers"][-1] - 1)
69
70             rewardVector = agent.GetRewardVector(agentSurround, self.paramDictionary["DeepQLearningLayers"][-1])
71             reward = rewardVector.matrixVals[action][0] # Get reward given action
72             self.cumReward += reward
73             self.batchReward += reward
74             self.maxBatchReward += rewardVector.MaxInVector()[0]
75             #print(reward, rewardVector.MaxInVector()[0], action)
76
77             agent.CommitAction(action, agentSurround, worldMap, enemyList) # Take Action
78
79             #self.dataPoints.append([reward, rewardVector.MaxInVector()[0], 0, self.step])
80
81             # Epsilon Regression
82             self.epsilon *= self.paramDictionary["DQLEpisonRegression"]
83
84             # Assigning values to tempExperience
85             tempExp = Experience()
86             tempExp.state = agentSurround
87             tempExp.action = action
88             tempExp.reward = rewardVector
89             tempExp.stateNew = agent.GetTileVector(worldMap, enemyList)
90
91             self.ExperienceReplay.PushFront(copy(tempExp))
92
93             # Back Propagation
94             LossVector = self.LossFunctionV2(output, tempExp, agent) # Calculating Loss
95
96             LossVector = self.Expected(output, LossVector)
97
98             self.batchLoss += LossVector.matrixVals[action][0]
99             #print(LossVector.matrixVals[action][0])
100
101             self.MainNetwork.layers[-1].errSignal = LossVector
102
103             self.MainNetwork.BackPropagationV2(self.activations) # Back Propagating the loss
104
105             # Do things every X steps passed
106             if self.step % self.paramDictionary["TargetReplaceRate"] == 0: # Replace Weights in Target Network
107                 self.TargetNetwork.layers = self.MainNetwork.layers
108
109             # Sample Experience Replay Buffer
110             if (self.paramDictionary["EREnabled"] and self.step % self.paramDictionary["ERSampleRate"] == 0 and self.
111                 self.SampleExperienceReplay(agent)
112
113             # Actions to run after every Batch
114             if self.step % self.paramDictionary["DQLEpoch"] == 0:
```

```python
115                    print(self.step, self.cumReward, self.epsilon)

116

117                    self.MainNetwork.UpdateWeightsAndBiases(self.paramDictionary["DQLEpoch"]) # Update weights and biases

118

119                    if self.paramDictionary["SaveWeights"]: # Saves weights if specified
120                        self.SaveState(self.fileName)

121

122                    #Log Action
123                    self.actionTracker.LogDataPoint([self.batchReward, self.maxBatchReward, self.batchLoss, self.step])
124                    #self.actionTracker.LogDataPointBatch(self.dataPoints)

125

126                    self.dataPoints = []
127                    self.actionTracker.SaveDataPoints()

128

129                    self.batchReward = 0
130                    self.maxBatchReward = 0
131                    self.batchLoss = 0

132

133        def SampleExperienceReplay(self, agent): # Samples the Experience Replay Buffer, Back Propagating its Finding
134            samples = self.ExperienceReplay.Sample(self.paramDictionary["ERSampleSize"])

135

136            for sample in samples:
137                postProcessedSurround = agent.TileVectorPostProcess(sample.state) # Post process the Tile Vector
138                netInput = postProcessedSurround[1]

139

140                self.MainNetwork.ForwardPropagation(netInput, self.activations) # Forward Prop the Main Network

141

142                output = self.MainNetwork.layers[-1].outputVector

143

144                Loss = self.LossFunctionV2(output, sample, agent) # Generate Loss for the sample

145

146                self.MainNetwork.layers[-1].errSignal = Loss

147

148                self.MainNetwork.BackPropagationV2(self.activations) # Back Propagate the error

149

150        def Expected(self, networkOutput, QValVector):
151            return ((QValVector - networkOutput) ** 2) * 0.5

152

153        def LossFunctionV2(self, output, tempExp, agent):
154            # L^i(W^i) = ((r + y*maxQ(s',a';W^i-1) - Q(s,a,W)) ** 2
155            # Loss = ((Reward[] + Gamma * MaxQ(s', a'; TNet)) - Q(s, a)[]) ^ 2

