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Maze Navigating Car

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# 1 Analysis

## 1.1 Problem identification

Robots that can navigate small or restricted areas are invaluable in modern day engineering. They allow project managers and developers to fully map out an area, potentially for development or removal of rubble. Other applications of self-learning algorithms apply to many other sectors of the world, such as car development with calculating the path of least resistance for airflow or calculating the shortest distance between stations in a city. The nature of self-learning algorithms means they can adapt and evolve in a large array of ideas.

To continue this trend, I will hopefully be exploring a small part of this in self driving cars. I will specifically be using a car to navigate a maze using several sensors to simulate the ability for cars to detect a path to follow. I will be exploring this by creating a small vehicle and attaching either a distance sensor or a colours sensor to follow a specific path, further expanding the path and even adding different routes.

Table 1 below presents a breakdown of the stakeholders who might be involved in such a project where a self-driving car would need to navigate and solve a maze.

### ***Table 1 - Identification of stakeholders***

|  |  |  |
| --- | --- | --- |
| **Stake Holder** | **Stakeholder Description** | **How will they use the system and why is it appropriate to them?** |
| Myself (The Designer) | I will be working directly on the project as the principal developer. Therefore, I will be responsible for the development, testing and main design of the system. | Will want the system to be:   * User-friendly – The users should be able to easily setup and use the system without confusion. * Efficient – The system should return the most efficient path each time. * Independent – The system should be able to navigate the maze without user interference. |
| Engineer (Final user) | An engineer will be using this project to navigate and survey small spaces (e.g., tunnels, service ducts). | Will want to the system to be:   * Robust – The system should not malfunction whilst operating. * Reliable – The system should consistently return the correct values.   Will want to have a remote connection possible with real time diagnostics. |
| Apprentice (Final user) | An apprentice will be using the system to learn how to use and manage the system. | Will want the system to be:   * Easy to learn – The system shouldn’t be too complicated for new users. * Simplistic – The system should be simple so inexperienced apprentices can use it. |

Table 2 below outlines the different computational methods that will be used during the production of the solution.

### ***Table 2 - Computational Methods***

| **Computational Method** | **Description of method** | **Explanation of suitability** |
| --- | --- | --- |
| Problem Recognition | Problem recognition is identifying separate problems that lie beneath the main problem being solved. This means identifying the nature and parameters of a problem. | The overall problem of the system is to navigate a maze with the most optimal path, whereas one underlying issue is identifying where the maze is and how to navigate it. Once this is complete, the data is then shared to the rest of the system and processed. |
| Back Tracking | Back tracking is using a previous save state to navigate back to once something has gone wrong or a dead end has been met. | The system will use backtracking when navigating the maze as when a dead end is met, the system will need to know how far back it needs to travel to return to a potential path. |
| Heuristics | Heuristics is where an approach that may not be the most efficient is developed in a reasonable time frame. This is used where there are many possibilities that need to be considered, with varying levels of success. | The system will need to roughly know when a path will become less efficient that another path, as this will save time in initially navigating the maze. |
| Performance Modelling | Uses maths and simulations to test and model the performance of an algorithm or system to understand the current abilities of the situation being tested. | Dijkstra’s algorithm needs to be tested and modelled before being used, as any potential errors could cause the system to fail, as well as any other subroutines. |
| Pipelining | Pipelining is where several subroutines are used in conjunction to perform a single task. This means the task will need to be separated into a series of smaller tasks. | The main search task will need to be broken down into several smaller steps that can be individually processed and executed. |
| Visualisation | This is where data and information are displayed used more graphical means to transfer knowledge, which improves the effectiveness of a presentation. | Since a graph will be used to store information, the option is always available to display the graph visually to understand different links. |
| Abstraction | Where any unneeded information is removed, leaving only the important information behind to work with. | The graph will be an abstracted form of the maze, as the physical properties will be ignored to concentrate on the specifics of the problem. |

## 1.2 Research

### 1.2.1 Existing similar solutions

#### 1.2.1.1 Example 1. AI in LEGO EV3 Maze-Driving Robot by Tony—K

##### 1.2.1.1.1 Goal of solution:

To navigate a maze, finding the optimal path, then executing the optimal path.

##### 1.2.1.1.2 Description of the Solution:

Multiple sensors are attached to a Lego EV3 car that can navigate a maze. The maze is first navigated inefficiently to crudely map out the maze and store the different directions it took. The directions are then converted into simplistic versions, reducing three instructions to one where possible. When placed back at the entrance, the car will navigate the optimal route back to the end.

##### 1.2.1.1.3 Features of the solution:

* Uses the left-hand wall following method
* Stores its path and eliminates dead ends
* Finds combinations in the movements in the maze and replaces them with simplified instructions
* Uses three different sensors as ev3 cannot manage more than one type of sensor
* Uses a 2-wheel chassis to move through the maze
* Uses a colour sensor to detect when the maze is finished

In table 3 below the positives and negatives of this solution are stated to gauge how effective the solution was.

##### *Table 3 - Positives and Negatives of the solution for Example 1:*

|  |  |
| --- | --- |
| Positives | Negatives |
| Efficient solution for solving the maze | Turning takes a large amount of space |
| Simple to reproduce for end users | Will be inefficient for larger mazes |
| Reduces the movements for optimal path | Does not allow for multiple ends |
|  | Does not allow for loops in the maze |

Figure 1 below shows an extract of the code used to program the solution. The language used is based on drag-and-drop principles, so would not be suitable for my solution.

##### *Figure 1 - A sample of code from solution Example 1:*

Graphical user interface, application, table, Excel

Description automatically generated

#### 1.2.1.2 Example 2. Design of a maze solving robot using Lego MINDSTORMS by B.J.S van Putten

##### 1.2.1.2.1 Goal of solutions:

To use LEGO Mindstorms RCX 2.0 to navigate a maze made of black on white line patterns.

##### 1.2.1.2.2 Description of the solution:

Uses the Mindstorm RCX 2.0 unit to explore the capabilities and restrictions of Lego hardware by developing a maze solving robot. The program designed will be able to efficiently navigate different maze scenarios and optimise a route through the maze, pushing the limits of the computing power of the RCX 2.0 unit. This identified the different restrictions of the unit and delivered solutions to the problems.

##### 1.2.1.2.3 Features of the Solution:

* Uses a programming language call NQC (Not Quite C)
* Uses the follow the wall method to navigate the maze.
* Uses two motors set up to be fully rotational to move.
* Uses a light sensor to understand where the maze is.
* Simple program outline to follow.
* Efficient for the capabilities of the RCX 2.0 unit
* Optimises the information gathered in the first run.

##### *Table 4 - Positives and Negatives of the solution for Example 2:*

|  |  |
| --- | --- |
| Positives | Negatives |
| Simple Algorithm to follow and adapt | Unable to accurately detect dead ends and 90 degree turns |
| Once the track is solved, can solve it efficiently | Battery of the robot can reduce accuracy |
|  | For much larger mazes, the RCX will run of memory |
|  | Cannot be easily reproduced |

##### 1.2.1.2.4 Code from the solution

The code presented below is an extract of the code used in the solution. This code is accompanied by an image in the solutions. See figure 2.

|  |
| --- |
| Right:  A visualisation of the solution’s algorithm:  If (on black line) {  Forward (left motor);  Off (right motor);  }  Else (on white) {  Forward (right motor);  Off (left motor);  } |

Figure 2 below shows an image representation of the method used to search the maze.

##### Diagram Description automatically generated*Figure 2 – A sample image of the tracking system in solution Example 2*

### 1.2.2 Features of the proposed solution

#### 1.2.2.1 Initial Concept of my solution considering my research.

My initial concept will be using the EV3 unit to follow a maze comprised of black lines on white background.

There are two different algorithms that exist that can navigate from A to B in a maze. These are presented in Table 5 below under the headings ‘Dijkstra’s’ and ‘Floyd’s’ algorithms respectively.

##### *Table 5 – Two algorithm approaches.*

|  |  |  |
| --- | --- | --- |
|  | Dijkstra’s | Floyd’s |
| Description | A simple algorithm that will compute the shortest distance from a single vertex to any other vertex | A complex, multistage algorithm that will compute the shortest distance from any vertex to any other vertex |
| Positives | Simple to code the algorithm  Much more efficient to run | Simple to implement using arrays  Returns the shortest Hamiltonian cycle |
| Negatives | Cannot be used when multiple goals must be achieved | Uses a large amount of memory |
| Efficiency |  |  |
| Suitability | Is suited towards smaller mazes with only a single goal | Is suited towards larger mazes where multiple goals must be achieved |

##### 1.2.2.1.1 Final comparison between algorithms

Due to its much more efficient nature, and not needing to compute the distance between many goals, I will be using Dijkstra’s algorithm to find the shortest path through the maze. This is different to the previous solutions, as they both use the left or right-hand wall hugging method before simplifying their results. My solution will be more durable than the other solutions, which have a 20% success rate (from solution 2).

##### 1.2.2.1.2 Sensor configuration

I have chosen to use a single colour sensor to navigate the maze for now. This is because it will be much more efficient to build and modify the maze compared to physical walls. This also allows me to calculate the result of Dijkstra’s algorithm beforehand to ensure the algorithm is working as intended. Also, this method is much more cost effective than other methods such as up-right walls, allowing me to develop the algorithm and work out any flaws.

##### 1.2.2.1.3 Software choice

Furthermore, I will be using EV3DEV software and OS to run my code. This allows me to use Bluetooth to communicate with the car and upload my program with ease. This means I am using MicroPython to program and control the car, as I am familiar with python and will be able to develop my code using Visual Studio Code.

The user will be able to interact with the car using a GUI interface located on the LCD display of the EV3 unit.

### 1.2.3 A brief explanation of the LEGO MINDSTORMS EV3 unit

Since I have decided to use an EV3 set to execute this project, I will explain the aspects of the EV3 that are useful in this project, and some that limit the potential of my final product. I will be further comparing the EV3 to a previous unit and stating why features of the EV3 are more suited to my project.

The specifications of the EV3 and NXT units are presented in Table 6 below.

#### *Table 6 – EV3 and NXT specifications*

|  |  |  |
| --- | --- | --- |
|  | EV3 | NXT |
| Display | 178x128 pixel | 100x64 pixel |
| Main Processor | 300 MHz | 48MHz |
| Main Memory | 64MB RAM, 16MB flash | 64KB RAM, 256KB flash |
| Extra Features | USB host port, Wi-Fi (through dongle), BT | BT |
| Ports | 4 sensors, 4 motors | 4 sensors, 3 motors |
| weight | 215g | 213g |

#### 1.2.3.1 Comparison of the EV3 and NXT and final choice

As a result of the low RAM, the limited CPU speed and smaller screen resolution the NXT is not as suitable for this project as the EV3, however if an OS allows EV3DEV code to be run on the NXT, then if the algorithm is efficient enough then the code should still run on the NXT.

As for the EV3, the larger RAM and much faster CPU speed are definite bonuses, as well as the increased screen resolution. The larger RAM will allow me to store many more data values in a list or an array, allowing the car to perform the search on larger mazes. The fast CPU means I can run many operations per second without the EV3 slowing down considerably, meaning that the maze can be traversed quicker, and the sensors will be more accurate in their timings. The screen size, whilst better than the NXT, is still very small, and will only allow me to have 4 different lines with a readable font, so navigation will have to be optimised to account for this.

The use of LEGO allows the project to be easily expandable and if any aspect does break then parts can be easily replaced. However, if the concept of this project were to be applied to a real-life scenario, then a much sturdier and durable option should be considered as LEGO may not be acceptable in some circumstances.

### 1.2.4 Limitations of my proposed solution

|  |  |  |
| --- | --- | --- |
| Limitation | Explanation | Justification |
| Storage Space | The EV3 has a limited amount of permanent storage which programs can be stored in, so programs and data must be small. | Due to the potential complexity of stored data, and that a large amount of it may be stored, storage space could run out quickly. |
| Memory Space | The EV3 has a limited amount of RAM which can be used when running, so any live data needs to be small. | Due to the potential complexity of temporary data, and that a large amount of it may be stored, memory space could run out quickly, leading to a system crash. |
| Colour Sensor | The colour sensor can only accurately detect certain colours as there is a very limited spec for a Lego sensor. | The colour sensor for the EV3 needs light to function correctly, and since light can be interfered with by the sensor itself, errors may arise where the colour can’t be identified. |
| Realtime Maintenance | The code may need maintenance when in use, and the system could corrupt over time. | The system will overtime become more and more corrupt, and so will need to be close to a computer to re-flash an OS image onto the SD card. |

## 1.3 Requirements

### 1.3.1 Software requirements

**Brickman OS** – This is the OS that is loaded onto an SD card so the EV3 can understand and interpret the code, as well as interfacing with the motors.

**Visual Studio Code** – Used to edit and load the code onto the car

**EV3Dev extension** – This is the extension that communicates with the car to transfer the code to the car

### 1.3.2 Hardware Requirements

**EV3 Brick and base set** – This will be what the car is built from, so will be needed to reproduce the final product.

**Micro SD Card** – The Brickman OS will need to be installed onto some medium for the brick to understand. The EV3 unit has a built-in micro-SD card reader which can be booted from.

**A Maze or path to follow and solve** – The car must have something to follow and solve to work as intended.

**A computer with Bluetooth or USB** – This allows for the program to be loaded onto the car

### 1.3.3 Stakeholder requirements

Table 7 below discusses the different requirements that are dictated by the design of the system.

#### *Table 7 - Design*

|  |  |
| --- | --- |
| Requirement | Explanation |
| Simple Menu | The menu must be simple so that the users can easily understand how to navigate and use it |
| Fully independent | The car being fully independent, past pressing the “run” button, means that it will allow operation to be hassle free |
| Simple Instructions with screenshots | This allows users to understand each function of in the menu |

Table 8 below discusses the different requirement surrounding the functionality of the system.

#### *Table 8 - Functionality*

| Requirement | Explanation |
| --- | --- |
| Use of the EV3 buttons to interact with the software | The software on the EV3 unit will require that buttons of the unit be pressed to begin operation. This allows the user to navigate the different menus and run different subroutines |
| Easy setup from box to final product | The setup process must be easy for users to recommend and continue to use the product in mass and to deploy remotely |
| The ability to remote into the EV3 unit | The ability to receive information and see the EV3 screen remotely will allow for the users to actively see the state of the car |
| The ability to change the speed of the motors | Users may wish to change the speed as the car is traversing different areas, so be able to change the speed will be useful |
| Different menus for stats and settings of the car | The user may wish to see the different values that the EV3 unit has stored or is using to allow for more in-depth debugging or logging |

Table 9 below discusses the hardware and software requirements for the project.

#### Table 9 - Hardware and Software

|  |  |
| --- | --- |
| Requirement | Explanation |
| A computer with USB or Bluetooth | This will allow the user to load the code and OS onto the EV3 brick and interact with it once the code is loaded |
| Brickman OS image | This is the OS that will be used to understand and process the code that will move the car |
| Micro SD Card | This will hold the Brickman OS image as well as any code loaded onto the car |
| Visual Studio Code with EV3DEV | This will be needed to load code from the computer onto the car. However, this can be avoided by creating a premade OS image of Brickman that includes all the code which can be loaded directly onto the car’s storage |
| Lego EV3 Unit | This will be the main ‘brain’ of the car. All algorithms and subroutines will be processed using this. |

## 1.4 Success Criteria

Table 10 states the chosen success criteria for the project and states the conditions under which the criteria have been successfully reached.

### *Table 10 – Success Criteria*

|  |  |  |  |
| --- | --- | --- | --- |
| Criteria No. | Criteria | Evidence of completion | Justification |
| 1 | Easy to read Menu titles and font (HCI) | The Menu title can easily be read from the screen. | For the system to be used, the system needs to be usable by any user. This means the Menus need to be user friendly enough for anyone to understand how to navigate them. |
| 2 | Easy to understand how to navigate the menu system | There will be a visible and understandable method to navigating the menu system. | The navigation of the system needs to be easy as this will allow the user to fully use and understand the menus. This means that the user can feel confident when the system is being used in a practical scenario. |
| 3 | Very little text displayed in the menu | Displayed text will be kept concise and to a minimum. | The menus can’t be too cluttered, as this will take away from the UX. This would mean that the user wouldn’t be able to use the system efficiently and would detract from the ability to test the system. |
| 4 | Algorithm that can calculate a path within a maze consistently and efficiently | The algorithm will be able to calculate a route through the maze of minimal weight. | This is needed for the car to function and find the shortest path through any maze. Without it, the car would take a much longer and inefficient pat compared to the best one. |
| 5 | Algorithm that can track out a maze efficiently and consistently. | The algorithm will be able to navigate and map the maze, being able to reach the end every time. | For the system to be robust and usable, the algorithm used to initially navigate the maze needs to map out the maze with repeatable accuracy and precision, returning the same result almost every time. Naturally, some errors will occur, but if the car can recover from them, then the usability will be greater and the system more robust. |
| 6 | Storage efficient object storing algorithms | Objects stored in files will take up minimal space on the SD card. | The system will have limited space, so any files that are made every time the system is ran (e.g. graphs) will start to take up enough space to fill any SD card. This means some time of compression system is needed to store the files which needs to be efficient. |
| 7 | RAM used efficiently during operation | The running code should use no more than 32MB of the available memory. | Since the system will have limited RAM, and a large maze could potentially use a large amount of RAM, the way in which temporary files and objects are stored and created needs to be efficient. This means each object will need a minimal number of properties. |
| 8 | Algorithms will be quick to process data and output information | The speed of the algorithms will be consistent with the same size data sets. | Since the processor will be limited in processing power, and the program can only be ran single threaded, any algorithms need to be reasonably consistent and efficient. This would mean the entire system is performing optimally. |
| 9 | Clear and abstracted user guide with pictures | Annotated screen shots of the guide. | There needs to be an easy-to-read user guide for new users to be taught how to use the system. This will include how to use each menu and what each subroutine will do and will be annotated to visually explain each menu to the user. |
| 10 | The ability to stop the program | A button that can turn off the EV3. | The car’s system will need to be exited once the user has completed their intended operation. |
| 11 | The ability to remotely read data from the system | Screen shots of the remote system capability | The ability to remote control and view the system information will allow the car to be used in a wide variety of locations and will allow for the log files to be accessed easily. This will improve the UX and the ability to understand what might be occurring during errors. |
| 12 | The ability to remotely write data to a config file in the system | Screen shots of the file and the remote system capability. | This will allow for the user to easily change any variables affecting the cars performance (speed, logging type, etc.) remotely without directly accessing the data in the code or the car. |
| 13 | The ability for the car to be stand alone | Tests and test results to show that car can function alone. | The car needs to be able to detach fully from a computer and report simple information back to the user through the built in display. |

# 2 Design

## 2.1 Overview of system

The system will be broken down into several different aspects that comprise the UI in the front end and the algorithms in the back end. Each diagram is an abstraction and decomposition of the system, allowing me visual aids with my programming.

### 2.1.1 System Navigation Chart

Figure 4 (below) is a visual representation of the navigation system for the user. It describes the different elements of the UI and how each one will interact with the user.

This chart is split into two keys sections, i.e., Car Menus AND Desktop Menu/UI. The initial sub-section, “Car Menus”, presents the four key visual components of the car’s user interface (i.e. visible to the user). The main menu sub-section presents the key visual aspects of the desktop user interface.   
Each red subsection implies that a menu will be interacting with the lower sections. Each green subsection implies a subroutine will be executed once the user interacts with it, returning the previous menu once completed.

The chart is broken down in such a way that allows me to visually aid my programming, so the structure of the menu system stays intact and robust. The chart is an abstraction of the high-level aspects of the system.

**Justification**

The chart breaks down the system into a clearer format for the client to understand the links between the different menus. This means the client can more clearly visualise the final navigation system.

#### ***Figure 4 – System Navigation Chart***

Diagram

Description automatically generatedKey: Menu, Subroutine, Misc.

### 2.1.2 System Layer Diagram

The diagram in figure 3 is a visualisation of the flow of data between subsections of the system, with each layer representing a different type of subsection. This chart allows me to visually see a decomposition and abstraction of the system including subroutines and data structures so I can quickly implement the different areas of my project.

Figure 3 also displays the interaction of the subsystems between different layers, such as the Main Menu leading to individual screens, each with a unique set of subroutines. These subroutines then interact with the data structures and variables within the code, and how one subroutine can interact with another object in the system.

**Justification:**

This diagram visually decomposes the different high level and low-level aspects of the system, and shows how they can interact with each other, allowing a potential client to fully understand the importance of each component in the system.

Chart, diagram

Description automatically generated***Figure 3 – Layer Diagram***

## 2.2 Algorithms and further breakdown

### 2.2.1 Car State Diagram

Figure 5 visually maps out each state that the car’s system can be in, showing the different paths that the state may follow during operation. The right section of the diagram shows the changes in state when the “execute subroutine” path is taken, with the left section of the diagram showing the changes in state when the “search subroutine” path is taken. The diagram enables me to accurately detail the general actions taken during a subroutine and how the car should behave at certain points.

This diagram shows the possible states that can occur during the operation of the system, and the transition between these states.

**Justification:**

Figure 5 provides a clear and concise visual representation of the system behaviour during operation, making it easy for a potential client to understand how this system will work. The diagram allows for the representation of complex behaviour in an easy to understand and communicate way.

#### ***Figure 5 – State diagram***



### 2.2.2 Dijkstra’s Algorithm Flow Chart

#### Diagram Description automatically generated***Figure 6 – Dijkstra’s algorithm Flow chart***

*This section means the algorithm will iterate through all the vertices until the end node is permanent. This means all the different paths are explored and their lengths compared to find the best one.*

*This section loops through each of the possible 4 directions that arc could be, and if the current weight of the vertex is more than the new weight, than the weight is updated.*

Figure 6 is an abstraction of the widely used Dijkstra’s algorithm used for network traversal. The algorithm used is an efficient and robust algorithm, which means the system will be able to run even with minor flaws in the detection algorithm or the environment. The structure of the algorithm allows for either recursion or iteration to be used, giving a flexible approach in its coding.

### 2.2.3 Search Algorithm Flow Chart

Figure 7 is an abstraction of the search algorithm that is going to be used. The search algorithm is used to create the initial network of corners used to represent the maze so the car can solve a path for it. The search algorithm involves different techniques to ensure that the system will be able to detect if there is a corner or the car has simply missed the line. This allows the system to remain robust and efficient, whilst also being reliable.

#### ***Figure 7 – Search algorithm flow chart***

*This subroutine checks if there is a black line between start\_point and end\_point. The 2 variables represent angles of a circle around the car. Positive and negative .*

### 2.2.4 Car’s Menu Flowchart

#### ***Figure \_\_\_ - Menu Flowchart***

*This section handles the user inputs each time the screen refreshes. The up and down buttons move the pointer, and the centre button selects the current item.*

## 2.3 Class layouts



Figure \_\_\_ shows the different classes involved in the project with their interactions. Each class has its name in red, properties in green and methods in blue. A “+” denotes a public attribute or method and a “-” denotes a private attribute or method.

The main class in this project is called “Main”. This allows me to centrally manage all the different objects through one object. Any “Main” object will have several different “Menu” objects, each containing the information for the menus displayed onto the EV3 screen. Along with this, a unique “Car” object will be created within the runMain () method of the “Main” object. This object is for storing all the information relevant to the operation of the car, such as the EV3 brick, the motors, the sensors, and several subroutines.

The “Car” object will have a “Graph” object which is made up of many “Vertex” type objects. Each “Vertex” object will represent a different corner or dead end. The “Graph” object has the Dijkstra’s algorithm as a public method, as the code in the “Car” object will be able to execute this.