156

157            Reward = tempExp.reward
158            Gamma = self.paramDictionary["DQLGamma"]

159

160            #stateNew = agent.TileVectorPostProcess(tempExp.stateNew) # Create new state input
161            self.TargetNetwork.ForwardPropagation(agent.TileVectorPostProcess(tempExp.state)[1], self.activations) #
162            tempRewardVec = agent.GetRewardVector(tempExp.stateNew, self.paramDictionary["DeepQLearningLayers"][-1])
163            maxQTNet = agent.MaxQ(tempRewardVec) # Max of Target network

164

165            LossVec = ((Reward + (Gamma * maxQTNet)) - output) ** 2 # Bellman Equation
166            return LossVec

167

168        def SaveState(self, file):
169            state = [self.MainNetwork, self.TargetNetwork, self.ExperienceReplay, self.step,
```

```
170                            self.epsilon, self.cumReward, self.layerActivation, self.finalLayerActivation]
171            with open("DQLearningData\\" + file + ".dqn", "wb") as f:
172                pickle.dump(state, f)
173
174        def LoadState(self, file): # Returns stored Neural Network data
175            with open("DQLearningData\\" + file + ".dqn", "rb") as f:
176                state = pickle.load(f)
177
178                self.MainNetwork = state[0]
179                self.TargetNetwork = state[1]
180                self.ExperienceReplay = state[2]
181                self.step = state[3]
182                self.epsilon = state[4]
183                self.cumReward = state[5]
184                self.layerActivation = state[6]
185                self.finalLayerActivation = state[7]
186
187    class NeuralNet(): # Neural Network Implementation
188        def __init__(self, layersIn, params): # Constructor for a Single Neural Network
189            self.paramDictionary = params
190
191            self.layers = []
192
193            for i in range(len(layersIn)):
194                if i == 0:
195                    self.layers.append(Layer(0, layersIn[0], True))
196                else:
197                    self.layers.append(Layer(layersIn[i - 1], layersIn[i]))
198
199        def ForwardPropagation(self, inputVector, activations): # Iterates through Forward Propagation
200            self.layers[0].outputVector = inputVector
201
202            for i in range(1, len(self.layers) - 1):
203                self.layers[i].ForwardPropagation(self.layers[i-1], activations)
204
205            self.layers[-1].ForwardPropagation(self.layers[-2], activations, finalLayer=True)
206
207        def BackPropagationV2(self, activations): # Iterates through Back Propagation V2
208            self.layers[-1].BackPropagationV2(self.layers[-2], self.paramDictionary["DQLLearningRate"], activations,
209
210            for i in range(len(self.layers) - 2, 0, -1):
211                self.layers[i].BackPropagationV2(self.layers[i-1], self.paramDictionary["DQLLearningRate"], activatio
212
213        def UpdateWeightsAndBiases(self, epochCount): # Update Weights and biases
214            for i in range(1, len(self.layers)):
215                self.layers[i].UpdateWeightsAndBiases(epochCount)
216
217    class Layer(): # Layer for a Neural Network
218        def __init__(self, prevSize, size, inputLayer=False): # Constructor for a Layer Object
219            if inputLayer == False: # Additional objects if not the input layer
220                self.weightMatrix = Matrix((size, prevSize), random=True)
221
222                self.biasVector = Matrix((size, 1), random=False)
223
224                self.weightUpdates = Matrix((size, prevSize))
```