## 2.3 Variables, Classes, and Data Structures

### 2.3.1 Descriptions

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Appears in** | **Description** | **Justification** |
| Start\_point | Search Algorithm | States the angle the car should turn from | Allows modularity in the system as a subroutine can be used |
| End\_point | Search Algorithm | States the angle the car should turn to | Allows modularity in the system as a subroutine can be used |
| Increment | Search Algorithm | States the angle the car should turn before checking for a line. | Allows for a variable increment rather than fixed |
| Dir | Dijkstra’s | A counter used to check each direction of a vertex | Allows for looping using an integer value, so the system will be more efficient |
| Weight from start | Dijkstra’s | The weight of a vertex from the start vertex in the maze | Allows the priority queue to be stored, and is used to calculate the shortest path |
| Start label | Dijkstra’s | The label of the start vertex in the maze | Used to backtrack through the network to find the final path the car must take |
| End label | Dijkstra’s | The label of the final vertex in the maze | Used to tell Dijkstra’s algorithm when to stop |
| Weight of arc | Dijkstra’s | The weight of an arc connecting 2 vertices | Needed for updating the weight of each vertex in the network |
| Permanent | Dijkstra’s | A Boolean to determine if a vertex has a permanent label | Will help to determine if a vertex has been made |
| Pointer | Menu Algorithm | Used to determine where the arrow should point in a menu | A fixed value won’t allow me to move where the pointer arrow is |
| IsActive | Menu Algorithm | Used to loop the menu output | Allows me to easily stop the main loop from anywhere inside the class, and recursion is not a viable replacement for this loop |

|  |  |  |  |
| --- | --- | --- | --- |
| **Classes** | **Appears in** | **Description** | **Justification** |
| Vertex | Search Algorithm, Dijkstra’s | Used to store information about corners | Gives the system modularity and consistency by using a single class to represent a repeating occurrence. |
| Graph | Search Algorithm, Dijkstra’s | Used to store and process all vertices in the maze | Creates a simple class that can store vertices consistently |
| Car | Search Algorithm, Menu Algorithm | Used to interact with the motors and sensors | Allows me to have validation and consistency in the way the motors and sensors behave, as well as store all the movement subroutines |
| Main | Menu Algorithm | Stores the runMain () subroutine | Python does not include a “main” function, so this class allows me to mimic techniques from other languages such as C# |
| Menu | Menu Algorithm | Stores the information needed to output a menu | Creates an easy template to fill in a menu. This means the code is modular |

|  |  |  |  |
| --- | --- | --- | --- |
| **Data Structures** | **Appears in** | **Description** | **Justification** |
| Graph | Search Algorithm, Dijkstra’s | An abstraction of the maze using corners as vertices and arcs as paths on the ground | Abstracts any unnecessary information from the maze, allowing for an easy understanding of the maze. Also, Dijkstra’s requires a graph to work on |
| Priority Queue | Dijkstra’s | A queue that is first sorted by some value (weight from start), before being enqueued or dequeued | Needed for Dijkstra’s to determine which vertex to visit next. |
| List | Dijkstra’s | A simple dynamic data structure that will store all the permanent vertices | Needed to separate the permanent vertices from the other vertices without deleting them completely |
| Log Files | Logging | Some data will be stored in log files. | Will be useful when trying to debug errors in the system. Also, will be used for storing serialized objects through pickle. |

### 2.3.2 Validation

| **Variable** | **Description of Validation** | **Justification for validation** |
| --- | --- | --- |
| Start\_point | Integer between -360 and 360 | The angle of turning may need to be negative, so a negative lower bound is needed |
| End\_point | Integer between -360 and 360 | The angle of turning may need to be negative, so a negative lower bound is needed |
| Increment | Integer | As turning in floats will be difficult to get precise |
| Dir | Integer between 0 and 3 | As there are only 4 directions Dijkstra’s needs to look in |
| Weight from start | Positive float greater than weight before | The replacing weight should be less than |
| Start label | Unique | If there is a label applied to more than one vertex, than Dijkstra’s won’t work |
| End label | Unique | If there is a label applied to more than one vertex, than Dijkstra’s won’t work |
| Weight of arc | Positive float value | Arc weights can’t be negative, as they represent distances |
| Pointer | Positive integer between 0 and 3 | There are only 4 options in a menu, if pointer goes beyond 3, the arrow pointer on screen will be too low |

## 2.4 User Interface

The user interface will be split into two sections, visible on the car and visible on a desktop.

### 2.4.1 Car’s UI

Figure 8 contains the design choice for the 4 different menus that are going to be active on the car. The user interface of the car must be simple and user-friendly, which is demonstrated in the above diagrams. Due to hardware restrictions, a maximum of 4 lines can be printed onto the screen at any time. This does however contribute to the overall user experience as the user is not overwhelmed by choices. Each menu will have a title to tell the user where they are, and up to 4 different operations they can execute, including exiting back the main menu or exiting the program.

#### ***Figure 8 – Car UI***

Diagram

Description automatically generated

### 2.4.2 Desktop UI

Figure 9 is a general abstraction of the proposed desktop user interface. The Desktop UI has all the features of the car’s UI in one window, allowing for the user’s to easily navigate the functionality of the car. The diagram is useful as it means I can visualise the desktop experience.

The desktop UI will have all the same features of the Car’s UI laid out in one window, allowing the user to see everything. The UI here will be split into two distinct sections, one being monitoring, and the other be interactive.

The monitoring section will display all the information the car is sending to the computer, while the interactive section of the display allows for the user to change aspects of the cars settings and to run subroutines from the desktop.

#### Table Description automatically generated with low confidence***Figure 9 – Desktop UI***

### 2.4.3 Usability Features

|  |  |  |  |
| --- | --- | --- | --- |
| Feature ID | Description | Explanation | Justification |
| F1 | Make text large and readable with clear indication and font to aid the UX. | The user needs to be able to read and understand the menu titles and text to navigate the system. | Without this, the user experience would not be useful. The user would easily get lost and not be able to use the system. |
| F2 | Easy to understand menu structure to help guide the users. This will use principles from HCI. | The user needs to navigate to the correct the menus and subroutines. An easy to learn menu structure will help the learning process. | Without this, the system cannot be navigated easily, making it hard for the user to use the system in any capacity. |
| F3 | Easy to find instructions on how to use the system to allow for the user to understand the functionality of the system. | If the user does not understand the system, they should be able to access an instruction manual to | Without this the user would be left to search the system to find out what each button does. This would reduce the usability of the system. |
| F4 | Visibility of current system state on screen to keep the user updated on how the system is functioning. | The user will be able to view the current system status to identify when errors occur and to understand what the system is currently doing. | Without the visibility of system state the user will be clueless as to what is happening. This will increase the usability of the system. |
| F5 | Error catching and prevention which reports any errors to the user with useful information. | The system should be able to catch any errors and return them to the user with any necessary information and with potential advice. | This means the user more accurately understands when an error occurs and what the error is. This improves usability. |
| F6 | Any icons match the real-world design are displayed on the screen in an appropriate fashion to aid the user. | This will mean the user can visually understand the current component being accessed/used, allowing a constant stream of information to be given to the user. | The usability of the system will depend on how well the user understands the different functions of the system. By using visual icons that link with the currently active component, the user can quickly understand what is currently happening. |
| F7 | Text is colour coded with a system wide style to create a uniform UX. | This means the user can distinguish between different options quicker. | The UX is improved when colours are used to differentiate between options on a screen. |

## 2.5 Sample Code

### 2.5.1 Menus

Since I have been testing the Menus in python to gauge how possible the solution is to produce, I have coded a simple menu program with only one menu to navigate. This will allow me to expand from this example. This is not pseudocode as pseudocode has a very limited approach to importing specific libraries with specific syntax, and since the syntax is different between python and pseudocode, it would not make sense to use pseudocode whilst working with the import section of the code.

#### ***Figure 10 – Pseudo code for a single menu***

|  |
| --- |
| Import required libraries and initialize objects  # Subroutines  def Run():  # Run the car straight for 1000mm and wait for 1 second  Clear the screen  Print "Run is running" on the screen  Move the car straight for 1000mm  Wait for 1 second  def LeftRight():  # Turn the car right and left, each for 90 degrees and wait for 1 second  Clear the screen  Print "Right is running" on the screen  Turn the car right by 90 degrees  Wait for 1 second  Clear the screen  Print "Left is running" on the screen  Turn the car left by 90 degrees  Wait for 1 second  def IDLine():  # Follow the black line until it ends  Clear the screen  Print "IDLine is running" on the screen  Repeat until the color sensor detects black color:  Print the color detected by the color sensor on the screen  Wait for 0.001 seconds  def FindLine():  # Find the black line and stop  Clear the screen  Print "FindLine is running" on the screen  Wait for 1 second  # Create objects  Create objects for EV3Brick, screen, buttons, motors, drivebase, and color sensor  # Create menu  Create a list of menu items  Create a list of menu items' lookup functions  # Set initial state  Set the current menu and lookup function  Set the pointer to 0  Set the car's straight speed to 200  # Main loop  Repeat forever:  # Output to screen  Clear the screen  Print menu items on the screen with cursor for the selected item  Print the menu title on the screen  # Navigation  If DOWN button is pressed:  Move the cursor down  Wait for 0.3 seconds  If UP button is pressed:  Move the cursor up  Wait for 0.3 seconds  If CENTER button is pressed:  Call the lookup function of the selected menu item  If an exception occurs, print the exception message on the screen and wait for 1 second  Wait for 0.1 seconds |

### 2.5.2 Search Algorithm

The pseudocode in figure 11 is used to navigate the maze and map each corner to a vertex, creating a graph for Dijkstra’s algorithm to use.

#### ***Figure 11 – Pseudocode for the search algorithm***

|  |
| --- |
| SUB Search()  SUB CheckLine(int start\_point, int end\_point)  Increment = (end\_point - start\_point)/10  Car.TurnTo(start\_point)  current\_angle = start\_point  DO WHILE current\_angle < end\_point:  Car.turn(increment)  IF ColourSensor.Colour() == "Black" THEN  RETURN TRUE  END IF  END WHILE  RETURN FALSE  END SUB  Car.State = "Searching"  DO WHILE Car.State == "Searching"  Car.Forward()  IF CheckLine(0,0) THEN # if the line is straight ahead  PASS  ELSE IF CheckLine(-45,45) THEN # if the line is roughly ahead  PASS  ELSE IF CheckLine(45, 135) THEN  Car.Graph.AddVertex()  Car.Graph.Vertex.PathD2 = TRUE  Car.Graph.Vertex.PathD1 = TRUE # adds a right arc to the vertex  ELSE IF CheckLine(-135, -45) THEN  Car.Graph.AddVertex()  Car.Graph.Vertex.PathD2 = TRUE # adds a backwards arc to the vertex  Car.Graph.Vertex.PathD3 = TRUE # adds a left arc to the vertex  ELSE IF CheckLine(135, -135) THEN  Car.Graph.AddVertex()  Car.Graph.Vertex.PathD2 = TRUE # adds a backwards arc to the vertex  END IF  END WHILE  END SUB |

### 2.5.3 Dijkstra’s

In figure 12 I have coded Dijkstra’s algorithm. This will take a graph input and output the shortest path from the start node to the end node with labels. This code does require the specific objects created elsewhere in the program, so they will need to be fully implemented before this code can start being made.

#### ***Figure 12 – Dijkstra’s algorithm pseudocode***

|  |
| --- |
| SUB Dijkstras(Graph)  Visited = []  Unvisited = []  Unvisited[0] = Graph.List[0] # adds the first vertex to the unvisited list  Unvisited[0].Cost = 0  start = Unvisited[0]  FOR i=1 to Graph.List.Length  Unvisited[i] = Graph.List[i]  Unvisited[i].Cost = Math.inf # sets the verticies cost from start to infinity  END FOR  DO WHILE Unvisited.Empty = FALSE  Unvisited[0].perm = TRUE # makes the current Vertex permanent  currentVertex = Unvisited[0]  dir = 0  DO WHILE dir < 4 # check each direction  IF currentVertex.dirList[dir].cost > currentVertex.cost + currentVertex.dirCostList[dir] THEN  FOR EACH item IN Unvisited  IF item.label == currentVertex.dirList[dir].label THEN  item.prev = currentVertex.label  item.cost = currentVertex.cost + currentVertex.dirCostList[dir]  END IF  END FOR  END IF  END WHILE # end dir check  Visited.add(Unvisited[0])  Unvisited.delete(0)  Main.Sort(Unvisited) # sort using bubble sort  END WHILE  # Return the final path taken to get to the end  path = []  currentLabel = Graph.end.label  DO WHILE currentLabel != start.label:  path.add(currentLabel)  FOR EACH item IN Unvisited  IF item.label =  END WHILE  END SUB |

## 2.6 Log File Handling

For my log file handling and data storage I will be using Pickle, a module that allows for objects to be serialized and stored as text, then retrieved in the future from a simple text file. This will allow me to store the entire graph data structure in a text file, if not multiple graphs. From this, I can simply import the graphs and compare whilst Dijkstra’s algorithm is running.