```python
225
226             self.biasUpdates = Matrix((size, 1))
227
228             self.errSignal = Matrix((size, 1))
229
230         self.sVector = Matrix((size, 1))
231         self.outputVector = Matrix((size, 1))
232
233     def ForwardPropagation(self, prevLayer, activations, finalLayer=False): # Forward Propagates the Neural Netwo
234         weightValueProduct = self.weightMatrix * prevLayer.outputVector
235
236         self.sVector = weightValueProduct + self.biasVector
237
238         if not finalLayer: # Apply different activation if Output Layer
239             self.outputVector = activations[0].Activation(copy(self.sVector))
240         else:
241             self.outputVector = activations[1].Activation(copy(self.sVector))
242
243     def BackPropagationV2(self, prevLayer, lr, layerActivations, finalLayer=False): # 2nd Revision of Back Propag
244         # Calculating Next Error Signal
245         halfErrSignal = (self.weightMatrix.Transpose() * self.errSignal)
246
247         if finalLayer:
248             zDerivative = layerActivations[1].Derivative(copy(prevLayer.sVector))
249         else:
250             zDerivative = layerActivations[0].Derivative(copy(prevLayer.sVector)) # Applying derivative functions
251
252         errSignal = halfErrSignal * zDerivative # Hadamard Product to get error signal for previous layer
253         prevLayer.errSignal = errSignal
254
255         # Calculating Weight updates
256         updatedWeightVectors = []
257         for delta in range(self.errSignal.order[0]):
258             errSignal = self.errSignal.matrixVals[delta][0]
259
260             selectedColumn = self.weightMatrix.Transpose().SelectColumn(delta)
261             updatedWeightVectors.append(selectedColumn * errSignal * (-lr))
262
263         # Combining the weight updates into a matrix and adding it to the weight updates Matrix
264         self.weightUpdates += Matrix.CombineVectorsHor(updatedWeightVectors).Transpose()
265
266         self.biasUpdates += self.errSignal * lr # Bias Updates
267
268     def UpdateWeightsAndBiases(self, epochCount): # Update Weights and Biases
269         self.weightMatrix -= (self.weightUpdates * (1 / epochCount))
270         self.biasVector -= (self.biasUpdates * (1 / epochCount))
271
272         self.weightUpdates.Clear()
273         self.biasUpdates.Clear()
274
275 class Experience(): # Used in Experience Replay
276     def __init__(self, state = None, action = None, reward = None, stateNew = None): # Constructor for an Experie
277         self.state = state
278         self.action = action
279         self.reward = reward
```

```
280             self.stateNew = stateNew
281
282   class Deque(): # Partial Double Ended Queue Implementation
283       def __init__(self, length):
284           self.length = length
285
286           self.queue = [None for i in range(self.length)]
287
288           self.frontP = -1
289           self.backP = -1
290
291       def PushFront(self, item): # Pushes item to front of Queue
292           self.frontP = (self.frontP + 1) % self.length
293
294           if self.queue[self.frontP] != None:
295               self.backP = (self.frontP + 1) % self.length
296
297           self.queue[self.frontP] = item
298
299       def Full(self): # Checks if Queue is full
300           if self.queue[self.length - 1] != None:
301               return True
302           return False
303
304       def First(self): # Returns Front Item from Queue
305           return self.queue[self.frontP]
306
307       def Last(self): # Returns Final Item from Queue
308           return self.queue[(self.frontP + 1) % self.length]
309
310       def Sample(self, n): # Samples N number of samples from the deque
311           temp = self.queue
312           return random.sample(temp, n)
```

5.8   activations.py

```
1    from abc import ABC, abstractmethod
2    from math import e, tanh, exp, cosh
3    from matrix import *
4
5    class Activation(ABC): # Abstract Base Class
6        @abstractmethod
7        def Activation(self, x): # Abstract Activation Method
8            pass
9
10       @abstractmethod
11       def Derivative(self, x): # Abstract Derivative Method
12           pass
13
14   class ReLu(Activation): # ReLu
15       def __init__(self):
16           pass
17
18       def Activation(self, x): # Returns value if greater than 0, else 0
```

```python
            for row in range(x.order[0]):
                x.matrixVals[row][0] = max(0, x.matrixVals[row][0])
            return x

    def Derivative(self, x): # If value is greater than 0 return 1, else return 0
            for row in range(x.order[0]):
                if x.matrixVals[row][0] > 0: x.matrixVals[row][0] = 1
                else: 0
            return x

class LeakyReLu(Activation): # Leaky ReLu
    def __init__(self):
        pass

    def Activation(self, x): # Returns value if greater than 0, else a apply a gradient to x and return it
            for row in range(x.order[0]):
                x.matrixVals[row][0] = max(x.matrixVals[row][0] * 0.01, x.matrixVals[row][0])
            return x

    def Derivative(self, x): # If value is greater than 0 return 1, else return 0.01
            for row in range(x.order[0]):
                if x.matrixVals[row][0] > 0: x.matrixVals[row][0] = 1
                else: 0.1
            return x

class Sigmoid(Activation): # Sigmoid
    def __init__(self):
        pass

    def Activation(self, x): # Mathematical Function to get "squish" values between 0 and 1
            for row in range(x.order[0]):
                if x.matrixVals[row][0] > 15: x.matrixVals[row][0] = 1
                elif x.matrixVals[row][0] < -15: x.matrixVals[row][0] = 0
                else: x.matrixVals[row][0] = 1 / (1 + exp(-x.matrixVals[row][0]))
            return x