For the log files, I will be using the integrated python file manager, and simply writing lines of text with a time stamp to indicate when tasks have been successfully completed. If tasks were to fail, I can use a “Try Except” statement to catch any errors and store them as a string. Figure 13 is an example of what the log file might look like, although the design might change to better suite different situations.

### ***Figure 13 – Log file example***

|  |
| --- |
| [00:00:00] Boot  [00:00:01] Main Initialized  [00:00:02] Car Initialized  [00:00:03] Graph Initialized  [00:00:04] Menus Initialized  [00:00:10] User Input – Menu Change  [00:00:16] User Input – Variable Change  [00:00:30] User Input – Run All Sub  [00:07:26] Sub Fin – Run All |

## 2.7 Testing During Development

During development certain key aspects of the coded solution must be tested, such as loops and subroutines. Several tests must be developed to ensure that the code is working as intended and returning the correct result using the correct method.

Each test is **justifiable**, as each part has been decomposed and abstracted into its smallest components. Hence, each test ensures that each individual part of the system is working. These tests allow me to ensure that even if the correct data is output, that the correct algorithm is occurring in the code. This means that the system will be more robust if the user inputs data incorrectly.

### 2.7.1 Dijkstra’s Algorithm

|  |  |  |  |
| --- | --- | --- | --- |
| Test ID | Description | Test Data | Expected Result |
| 101 | The vertex classes’ ability to instantiate and update its adjacency through the graph class. | Labels and weights are passed in. Then, the list will be iterated through, and vertex attributes are output. | All the vertex values are unchanged from their inputs. |
| 102 | Dijkstra’s loop. The shortest path is calculated. | Some vertex values with labels and weights. | The algorithm should return the shortest path from “A” to the end, as well as the total weights of each vertex. |
| 103 | Find vertex subroutine. | Vertex labels are passed in, with a network list already built | The subroutine should return the vertex object with the specified label. |
| 104 | Bubble sort algorithm | Values are passed into the bubble sort. | The list outputted should be in ascending order |

### 2.7.2 Search Algorithm

|  |  |  |  |
| --- | --- | --- | --- |
| Test ID | Description | Test Data | Expected Result |
| 105 | Check line algorithm. This is the algorithm responsible for following the line. | The car placed down and will trace out the nearby adjacency of a vertex. | The car should be able to navigate the maze using the right wall. |
| 106 | Add vertex subroutine from graph class. | The car will be placed on a simple maze and trace it out. | The graph should be populated with vertexes, each with weights and adjacent vertexes. |
| 107 | Simple maze navigation without creating any vertices. Just looking at the consistency of the search algorithm. | A simple maze, increasing in vertexes each time the test is ran. | The car should be able to navigate a maze completely without adding any vertices. |

### 2.7.3 Car’s Menu Algorithm

|  |  |  |  |
| --- | --- | --- | --- |
| Test ID | Description | Test Data | Expected Result |
| 108 | The draw subroutine of the menu handles how the menu’s attributes are visible on the screen. | A menu object should be created with a name and titles. | The screen should be evenly proportioned with none of the text off the screen. |
| 109 | Pointer movement is important for the user to interact with the system. | The buttons on the EV3 brick will be pressed. | The visual pointer should increment and decrement with each press of the respective buttons. |
| 110 | Menu’s linking will be important with the user experience. | Menus should be created and linked together. The menu systems should then be navigated. | The screen should update with each menu change, the pointer should return the 0. |

## 2.7 Post Testing

Each section of the solution must be testing using iterative methods to test whether they are suitable. This means that several tests must be designed and reviewed to ensure that the output shows that the section meets the success criteria.

### 2.7.1 Menu Testing

Both types of menus need to be tested to ensure that they are suitable for the end users.

#### 2.7.1.1 Car’s UI

Table 11 lays out the different tests that will be used to determine whether the car’s UI has been successful.

##### Table 11 – Tests for the Car’s UI

|  |  |  |  |
| --- | --- | --- | --- |
| Test ID | Description | Test Data | Expected Result |
| 01 | The EV3 brick will be handed to several people. They will be asked to navigate to and indicate towards different subroutines within the menu. | A random list of subroutines to find. | That the person taking part in the test can navigate to every subroutine in a random list. |
| 02 | Many buttons will be pressed to test if the program can take many inputs at once without freezing. | Button inputs. | The system should not slow down at all. |
| 03 | The pointer will be increased past 4. | - | The system should remain operational when the pointer is between 0 and 3 |
| 04 |  |  |  |

#### 2.7.1.2 Desktop UI

Table 12 lays out the different tests that will be used to determine whether the Desktop UI has been successful.

##### Table 12 – tests for the Desktop UI

|  |  |  |  |
| --- | --- | --- | --- |
| Test ID | Description | Test Data | Expected Result |
| 05 | The usability of the UI must be tested. A list of subroutines will be given, and the user must point them out. | A random list of information to find. | All the item on the list can be found within a few seconds. |
| 06 | Many buttons pressed to test how the program can deal with many inputs | Buttons inputs | The system should remain stable. |

### 2.7.2 Search Algorithm Testing

Table 13 lays out the different tests that will be used to determine whether the Search algorithm has been successful.

#### Table 13 – Tests for the search algorithm

|  |  |  |  |
| --- | --- | --- | --- |
| Test ID | Description | Test Data | Expected Result |
| 08 | Car must navigate a test mat with 4 vertices (start, 2x corner, end) | The lines on the easy mat. | The car will be able to navigate the mat. |
| 09 | Car must navigate a medium difficulty maze (start, 3-6x corner, end, dead ends) | The lines on the medium mat. | The car will be able to navigate the mat with minor difficulty |
| 10 | Car must navigate a large and very difficult maze. (Start, 8+ corners, end, dead ends) | The lines on the difficult mat. | The car will be able to navigate some of the maze but may get stuck in places. It will take a long time. |

### 2.7.3 Dijkstra’s Algorithm Testing

Table 14 lays out the different tests that will be used to determine whether Dijkstra’s has been successful.

#### Table 14 – Tests for Dijkstra’s Algorithm

|  |  |  |  |
| --- | --- | --- | --- |
| Test ID | Description | Test Data | Expected Result |
| 11 | Use the output data from Test 08 to test how efficient the algorithm is. | Test 08 output graph | The algorithm should be able to output quickly. |
| 12 | Use the output data from Test 09 to test how efficient the algorithm is. | Test 09 output graph | The algorithm should be able to output moderately quickly. |
| 13 | Use the output data from Test 10 to test the extreme side of the data input. If Test 10 does not produce a valid graph, a graph may be used from elsewhere. | Test 10 output graph, or a difficult graph from another source. | The algorithm should be able to output but may take a while. |

### 2.7.4 “Run All” Algorithm Testing

Table 15 lays out the different tests that will be used to determine whether the “Run all” algorithm has been successful.

#### Table 15 – Tests for the “Run All” Algorithm

|  |  |  |  |
| --- | --- | --- | --- |
| Test ID | Description | Test Data | Expected Result |
| 14 | Tests 08 and 11 | The easy test mat | The algorithm should be able to run through the maze, produce the best path and run the best path. |
| 15 | Tests 09 and 12 | The medium test mat | The algorithm should be able to run through the maze, produce the best path and run the best path. |
| 16 | Tests 10 and 13 | The difficult test mat | The algorithm might be able to run through the maze, produce the best path and run the best path. If at least halve the maze is covered and then Dijkstra’s is run successfully, then the test is successful. |

### 2.7.5 Log File Testing

Table 16 lays out the different tests that will be used to determine whether the Log file handling has been successful.

#### Table 16 – Tests for the log file handling

| Test ID | Description | Test Data | Expected Result |
| --- | --- | --- | --- |
| 17 | The system will be booted up, some random inputs will be given, and then the system will be shut down. | Any sample menu. | Everything should run smoothly, and by the end a log file with time stamps should be stored in memory. |
| 18 | The system will be booted, some buttons will be pressed, and the program will be exited unexpectedly. | Any sample menu. | The system should record the error and exit safely. |
| 19 | An object will be serialised using Pickle and stored in a file.  The object will then be loaded back in and accessed. | Any sample menu.  Any sample objects. | The object should load correctly, in the same state as when it was serialised. |

### 2.7.6 Motor Control Testing

Table 17 lays out the different tests that will be used to determine whether the motor control has been successful.

#### Table 17 – Tests for the motor controls

|  |  |  |  |
| --- | --- | --- | --- |
| Test ID | Description | Test Data | Expected Result |
| 20 | Move 1m | - | The car should move 1m +/- 10 cm |
| 21 | The car will turn 90 one way, then back to 0 before turning 90 the other way. | - | The car should be within 5 degrees of 90 degrees from the origin line. |
| 22 |  |  |  |

# 3 Implementation phase

## 3.1 Iteration 1

Iteration 1 of the solution will contain only the bare basics of the programs. This means that the code will mimic the flow charts described above. This phase will ignore efficiency and integration between the different systems. **This iteration is a prototype** – it will gauge how much I am following the user requirements. This is made from the components mentioned and decomposed in the design phase. Whilst this system will show some modularity, the components will not be fully integrated with each other.

This is a prototype because it is an early, preliminary version of the final solution used to test and refine a design and further understand the client’s requirements. This means that this iteration will be used to identify any errors, and improve upon the basic UI and functionality.

### 3.1.1 Dijkstra’s

Dijkstra’s algorithm requires vertexes to trace and calculate a path through the maze. These vertexes must have adjacent weights and labels linking a vertex to another.

In this iteration of the vertex class, I have used individual lists for each of the directions, prefilled with None type vales. This means that even if the list is left blank, the system will not report an error. Each of these lists are then added to a dictionary using the directions as a key.

**Validation:**

In the vertex class the values must be entered in pairs (list of 2).

class Vertex():

    def \_\_init\_\_(self, label, left = [None,None], right = [None,None], rear = [None, None], front = [None, None]): # lists stored as [label, weight]

        self.label = str(label)

        self.adjacencyDict = {"Left":left, "Right":right, "Rear":rear, "Front":front} # dictionary of the adjacent verticies

        self.totalweight = 0

        self.permanent = False

The other major component of Dijkstra’s algorithm is the graph used to store the vertices. In this iteration of the graph class, a list called network is defined which will store all the vertices of the graph. Since the vertices are added directly to the list, the objects in the graph can be iterated through, crucial for Dijkstra’s in the priority queue. The graph will also have an index used for deciding which character gets assigned to a vertex.

The graph will have an add vertex subroutine, allowing for the label index to be incremented correctly, and for the instantiation of the new vertex to be validated and consistent with the others in the network.

**Validation:**

The graph class uses a subroutine to add a vertex to ensure all the values entered into the vertex constructor method are correct. The label index is also incremented by 1 here rather than other programs manually entering.

class Graph():

    def \_\_init\_\_(self, end\_label):

        self.network = []

        self.label\_index = 65 # 65 in unicode is A

        self.end = end\_label

    def add\_vertex(self, left = [None,None], right = [None,None], rear = [None, None], front = [None, None]):

        Vert = Vertex(chr(self.label\_index), left, right, rear, front)

        self.network.append(Vert)

        self.label\_index += 1

The Dijkstra’s subroutine copies the current state of the network to a priority queue, and creates an empty list called permanent which will hold all the vertexes that have become permanent (no new shorter route exists to get to the vertex). For each vertex in the queue that is not the first vertex a weight of infinity is given, to enable the bubble sort to have only the vertexes with calculated weights to become permanent.

The main loop in the algorithm then sorts and dequeues the priority queue. This vertex will then become part of the permanent list so it can be referenced and found later. Each vertex has four possible directions for an arc to exist, which are all checked, and the vertex is updated. The algorithm will stop once the length of the queue is 0.

    def Dijkstras(self):

        Queue = self.network

        Permanent = []

        dirList = ["Left", "Right", "Rear", "Front"]

        for i in range(1, len(self.network)): # setting up the initial values of the distance from the start node.

            Queue[i].totalweight = math.inf

        while len(Queue) > 0: # the main loop which checks  all the vertices

            self.bubble(Queue)

            current\_vertex = Queue.pop(0) # dequeue

            current\_vertex.permanent = True

            Permanent.append(current\_vertex)

            for i in range(0,4): # iterates from 0 to 3, stops when at 4

                dirVertexLabel = current\_vertex.adjacencyDict[dirList[i]][0] # finds the vertex in the direction

                try:

                    if self.find\_vertex(Queue, dirVertexLabel).totalweight > current\_vertex.totalweight + current\_vertex.adjacencyDict[dirList[i]][1]:

                        self.find\_vertex(Queue, dirVertexLabel).totalweight = current\_vertex.totalweight + current\_vertex.adjacencyDict[dirList[i]][1]

                except Exception as e: print(e)

        # Output the final path to follow

        for item in Permanent:

            print("\n\n {}".format(item.label))

            for direction in dirList:

                print("{}: {}".format(direction, item.adjacencyDict[direction]))

            print(item.totalweight)

The find vertex subroutine is used to iterate through the queue and return a vertex with a unique label.

    def find\_vertex(self, Queue, label):

        for item in Queue:

            if item.label == label:

                return item # returns the vertex

        try:

            return Queue[len(Queue)-2]  #  returns the final value of the queue

        except:

            print(len(Queue))

            print(label)

            for thing in Queue:

                print(thing.label)

The bubble sort used in this algorithm is standard, just checks the specific attribute total weight when sorting.

    def bubble(self, queue):

            swaps = 1

            while swaps > 0:

                swaps = 0

                for i in range(0, len(queue)-1):

                    if queue[i].totalweight > queue[i+1].totalweight:

                        queue[i], queue[i+1] = queue[i+1], queue[i] # swaps the two values round

                        swaps += 1

            return queue # returns the sorted version of queue

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 101 | To test how functional and appropriate the vertex class is to the solution. | 5 Vertices, 4 arcs each with weight 4. | “A, B, C, E” | The algorithm returns the weights and the adjacency of each vertex. | Improve efficiency of entering and storing data into the vertex constructor. The values are unchanged from the input.  Stop iterating through a list to access a dictionary. |
| 102 | To test if Dijkstra’s algorithm loops correctly until the end vertex is permanent. | 5 Vertices, 4 arcs each with weight 4. | “A, B, C, E” | The algorithm loops through all the vertices instead of up till the end vertex is permanent. | More efficiently track the end vertex by the making the loop run whilst the end vertex is in the Queue.  Stopped using NoneType values in the code. |
| 103 | Testing to determine if the find vertex subroutine can retrieve the correct vertex. | Graph with vertices and a label of the vertex to find:  “E”, “A”, “D” | The Respective objects were returned with correct adjacency. | The Respective objects were returned with correct adjacency with inefficiency. | Using a precondition of the length of the queue being greater than 1.  Using a null vertex with no lengths instead of accessing a random vertex. |
| 104 | To test the efficiency and accuracy of the bubble sort algorithm | A queue with some basic objects with different weight attributes | The queue will be sorted in ascending order. | The queue was returned in the correct order. | The bubble sort is reliable and does not need improvements. |

### 3.1.2 Car’s Menu

The cars menu will be the main way the user can interact with the car’s system. This means the code needs to be efficient.

In this first iteration I will be using a Menu class to hold the data needed to display individual menus. This class will hold the name of the menu, the titles to be display and the action that each titles executes when pressed. A subroutine will handle the printing of the menu to the screen, allowing for consistency.

class Menu: # used for the different submenus in the UI

    def \_\_init\_\_(self, name, titlesList:list, subroutines:list) -> None:

        self.name = name

        self.titles = titlesList

        self.subroutines = subroutines

    def draw(self, screen, pointer): # draws onto the ev3 screen

        screen.draw\_text(115, 5, self.name)

        screen.print("")

        for i in range(len(self.titles)):

            if pointer == i:

                screen.print(self.titles[i]+" <--")

            else:

                screen.print(self.titles[i])

Python does not have a “Main” subroutine that runs initially, so to give myself modularity, and the ability to widely catch errors in the program. I have called this subroutine runMain. This also handles the user inputs for navigation. The active Boolean determines when the runMain subroutine should stop, allowing me to stop it from anywhere in the program. Here I am using a sleep method to stop the algorithm from outputting too much data, causing the program to crash.

class Main: # will hold the main section of the program. useful for dropping in different main loops

    def \_\_init\_\_(self) -> None:

        self.active = True

    def runMain(self): # the main section of the code is here vvv

        Car = car()

        MainMenu = Menu("Main", ["Run meter", "Left Right", "ID Line", "Find Line"], [Car.RunM, Car.LeftRight, Car.IDLine, Car.Findline])

        currentMenu = MainMenu

        pointer = 0

        while self.active:

            Car.screen.clear()

            currentMenu.draw(Car.screen, pointer)

            if Button.DOWN in Car.buttons.pressed():

                pointer += 1

                time.sleep(0.3)

            if Button.UP in Car.buttons.pressed():

                pointer -= 1

                time.sleep(0.3)

            if Button.CENTER in Car.buttons.pressed():

                try: # will try to run the subroutine in the current menu

                    currentMenu.subroutines[pointer]()

                except:

                    pass

            time.sleep(0.1)

Here I define the car class. The constructor method contains the instantiation of the EV3 brick and assigning the aspects of the brick such as drivebase, colour sensor and screen to individual properties of the car. Using a class allows for modularity in the program and allows me to add subroutines to the car that can be accessed by the menu class.

class car:

    def \_\_init\_\_(self):

        self.ev3 = EV3Brick()

        self.screen = self.ev3.screen

        self.buttons = self.ev3.buttons

        self.motorA = Motor(Port.A)

        self.motorD = Motor(Port.D)

        self.driver = DriveBase(self.motorD,self.motorA,31,190) # wheels have diameter of 31mm and a drivebase width of 190mm

        self.colsense = ColorSensor(Port.S4)

        self.driver.settings(straight\_speed=200) # sets the cars speed to 200mm /s

I have coded some simple placeholder movement and sensor subroutines into the car class. These allow me to do some simple tests on the hardware and understand how the code communicates with the hardware. These are ONLY placeholders. The ID line subroutine identifies when a black object is below the colour sensor.

    def RunM(self):

        self.screen.clear()

        self.screen.print("Run is running")

        self.driver.straight(1000) # forwards 1000 mm

        time.sleep(1)

    def LeftRight(self):

        dirs = ["Right", "left"]

        for i in (0,1):

            self.screen.clear()

            print (dirs[i] + " is running")

            self.driver.turn(90-180\*i)

    def IDLine(self):

        self.screen.clear()

        self.screen.print("IDline is running")

        while self.colsense.color() != Color.BLACK:

            self.screen.print(self.colsense.color())

            time.sleep(0.001)

    def Findline(self):

        self.screen.clear()

        self.screen.print("Finding Line")

        time.sleep(1)

The final two lines of the code are the instantiation of the Main object and running the runMain subroutine.

MyMain = Main() # creates the main object

MyMain.runMain() # runs the main section of the code

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 108 | To test if the menus can draw themselves onto the screen. | The screen objects. | The menu data will be written to the screen. | The menu data is written to the screen. | No action needed; the desired result occurs. |
| 109 | To test if the pointer increment is shown on screen. | The screen object pointer button events | The pointer will move with the button pressed and display on screen. | The pointer moves with each press and displays on screen | The pointer is less responsive than it could be. Reducing the time between each frame could reduce the lag. |
| 110 | To determine if the menus are linking correctly. | - | - | - | This section is not yet implemented so cannot be tested. |

### 3.1.3 Search Algorithm

The search algorithm will be used to map out the maze and convert it into a graph for the path finding algorithm to compute. Currently, this iteration of the search algorithm does not fully work, as it can only navigate a straight line before stopping.

I will only be showcasing the search algorithm, as the other sections have been shown and explained in other parts. This allows me to concentrate on the specific code for the search.

def Search(self):

        self.maze.add\_vertex() # creates the initial vertex

        while self.colsense.color() != Color.BLUE:

            time.sleep(0.1)

            dir\_offset = 0

            self.driver.drive(200,0) # sets the motors to drive forward

            if self.colsense.color() == Color.RED: # go straight ahead

                print("running")

Here, we define the search algorithm. The only parameter needed for this to work is the object, as everything else is attached to that object. The initial vertex is added before the main loop, as otherwise the program would either add a vertex every time it looped, or never add an initial vertex.

Since the ending point will be blue, the ending condition has been set to when the colour sensor detects blue underneath it. Every time the loop repeats, the motors are set to running at 200mm/s with 0 degrees of rotation. The direction offset variable will be used later when the car begins to turn and directions to be absolute not relative. Since the colour of the path will be red, if the colour sensor detects red, it will just continue.

            elif self.check\_line(-45,45): # within 90\* ahead

                pass

            elif self.check\_line(45,135): # within the 90\* to the right

                self.maze.add\_vertex(left=[chr(self.maze.label\_index), self.driver.distance])

                self.driver.reset()

                dir\_offset += 1 # increments the direction offset

            elif self.check\_line(-135, -45): #within 90\* to the left

                self.maze.add\_vertex(right=[chr(self.maze.label\_index), self.driver.distance])

                self.driver.reset()

                dir\_offset -= 1

            elif self.check\_line(135,-135): # within 90\* behind

                self.maze.add\_vertex()

This piece of code determines whether there is another path to the left or right if the car has drifted or if it has hit a dead end. If the path is cut, then a vertex is created and added to the graph. The vertex is then updated with the information of the previous vertex before the car’s distance memory is reset.

**Validation:**

The code validates if there is a vertex in any direction and adjusts to be able to navigate to that vertex.

Several errors were encountered during the development of the search algorithm but not all were fixed.

|  |  |  |
| --- | --- | --- |
| Error type | Description and Comment | Fixed |
| AttributeError: 'module' object has no attribute 'inf' | The math module does not exist in the code already on the EV3. This means that the value math.inf cannot be used for comparing the weights of each arc. | Use float(“inf”) to represent infinity. |
| The EV3 not turning to correct point | The EV3 does not yet turn to the correct point, hence it does not know if there is a corner or if it is a dead end, or if it has simply gone off track. | **Needs to be brought forward to next iteration.** |
| TypeError: unsupported types for \_\_sub\_\_: 'bound\_method', 'int' | Multiple data types are being input into a subroutine. This means that the calculations in checkline are not working. | Update code to use parenthesis instead of using the function. i.e. colour -> colour() |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 105 | To test if the check line algorithm can detect a line in the range specified | (-45,45)  (45,135)  (-135, -45)  (135, -135) | The car should turn to the first angle relative to the original angle, then turn to the second angle. | The car turns in completely the wrong direction and does not move through the angle. | The algorithm needs to be redone so that the correct directions can be determined. Perhaps by turning through the entire 360 and returning the possible directions. |
| 106 | To test if the graph can store multiple unique vertices within a list during operation | A line with a single corner | That the car will create a vertex with the correct adjacency. | The car does not yet turn down the correct path, so it does not create a vertex. | The car will need to turn down the path to create the vertex, so the corner algorithm will need to be improved and a line of code will need to be added to create the vertex. |
| 107 | To be able to trace out a simple maze | A simple maze is placed down on a surface. | The car can move through the maze without any hinderance. | The car does not move beyond the first corner, so does not navigate the maze. | The line finding algorithm needs to be redone to find all the paths and to navigate through the maze effectively. |

### 3.1.4 Iteration Review

This iteration was purely the start of building the system. None of the subsections are fully working as intended, with the search algorithm needing major work.