    def Derivative(self, x): # Derivative of the Sigmoid Function
            for row in range(x.order[0]):
                sigmoidSingle = self.ActivationSingle(x.matrixVals[row][0])
                x.matrixVals[row][0] = sigmoidSingle * (1 - sigmoidSingle)
            return x

    def ActivationSingle(self, x): # Single value for use in the derivative
            if x > 15: return 1
            elif x < -15: return 0
            else: return 1 / (1 + exp(-x))

class SoftMax(Activation): # SoftMax
    def __init__(self):
        pass

    def Activation(self, x): # Returns a probability distribution between a vector of values totalling to 1
            sumToK = 0

            for i in range(x.order[0]):
```

```
74                    sumToK += exp(x.matrixVals[i][0])
75
76            outVector = Matrix(x.order)
77
78            for i in range(x.order[0]):
79                outVector.matrixVals[i][0] = (exp(x.matrixVals[i][0])) / sumToK
80
81            return outVector # Returns vector and best index
82
83        def Derivative(self, x): # Derivative of the softmax function
84            for row in range(x.order[0]):
85                x.matrixVals[row][0] = x.matrixVals[row][0] * (1 - x.matrixVals[row][0])
86
87            return x
88
89   class NullActivation(Activation): # No activation function
90        def __init__(self):
91            pass
92
93        def Activation(self, x): # Returns the same values
94            return x
95
96        def Derivative(self, x): # Returns the same values
97            return x
98
99   class TanH(Activation): # TanH
100       def __init__(self):
101           pass
102
103       def Activation(self, x): # TanH mathematical function
104           for row in range(x.order[0]):
105               x.matrixVals[row][0] = tanh(x.matrixVals[row][0])
106           return x
107
108       def Derivative(self, x): # Derivative of TanH
109           for row in range(x.order[0]):
110               x.matrixVals[row][0] = (1 / (cosh(x.matrixVals[row][0]))) ** 2
111           return x
```

5.9   datalogger.py

```
1    import pickle, random
2    from heap import *
3
4    # Data Logger Class for logging information for analysis
5    class DataLogger():
6        def __init__(self, name, dataStructure, load=True): # Constructor Method
7            self.name = name
8
9            self.dataStructure = dataStructure
10
11           if load: # Loads Data if available but else create blank
12               self.dataPoints = DataLogger.LoadDataPoints(name)
13           else:
```

```python
            self.dataPoints = []

    def LogDataPointBatch(self, dataPoints): # Logs a Batch of Data Points
        for i in range(len(dataPoints)):
            self.LogDataPoint(dataPoints[i])

    def LogDataPoint(self, dataPoint): # Logs Data Point to Data Point list
        if self.CheckMatchStructure(dataPoint):
            self.dataPoints.append(dataPoint)


    def CheckMatchStructure(self, dataPoint): # Checks the given Data Point is in the correct Form
        if len(dataPoint) != len(self.dataStructure): # Throws error if lengths dont match
            raise Exception("Structure of Data Point does not match Collector Specified Structure")

        for i in range(len(dataPoint)):
            t1 = type(dataPoint[i]) # Type 1
            t2 = self.dataStructure[i] # Type 2

            if t1 == list and type(t2) != list: # Checks if list is all of same type
                flag = False

                for x in range(len(dataPoint[i])):
                    if type(dataPoint[i][x]) != t2:
                        flag = True
                if not flag:
                    continue

            elif t1 == list and type(t2) == list: # Checks list against list
                if len(dataPoint[i]) == len(t2):
                    flag = False
                    for x in range(len(dataPoint[i])):
                        if type(dataPoint[i][x]) != t2[x]:
                            flag = True

                    if not flag:
                        continue

            elif type(t2) == list: # Checks Multiple types against t1
                flag = False

                for x in range(len(t2)):
                    if t1 == t2[x]:
                        flag = True
                if flag:
                    continue

            else:                   # Checks Singular type against t1
                if t1 == t2:
                    continue

            raise Exception(("Type: {} != Data Structure Type: {} \n {}").format(t1, t2, self.dataStructure))
        return True

    def HeapSort(self, parameterIndex): # O(n*log n) sorting algorithm utilising a Heap Data structure, Sorts the
```