Improvements to bring forward and further tests to be carried out:

| Test ID | Component being tested | Test information | Test data | Test Output for completion |
| --- | --- | --- | --- | --- |
| 111 | Dijkstra’s | The usability and simplicity of the algorithm inputs need to be redone. This means that data shouldn’t be repeated. | This will be a graph with 5 vertices and every arc with a weight of 4. | The algorithm should be able to take inputs correctly and not repeat data. |
| 112 | Dijkstra’s | The output of the algorithm is not yet complete. This means that the algorithm cannot yet return a path, hence the algorithm in its current state is useless to the system. | The same test data as test 111 will be used. A simple graph with 5 vertices. | The algorithm should return the shortest path from the start vertex to the end vertex. |
| 113 | Car’s menu | The menu system in its current state is not a great UX. This means that the system should be remade using more appealing aspects. | Some menus (such as the main menu and the Run menu) will be instantiated and linked. | The menus will be able to be easier to navigate and differentiate than before. |
| 114 | Search | I have decided to change from just following the right side of the maze to following the ride side and tracking any other possible turns. | A simple U-shaped maze with a T junction included. | The car should traverse the maze and print a set of possible directions for each corner. |
| 115 | Search | The algorithm used for turning to find the line is jittery and inefficient. This means more battery is used and the results may vary. Hence a smoother turning method is required. | The car will be required to turn 360 degrees. | The car will turn smoothly without jittering and will turn quickly. |
| 116 | Logger | A logging algorithm or object is now required so I can fully understand where each program is failing or stopping with simple log files. | A sample start-up will be done where each object will be instantiated. | The logging object will be log that the objects have been setup with appropriate time stamps. |
| 117 | Logger | The logging object will need to be able to store and retrieve objects in serial form. | Some of the objects in the program will be serialized and stored in a text file. | The file will be small, and the objects will be storable and retrievable. |
| 118 |  |  |  |  |

Currently this iteration meets the following criteria:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria No. | Purpose | Met | Evidence | Improvement to meet criteria |
| 1 | Easy to read Menu titles | Yes |  | The Menu titles could use some sort of differentiation between each other, perhaps colour. |
| 2 | Easy to understand how to navigate the menu system | No | - | The navigation needs to be there to gauge how easy it will be to navigate. |
| 3 | Very little text displayed in the menu | Yes |  |  |
| 4 | Algorithm that can calculate a path within a maze consistently and efficiently | Partially |  | Create a more efficient version of Dijkstra’s that can take inputs better and can create a more computer readable output. |
| 5 | Algorithm that can track out a maze efficiently and consistently. | No |  | Create a search algorithm that can simply track out the maze by colour. |
| 6 | Storage efficient object storing algorithms | No |  | Not yet implemented, so needs to have object retention to meet this success criterion. |
| 7 | RAM used efficiently during operation |  |  |  |
| 8 | Algorithms will be quick to process data and output information | Yes | Dijkstra’s: |  |
| 9 | Clear and abstracted user guide with pictures | No |  | This will need to be created to meet any criteria. |
| 10 | The ability to stop the program | No |  | An exit subroutine at the bottom of the main menu. |
| 11 | The ability to remotely read data from the system | No |  | The wire needs to be attached to read data, as Bluetooth doesn’t connect. Hence, I cannot change this. |
| 12 | The ability to remotely write data to a config file in the system | No |  | The wire needs to be attached to read data, as Bluetooth doesn’t connect. Hence, I cannot change this. |
| 13 | The ability for the car to be stand alone | Yes | The car is run from the menu it holds. |  |

## 3.2 Iteration 2

This iteration is a…

### 3.2.1 Dijkstra’s

In the previous iteration of Dijkstra’s there is the vertex class used to store corners. This iteration has been used to improved how the parameter passing works with the objects. As a result, I have scrapped any parameters passed into the constructor in favour of a new subroutine. Here I have chosen to use two separate lists for the labels of adjacent vertices and the weights of the arc connecting them. I have also added some extra attributes to help identify which path to take through the maze.

The new subroutine uses conditions and validation to ensure that each of the values passed in will work in the algorithm. The input parameter is where the values of the adjacent vertices will be passed in, allowing for flexibility and modularity.

class Vertex():

    def \_\_init\_\_(self, label):

        self.label = str(label)

        # left, right, rear, front

        self.adjacencyLabels = ["","","",""] # dictionary of the adjacent verticies

        self.adjacencyWeights = [math.inf, math.inf, math.inf, math.inf] # has all the connected arc weights set to infinity

        self.totalweight = math.inf

        self.permanent = False

        self.previousVertex = ""

        self.previousDir = 0

    def update\_adjacency(self, input = [[],[],[],[]]):

        for i in range(0,4):

            try:

                if len(input[i]) > 0:

                    self.adjacencyLabels[i] = str(input[i][0])

                    self.adjacencyWeights[i] = int(input[i][1])

            except:

                print("one of your values isn't the correct type")

This section of code includes the constructor method for the graph and the add vertex method for creating a new vertex in the graph.

The network is stored as a list of vertices, which is initially set to a length of 0 with no items. The label index starts at 65 (“A” in ASCII) so this value can be incremented to keep the vertex labels unique within the graph. In this iteration, I have used a null vertex to use for if an error occurs within the program. The null vertex can be used as a stop point if the vertex needed cannot be found.

The subroutine add\_vertex is used here to ensure that the vertex is correctly created and added to the network. A general vertex is instantiated with the name Vert, passing in the label index as a character for the unique label of the vertex. The adjacency is then updated using the update adjacency method of the vertex, allowing validation, passing in the values passed into the subroutine. The vertex is then added, and the label index incremented by one.

class Graph():

    def \_\_init\_\_(self, end\_label):

        self.network = []

        self.label\_index = 65 # 65 in unicode is A, works as an offset

        self.end = end\_label

        self.nullVertex = Vertex("\*")

    def add\_vertex(self, left = [], right = [], rear = [], front = []):

        Vert = Vertex(chr(self.label\_index))

        Vert.update\_adjacency([left,right,rear,front])

        self.network.append(Vert)

        self.label\_index += 1 # increments the label by 1 e.g A -> B

The Dijkstra’s subroutine has been updated since the previous iteration. The same approach remains similar, but this iteration uses whether the end vertex is in the queue to finish looping, improving efficiency. Furthermore, the exclusion of dictionaries for adjacency allows me to loop through each adjacent vertex with a simple for loop. The same method of comparing and updating the total weight of the vertex is used here.

    def Dijkstras(self):

        Queue = self.network

        Permanent = []

        Queue[0].totalweight = 0 # sets the initial vertex weight to 0

        end\_vertex = self.find\_vertex(Queue, self.end)

        while end\_vertex in Queue: # the main loop which checks all the vertices

            self.bubble(Queue) # sorts the queue

            current\_vertex = Queue.pop(0) # similar to the dequeue in static languages

            current\_vertex.permanent = True

            Permanent.append(current\_vertex)

            for i in range(0,4): # iterates from 0 to 3, stops when at 4

                dirVertex = self.find\_vertex(Queue,current\_vertex.adjacencyLabels[i]) # finds the vertex in the direction

                if dirVertex.totalweight > current\_vertex.totalweight + current\_vertex.adjacencyWeights[i]:

                        dirVertex.totalweight = current\_vertex.totalweight + current\_vertex.adjacencyWeights[i]

                        dirVertex.previousVertex = current\_vertex.label

                        dirVertex.previousDir = i

        # Output the final path to follow

        print(self.findPath(Permanent, self.end))

The findpath subroutine is a recursive piece of code used to trace the path back that Dijkstra’s has created. The information returned in string form will be used by the car to navigate the maze. Recursion is used here as the same operations are being carried out on the same information. This means that the data can be easily passed back into the subroutine and no extra list is needed to form the path.

    def findPath(self, final\_list, curlabel, output = ""): # traces the path back to the start

        dirList = ["Left", "Right", "Rear", "Front"]

        curVertex = self.find\_vertex(final\_list, curlabel)

        output += "\n\nlabel: {},\nweight: {},\ndir: {}".format(curVertex.label, curVertex.totalweight, dirList[curVertex.previousDir])

        if curVertex.label == "A":

            return output

        else:

            return self.findPath(final\_list,curVertex.previousVertex, output)

This method is largely similar to the previous iteration, but has removed all the try except conditions, as new validation in the previous code has made the inputs more accurate. The precondition that the queue must be greater than 0 means that the code cannot access a null index in the list.

    def find\_vertex(self, Queue, label):

        if len(Queue)>0:

            for item in Queue:

                if item.label == label:

                    return item # returns the vertex

        return self.nullVertex

Here the graph is instantiated, and the test data is input. Once the program has finished the user is told.

myNetwork = Graph("E")

myNetwork.add\_vertex(right=["B", 4])

myNetwork.add\_vertex(left=["A", 4], front=["C", 4])

myNetwork.add\_vertex(right=["E", 4], rear=["B", 4], front=["D", 4])

myNetwork.add\_vertex(rear=["D", 4])

myNetwork.add\_vertex(left=["C", 4])

myNetwork.Dijkstras()

print("reached the end")

| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| --- | --- | --- | --- | --- | --- |
| 101 | To test how functional and appropriate the vertex class is to the solution. | 5 Vertices, 4 arcs each with weight 4. | “A, B, C, E” | The algorithm returns the weights and the adjacency of each vertex. | The algorithm works, with a better way of updating the adjacency with validation. |
| 102 | To test if Dijkstra’s algorithm loops correctly until the end vertex is permanent. | 5 Vertices, 4 arcs each with weight 4. | “A, B, C, E” | The algorithm loops through until the end vertex is permanent | The outcome is correct, no need to update anything. The algorithm now stops when the end vertex is no longer in the queue. |
| 103 | Testing to determine if the find vertex subroutine can retrieve the correct vertex. | Graph with vertices and a label of the vertex to find:  “E”, “A”, “D” | The Respective objects were returned with correct adjacency. | The Respective objects were returned with correct adjacency | The find vertex subroutine now works more efficienctly by not using any try, except conditions and instead using a precondition to determine if the operation is possible. |
| 104 | To test the efficiency and accuracy of the bubble sort algorithm | A queue with some basic objects with different weight attributes | The queue will be sorted in ascending order. | The queue was returned in the correct order. | The bubble sort is reliable and does not need improvements. |
| 111 | The data input layout was not consistently working, so the data shouldn’t be repeated and should be much easier to pass as a parameter. | Vertices are created and initialised with adjacency. | The vertices should store the adjacency correctly. | The adjacency is stored correctly. | Nothing to be done, the correct output occurs. |
| 112 | The algorithm should retrace its steps and output the correct path. | The permanent list with a complete set of vertices | The algorithm retraces the path backwards with correct lengths | The algorithm retraces the path backwards with correct lengths. | The output now needs to be changed from a human readable format to one which can be easily read by a computer. |

### 3.2.2 Menu Algorithm

Initially the appropriate classes and modules are imported for the screen to work.

#!/usr/bin/env pybricks-micropython

#This is the Second menu prototype, which will include running subroutines from the menu

#This version will include the OOP approach

# Imports

import sys

import time

from pybricks.hubs import EV3Brick

from pybricks.ev3devices import (Motor, TouchSensor, ColorSensor,

                             InfraredSensor, UltrasonicSensor, GyroSensor)

from pybricks.parameters import Port, Stop, Direction, Button, Color

from pybricks.tools import wait, StopWatch, DataLog

from pybricks.robotics import DriveBase

from pybricks.media.ev3dev import SoundFile, ImageFile

# This program requires LEGO EV3 MicroPython v2.0 or higher.

# Click "Open user guide" on the EV3 extension tab for more information.

The menu class is used to all the necessary information for storing and outputting the menus. The constructor method assigns a name, a given list of titles for the user to see, and a list of the subroutines behind each title.

The draw method here takes the screen of the EV3 as a parameter and prints all the information stored in the menu. The menu name is printed top right corner of the screen and the menu titles are printed left hand side of the screen. A pointer that can be incremented and decremented is used to display the currently selected titled and used as an index to access the subroutine or menu behind the title. The for loop here is used to display each title, with only the selected title having the arrow.

class Menu: # used for the different submenus in the UI

    def \_\_init\_\_(self, name, titlesList:list, subroutines=[]) -> None:

        self.name = name

        self.titles = titlesList

        self.subroutines = subroutines

    def draw(self, screen, pointer): # draws onto the ev3 screen

        screen.draw\_text(115, 5, self.name)

        screen.print("")

        for i in range(len(self.titles)):

            if pointer == i:

                screen.print(self.titles[i]+" <--")

            else:

                screen.print(self.titles[i])

The car class here identical to the one in the previous iteration. It’s constructor method creates an ev3 object accessible through the class and assigns different aspects of the ev3 brick to separate variables within the car class such as the screen, the buttons, and the sensor. The motors are put into a Drive Base object, which allows for better control of the motors in conjunction with each other. The driver is set to have a straight speed of 0.2m/s, allowing for accuracy and precision with fast movement. This section of code has omitted the blank subroutines used for brief testing.

class car:

    def \_\_init\_\_(self):

        self.ev3 = EV3Brick()

        self.screen = self.ev3.screen

        self.buttons = self.ev3.buttons

        self.motorA = Motor(Port.A)

        self.motorD = Motor(Port.D)

        self.driver = DriveBase(self.motorD,self.motorA,31,190) # wheels have diameter of 31mm and a drivebase width of 190mm

        self.colsense = ColorSensor(Port.S4) # Left out as wont work right now, FIX THIS!!!!!

        self.driver.settings(straight\_speed=200) # sets the cars speed to 200mm /s

The main class holds all the currently active objects and variables and uses a main loop to output information to the display and allow for the users to press buttons.

The constructor method of the main class only has the attribute active, which controls whether the loop runs or not. This allows for the attribute to be changed anywhere in the program.

The runMain method will hold all the running code. First, a car object is instantiated so the code can communicate with the ev3. Then, each of the menus are instantiated: Main, Run, Calibration and Settings. Initially, each of the menus only have the titles set, as if a reference is made to another menu, then an error will be returned. Each of the menus, once setup, are given their subroutines or menus to interact with i.e., Main is given each menu to navigate to, and the other menus are given subroutines to execute. The current menu is then set to the main menu, so when the system is booted up, the menu the user sees is the main menu.

class Main: # will hold the main section of the program. useful for dropping in different main loops

    def \_\_init\_\_(self) -> None:

        self.active = True

    def runMain(self): # the main section of the code is here vvv

        Car = car()

        MainMenu = Menu("Main", ["Run Menu", "Calibration Menu", "Settings Menu", "Quit"])

        RunMenu = Menu("Run", ["Run All", "Run Search", "Run Solve", "Main Menu"])

        CalMenu = Menu("Calibration", ["Track Line", "Turning", "Main Menu"])

        SetMenu = Menu("Settings", ["Motor Speed", "Logging Type", "Logging Intervals", "Main Menu"])

        MainMenu.subroutines = [RunMenu, CalMenu, SetMenu, self.Exit]

        RunMenu.subroutines = [Car.RunAll, Car.RunSearch, Car.RunSolved, MainMenu]

        CalMenu.subroutines = [Car.CalTrackLine, Car.CalTurning, MainMenu]

        SetMenu.subroutines = [Car.SetMotorSpeed, Car.SetLogType, Car.SetLogInterval, MainMenu]

        currentMenu = MainMenu

        pointer = 0

        while self.active:

            Car.screen.clear()

            currentMenu.draw(Car.screen, pointer)

            if Button.DOWN in Car.buttons.pressed():

                pointer += 1

                time.sleep(0.3)

            if Button.UP in Car.buttons.pressed():

                pointer -= 1

                time.sleep(0.3)

            if Button.CENTER in Car.buttons.pressed():

                try: # will try to run the subroutine in the current menu

                    if isinstance(currentMenu.subroutines[pointer],Menu):

                        currentMenu = currentMenu.subroutines[pointer]

                        pointer = 0

                    else:

                        currentMenu.subroutines[pointer]()

                except Exception as e:

                    print("hmmm, this didnt work")

                    print("here is why:", e)

            time.sleep(0.1)

        # close the log file here

        Car.screen.clear()

        Car.screen.print("Shutting Down...")

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 108 | To test if the menu can write its information onto the screen. | Screen object | The information is outputted onto the screen | The screens are printing, but are becoming more cramped, some of the menu names are not fitting in correctly. | The screen design needs to be variable in the way it handles the titles and menu name. There needs to be a way for the menu to determine how long a word is and adjust the position of the word accordingly. |
| 109 | The pointer needs to be updating in real time to respond to the users’ actions. | Buttons on the ev3 | The pointer will increment and decrement with the button presses. | The pointer updates correctly with some lag. | The screen output interval needs to be reduced without it being so low to produce too many frames per second. |
| 110 | The menus should be able to link from one to another and execute subroutines. | The menus are created and linked, then navigated. | The menus will link correctly, and the screens should change with the pointer updated to 0. | The menus link correctly, and the pointer resets to 0 each time. | The code works as intended, so no action is needed. |
| 113 | The menu should be more friendly to navigate from a user’s approach. | Some menus will be created and linked. | The menus are easier and more responsive to navigate. | The visual system is still black and white and is hard to understand for the user. | The visual system needs to be redone to be more appealing to the user, or a detailed user guide needs to be created explaining each menu. |

### 3.2.3 Search Algorithm

In the previous iteration, the search algorithm was not usable or functional at all. This meant that all the tests designed for the search algorithm were failed. In this iteration, I have evaluated what went wrong in the previous iteration, and how this can be changed to create a functional search. I have further added logging abilities to the program, allowing me to understand where errors occur and to keep track of what is happening when the program is running headless.

The vertex class, graph class and majority of the car class have remained unchanged. As a result, the only sections needing explanation here are the search algorithm and the find line algorithm.

The search algorithm starts by creating a log entry that the subroutine has started. An initial vertex is then created. I have chosen to use the colour green as the end indicator, as the colour sensor would return blue more often than the program would allow for. Hence, whilst the colour the sensor detects is not green, the search algorithm will iterate. Each time the loop iterates, the program waits 0.1 seconds, as this prevents the sensor from being overloaded with input requests. The car then drives straight ahead, and whilst the colour underneath the sensor is red, don’t change anything.

   def Search(self):

        evLogger.log("Starting Search")

        self.maze.add\_vertex() # creates the initial vertex

        while self.colsense.color() != Color.GREEN:

            time.sleep(0.1)

            dir\_offset = 0

            self.driver.drive(200,0) # sets the motors to drive forward

            if self.colsense.color() == Color.RED: # go straight ahead

                pass

If the colour underneath the sensor is not red or green, then the car will start searching for the line. A log entry is created to identify that the line has been lost. Then, the car is stopped, and turns -30\*. While the relative angle is less than 30\* (turned 60\* overall), the car will turn and poll at regular intervals to detect if there is a line. If the line is found, the loop is broke, and the event is logged.

            if self.colsense.color() != Color.RED: # re-adjust to find the line

                evLogger.log("Lost Line")

                self.driver.drive(0,0)

                self.driver.turn(-30)

                rel\_angle = -30

                while rel\_angle<30:

                    self.driver.turn(10)

                    if self.colsense.color() == Color.RED:

                        evLogger.log("Found Line")

                        break

                    rel\_angle += 10

If the line is not found, and the colour is still red, then the car readjusts back to where is first lost the line. The car then performs the check line algorithm and is returned a list of directions that can be turned. The car then readjusts again, and moves forwards so the turn is more accurate. The car then turns and logs that it has turned.

            if self.colsense.color() != Color.RED: # find out which directions are possible to turn.

                self.driver.turn(-30)

                directions = self.check\_line()

                self.screen.print(directions)

                self.driver.straight(50)

                self.driver.drive(0,0)

                if "Left" in directions:

                    self.driver.turn(-90)

                    evLogger.log("Found Corner")

                elif "Right" in directions:

                    self.driver.turn(90)

                    evLogger.log("Found Corner")

                elif "Back" in directions:

                    self.driver.turn(180)

                    evLogger.log("Found Dead End")

The check line subroutine is used to detect all the possible directions that the car can turn when met with a corner or a dead end. This is done by rotating 360 degrees, and if a line is detected within a certain range and there hasn’t been another detection in that range, add the direction to a list that is then returned and used in the main search.

    def check\_line(self): # finds which directions are possible to turn.

        evLogger.log("Check Line algorithm")

        self.driver.drive(0,0) # stops the motors

        rel\_angle = 0

        possible\_dirs = []

        while rel\_angle<330:

            self.driver.turn(10)

            if rel\_angle > 0 and rel\_angle < 135 and "Right" not in possible\_dirs and self.colsense.color() == Color.RED:

                possible\_dirs.append("Right")

            if rel\_angle > 135 and rel\_angle < 225 and "Back" not in possible\_dirs and self.colsense.color() == Color.RED:

                possible\_dirs.append("Back")

            if rel\_angle > 225 and rel\_angle < 360 and "Left" not in possible\_dirs and self.colsense.color() == Color.RED:

                possible\_dirs.append("Left")

            rel\_angle+= 10

        return possible\_dirs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 105 | To test if the check line algorithm can detect a line in the range specified | - | - | - | This test has been scrapped, as the function no longer works the same, and the similar functionality is instead tested in test 114. |
| 106 | To test if the graph can store multiple unique vertices within a list during operation | A line with a single corner | That the car will create a vertex with the correct adjacency. | This has not yet been implemented, so cannot be tested | The algorithm needs to create vertices now, even if incorrect values are passed in to test if the algorithm can link the vertices correctly. |
| 107 | To be able to trace out a simple maze | A simple maze is placed down on a surface. | The car can move through the maze without any hinderance. | The car navigates through the maze with some difficulty. The car will sometimes move round a corner slowly, without giving the chance to create a vertex. | The car needs to have a better method of detecting the end of a line, and perhaps reducing the angle to look for the continuing of the line. This will make the algorithm more efficient. |
| 114 | To produce a list of possible directions at any vertex. | A simple maze with 2 right hand turns, 2 left hand turns, 2 dead ends. | At each corner, the correct adjacency directions will be printed on screen. | The car detects the correct adjacency at each vertex and prints this to the screen. | The correct result occurs. This means no work needs to be done for now. |
| 115 | To test the smoothness of the turning within the search. | The car is put on a corner and must navigate it. | The car turns round the corner with minimal jittering. | The car mostly moves round the corner correctly but will always jitter when polling for the adjacency. | The algorithm needs to use another method of turning, such as turning for a certain amount of time without stopping, the continue with the program whilst polling for the red line. |

### 3.2.4 Logger Object

The car needs to have some sort of logging ability to store any errors that occur and to help understand where a program went wrong. The object will also allow for the storage and retrieval of other objects within the system.

The object’s constructor method defines several aspects of the object, such as:

* The filename used to store logs
* The interval between the logs (yet to be used)
* The time the object is instantiated
* Its ObjectID, used for copying the object to a file.
* An initial line in the log file, stating that the object is initialized.

import time

import os

class logger:

    def \_\_init\_\_(self, filename="Log.txt") -> None:

        self.filename = filename

        self.interval = 0.1

        self.init\_time = time.time()

        self.log(index=0, lineStart="\n") # logs that it has initialised itself.

        self.ObjectID = "logger"

The class uses a method called dump to copy the information about an object and store it in a file. Currently, this method does not work on the EV3, as the pickle library does not function correctly with the version of python used on the OS. As a result, the methods used involving pickle must be rewritten from base to mimic the behaviour of the pickle module.

This method would have written each individual object to its own file, with an iteration index and a name to easily iterate through the list of objects and pick a specific one.

   def dump(self, objects): # dumps an object into a text file

        #finding what increment is next and updating the file to store this increment.

        with open("increment.txt", "r") as openFile:

            for line in openFile: pass

            this\_increment = int(line) + 1

        with open("increment.txt", "w") as openFile:

            openFile.write(str(this\_increment))

        self.object\_increment = this\_increment

        for item in objects:

            with open(str(this\_increment) + " " + item.name, "wb") as Tomb:

                #pickle.dump(item, Tomb)

                self.log("{} dumped".format(item.name))

The retrieve method would have searched for the object within the file structure and returned the unpickled version for use within the program.

    def retrieve(self, searchName, index=1): # retrieves an object from a text file

        with open(str(index) + " " + searchName, "rb") as Tomb:

            #return pickle.load(Tomb)

            pass

The log method is used to log text passed into the method into the specified log file. This is done by opening the file as writable using the with keyword, which opens and automatically closes the file. Each time the log method is called, a time stamp is added to the beginning of the line to record how long after boot an event occurs.

def log(self, text="", index = -1, lineStart = ""): # used to log things.

        presets = ["Logger Initialised",

                   "Graph Initialised",

                   "",

                   ""] # creates a list of presets that can be accessed using an index.

        if index == -1:

            pass

        elif index < -1:

            text = "Log Index Does Not Exist"

        else:

            text = presets[index]

        with open(self.filename, "a") as writer:

            writer.write(lineStart + "[{}]".format(round(time.time() - self.init\_time, 2)) + text + "\n")

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 116 | To test the logging capabilities of the logger object | A sample start up of any module with sample log lines | A log file is created, and each event is logged and has the correct timestamp. | The log file is created, when an object is instantiated, the log file has a new line added with a time stamp. | Some timestamps have an incorrect rounded time, such as 58.77000000000001, as the rounding in python falls victim to floating points errors. |
| 117 | To test the object serialization of the logger object | A sample object will be created, serialized, then be retrieved, and tested. | The object is dumped and retrieved without any loss of data | The pickle module does not work with older versions of python (such as 2.7.13), so the code crashes. | Either rewrite the code used for pickle, find a version of pickle that works with 2.7.13, or write some similar code from base that works with the version of python on the EV3. |

### 3.2.5 Iteration Review

This iteration is built from the base of the previous iteration but amended some of the issues that occurred.