```python
            # 1000 Items -> 0.13
            # 10000 Items -> 12.1
            # 100000 Items -> 1646 or 27.4 minutes

            if type(self.dataStructure[parameterIndex]) == list: # Throw error if data structure element is List
                raise Exception("Cannot sort by structure: {}".format(type(self.dataStructure[parameterIndex])))

            elif self.dataStructure[parameterIndex] == bool: # Throw error if data structure element is Bool
                raise Exception("Cannot sort by structure: {}".format(self.dataStructure[parameterIndex]))

            sortedList = []

            heap = Heap(self.dataPoints, parameterIndex) # Creates a new heap

            while heap.Length() - 1 >= 0:
                sortedList.append(heap.RemoveTop()) # Loops popping and appending greatest element from Heap

            return sortedList

    def Select(self, searchIndex, searchContents): # Select a specified element with contents from data points
        returnedList = []

        for i in range(len(self.dataPoints)):
            if self.dataPoints[i][searchIndex] in searchContents:
                returnedList.append(self.dataPoints[i])

        return returnedList

    # Using Pickle to Save/Load
    @staticmethod
    def LoadDataPoints(file): # Returns stored dataPoints
        with open("DataLogger\\" + file + ".data", "rb") as f:
            temp = pickle.load(f)
        return temp

    def SaveDataPoints(self): # Saves dataPoints to a file
        with open("DataLogger\\" + self.name + ".data", "wb") as f:
            pickle.dump(self.dataPoints, f)
```

5.10   heap.py

```python
import math

# A Binary tree with the heap property, such that for every element, both children are <= to the parent
class Heap:
    def __init__(self, elements, indexIn): # Creates a new heap from a list of elements, and assigns an index for
        self.elements = elements
        self.index = indexIn

        self.Heapify()

    def AddElement(self, element): # Adds Singular element to Heap
        self.elements.append(element)
        self.SiftUp(len(self.elements) - 1)
```

```python
14
15      def SiftUp(self, elementIndex): # Sifts a singular element up the heap if possible
16          newElementIndex = elementIndex
17          isHeap = False
18
19          while not isHeap: # Repeat until is a heap again
20              parentIndex = math.floor((newElementIndex - 1) / 2)
21
22              if parentIndex == 0 and newElementIndex == 0: # Base Case
23                  isHeap = True
24
25              elif self.elements[newElementIndex][self.index] >= self.elements[parentIndex][self.index]: # Swaps el
26                  tempSwap = self.elements[parentIndex]
27                  self.elements[parentIndex] = self.elements[newElementIndex]
28                  self.elements[newElementIndex] = tempSwap
29
30                  newElementIndex = parentIndex
31              else:
32                  isHeap = True
33
34      def SiftDown(self, elementIndex): # Sifts a singular element down the heap if possible
35          rootIndex = elementIndex
36          isHeap = False
37
38          end = len(self.elements) - 1
39
40          while ((2 * rootIndex) + 1) <= end: # Repeat until the next root index is outside the dimensions of the h
41              childIndex = (rootIndex * 2) + 1
42
43              if childIndex + 1 <= end and self.elements[childIndex][self.index] < self.elements[childIndex + 1][se
44                  childIndex += 1
45
46              if self.elements[rootIndex][self.index] < self.elements[childIndex][self.index]: # Swapping elements
47                  tempSwap = self.elements[childIndex]
48                  self.elements[childIndex] = self.elements[rootIndex]
49                  self.elements[rootIndex] = tempSwap
50
51                  rootIndex = childIndex
52              else:
53                  break
54
55      def RemoveTop(self): # Pops top element off of Heap and returns it, heapifies the heap once removed
56          tempSwap = self.elements[-1]
57          self.elements[-1] = self.elements[0] # Swaps First and Last elements
58          self.elements[0] = tempSwap
59
60          returnElement = self.elements[-1] # Stores and deletes the final element
61          self.elements = self.elements[:-1]
62
63          self.Heapify() # Creates Heap again
64
65          return returnElement # Returns Top element
66
67      def Peek(self): # Returns root/top element
68          return self.elements[0]
```

```
69
70        def Length(self): # Returns size of heap
71            return len(self.elements)
72
73        def Heapify(self): # Returns values to a heap form, where all children of parents are less than or equal too
74            for i in range(math.floor((len(self.elements) - 1) / 2), -1, -1):
75                self.SiftDown(i)
```