No more tests are required to be made, as the current tests will test every section of the solution during the iterative development in the next iteration.

The success of the iteration will be based on the number of success criteria met.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria No. | Purpose | Met | Evidence | Improvement to meet criteria |
| 1 | Easy to read Menu titles | Partially |  | A relative position title is needed. |
| 2 | Easy to understand how to navigate the menu system | Partially |  | The navigation from one sub menu to another is clunky. Perhaps using the back button? |
| 3 | Very little text displayed in the menu | Partially | As above | Most menus are alright, but the main menu needs tidying up. |
| 4 | Algorithm that can calculate a path within a maze consistently and efficiently | Yes |  | The computer should be able to read it, so very few lists with the bare minimum. |
| 5 | Algorithm that can track out a maze efficiently and consistently. | Partially |  | The car will sometimes not pick up a line correctly, and hence doesn’t detect it needs to go forwards. |
| 6 | Storage efficient object storing algorithms | No |  | The file storage does not work yet, as pickle does not work on the version of python. |
| 7 | RAM used efficiently during operation | Yes | 50% of the RAM is available for use. | No more work needed, the program is efficient with RAM. |
| 8 | Algorithms will be quick to process data and output information | yes |  |  |
| 9 | Clear and abstracted user guide with pictures | No | - | Will be visited in the last iteration. Needs to be useful. |
| 10 | The ability to stop the program | Yes |  | The program needs to be fully stopped, not just ended. |
| 11 | The ability to remotely read data from the system | No | - | Cannot do this anymore since the Bluetooth integration is poor. |
| 12 | The ability to remotely write data to a config file in the system | No | - | Cannot do this anymore since the Bluetooth integration is poor. |
| 13 | The ability for the car to be stand alone | Yes | The car will only work using the menus onboard. |  |

## 3.3 Iteration 3

### 3.3.1 Dijkstra’s

Dijkstra’s algorithm depends on having a connected graph with different vertices present. Hence two classes are needed: a graph and a vertex.

The Vertex class is responsible for holding all the information for movement throughout the network. Hence, it must store all connected vertices, the weights to reach each one and its own weights. This large amount of data needs to be stored correctly, and in an easily usable and accessible fashion.

The constructor method of the Vertex displays how complex the storage of all the data is. First, the label is assigned to the vertex. This is **unique**. Then, the adjacencies are stored in 3 separate lists. First, the different adjacent labels are stored, then the weight to each respective vertex, then the potential for adjacency to determine if the full maze has been explored. Then, the total weight from start is stored, along with other information needed to process Dijkstra’s.

class Vertex():

    def \_\_init\_\_(self, label):

        self.label = str(label)

        # North, East, South, West

        self.adjacencyLabels = ["","","",""] # dictionary of the adjacent verticies

        self.adjacencyWeights = [math.inf, math.inf, math.inf, math.inf] # has all the connected arc weights set to infinity

        self.adjacencyPot = [False,False,False,False] # currently, no directions are possible

        self.totalweight = math.inf

        self.permanent = False

        self.previousVertex = ""

        self.previousDir = 0

The update adjacency method simply takes a list of labels and weight values to update the adjacency of the selected vertex. This allows for easy updating with **validation.**

    def update\_adjacency(self, input = [[],[],[],[]]):

        for i in range(0,4):

            try:

                if len(input[i]) == 2:

                    self.adjacencyLabels[i] = str(input[i][0])

                    self.adjacencyWeights[i] = int(input[i][1])

            except:

                print("one of your values isn't the correct type")

The add vertex subroutine has been greatly changed since the previous iteration. Before, the values used to be hard coded in with the adjacency. This meant that the system would need to predict the future to understand how to fill in the adjacencies for the new vertex. Now, the absolute directions are passed, with the possible directions and the distance since the last vertex.

First, the network is **validated** to ensure that the new vertex is not overwriting any vertex. Then, a new vertex is instantiated. If this is the first vertex, then the system will just add a north adjacency to it and continue. Else, the system will setup the new one, and update the previous one. The new vertex is then added to the graph.

    def add\_vertex(self, direction, distance, possibleDirs):

        if self.find\_vertex(self.network, self.label\_index).label == "\*":

            Vert = Vertex(chr(self.label\_index))

            if chr(self.label\_index) == "A": # if the vertex is the initial vertex

                Vert.adjacencyPot[0] = True

            else: # if the vertex is any other vertex in the maze

                # updating the previous vertex

                previous\_vertex = self.find\_vertex(self.network, chr(self.label\_index - 1))

                adjacency = [[],[],[],[]]

                adjacency[direction%4] = [chr(self.label\_index),distance]

                previous\_vertex.update\_adjacency(adjacency)

                # updating the new vertex

                prev\_label = chr(self.label\_index - 1)

                adjacency = [[],[],[],[]]

                prev\_dir = (direction+2)%4 # calculates the direction that the link should be made

                adjacency[prev\_dir] = [prev\_label,distance]

                Vert.update\_adjacency(adjacency)

                Vert.adjacencyPot = possibleDirs

            self.network.append(Vert)

            self.label\_index += 1 # increments the label by 1 e.g A -> B

The code for Dijkstra’s remains unchanged. This is due to its efficiency being optimal and no work is needed to be done.

    def Dijkstras(self):

        Queue = self.network

        Permanent = []

        Queue[0].totalweight = 0 # sets the initial vertex weight to 0

        end\_vertex = self.find\_vertex(Queue, self.end)

        while end\_vertex in Queue: # the main loop which checks all the vertices

            self.bubble(Queue) # sorts the queue

            current\_vertex = Queue.pop(0) # similar to the dequeue in static languages

            current\_vertex.permanent = True

            Permanent.append(current\_vertex)

            for i in range(0,4): # iterates from 0 to 3, stops when at 4

                dirVertex = self.find\_vertex(Queue,current\_vertex.adjacencyLabels[i]) # finds the vertex in the direction

                if dirVertex.totalweight > current\_vertex.totalweight + current\_vertex.adjacencyWeights[i]:

                        dirVertex.totalweight = current\_vertex.totalweight + current\_vertex.adjacencyWeights[i]

                        dirVertex.previousVertex = current\_vertex.label

                        dirVertex.previousDir = i

Finally, the final path is outputted into a computer readable format.

self.finalPath = self.findPath(Permanent, self.end)

        return self.finalPath

Since there some errors occurred where a vertex would be skipped as the search algorithm would run, this would lead to Dijkstra’s algorithms being useless, as the car would include every vertex in the shortest path. This meant that some logic was needed to bridge the gap and have all the vertices link together correctly.

The subroutine is called fixGraph, as it does just this. It fixes any errors in the graph originating from the search algorithm, so the graph is ready for use with Dijkstra’s. Effectively, the subroutine splits the length stretching over a vertex into 2 parts, with each linking to the vertex in the middle.

In the figure below, it is easy to see that from the search algorithm E links directly to F. Therefore, the links need to be made to connect F to D and D to E.

Diagram

Description automatically generated

    def fixGraph(self): # fixes the graph so that vertices are not 'hopped' over

        for vert\_i in self.network:

            for vert\_j in self.network:

                for i in range(0,4):

                    if vert\_i.label != vert\_j.label and vert\_i.adjacencyLabels[i] == vert\_j.adjacencyLabels[i] and len(vert\_j.adjacencyLabels[i])>0:

                        if vert\_i.adjacencyWeights[i] <= vert\_j.adjacencyWeights[i]:

                            firstVert = vert\_j

                            secondVert = vert\_i

                            thirdVert = self.find\_vertex(self.network, firstVert.adjacencyLabels[i])

                        elif vert\_j.adjacencyWeights[i] <= vert\_i.adjacencyWeights[i]:

                            firstVert = vert\_i

                            secondVert = vert\_j

                            thirdVert = self.find\_vertex(self.network, firstVert.adjacencyLabels[i])

                        print(firstVert.label, secondVert.label, thirdVert.label)

                        firstVert.adjacencyLabels[i] = secondVert.label

                        firstVert.adjacencyWeights[i] = firstVert.adjacencyWeights[i] - secondVert.adjacencyWeights[i]

                        secondVert.adjacencyLabels[(i+2)%4] = firstVert.label

                        secondVert.adjacencyWeights[(i+2)%4] = firstVert.adjacencyWeights[i]

                        thirdVert.adjacencyLabels[(i+2)%4] = secondVert.label

                        thirdVert.adjacencyWeights[(i+2)%4] = secondVert.adjacencyWeights[i]

| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| --- | --- | --- | --- | --- | --- |
| 101 | To test how functional and appropriate the vertex class is to the solution. | 5 Vertices, 4 arcs each with weight 4. | “A, B, C, E” | The algorithm returns the weights and the adjacency of each vertex. | The algorithm works. |
| 102 | To test if Dijkstra’s algorithm loops correctly until the end vertex is permanent. | 5 Vertices, 4 arcs each with weight 4. | “A, B, C, E” | The algorithm loops through until the end vertex is permanent | The outcome is correct, no need to update anything. |
| 103 | Testing to determine if the find vertex subroutine can retrieve the correct vertex. | Graph with vertices and a label of the vertex to find:  “E”, “A”, “D” | The Respective objects were returned with correct adjacency. | The Respective objects were returned with correct adjacency | The expected outcome occurs |
| 104 | To test the efficiency and accuracy of the bubble sort algorithm | A queue with some basic objects with different weight attributes | The queue will be sorted in ascending order. | The queue was returned in the correct order. | The bubble sort is reliable and does not need improvements. |
| 111 | The data input layout was not consistently working, so the data shouldn’t be repeated and should be much easier to pass as a parameter. | Vertices are created and initialised with adjacency. | The vertices should store the adjacency correctly. | The adjacency is stored correctly. | Nothing to be done, the correct output occurs. |
| 112 | The algorithm should retrace its steps and output the correct path. | The permanent list with a complete set of vertices | The algorithm retraces the path backwards with correct lengths | The algorithm retraces the path backwards with correct lengths. | The output is now much more readable by a computer. |

### 3.3.2 Menu Algorithm

In this iteration, small changes have been made to the menu algorithms.

The imports are used to interface with the car.

# Imports

# the code will not run without these, but this code cannot be ran on a desktop.

# hence, future maintenance could use a simulate a virtual car.

import os

import time

from pybricks.hubs import EV3Brick

from pybricks.ev3devices import (Motor, TouchSensor, ColorSensor,

                             InfraredSensor, UltrasonicSensor, GyroSensor)

from pybricks.parameters import Port, Stop, Direction, Button, Color

from pybricks.tools import wait, StopWatch, DataLog

from pybricks.robotics import DriveBase

from pybricks.media.ev3dev import SoundFile, ImageFile

The draw method now has a variable title length, by calculating how far left the title should move from 170 pixels to the right. This makes the menus much tidier, as before some titles would overhang the edge and not display properly. The printing to the screen is still handled in the same way.

    def draw(self, screen, pointer): # draws onto the ev3 screen

        screen.draw\_text(170-(len(self.name)\*10), 5, self.name)

        screen.print("")

        for i in range(len(self.titles)):

            if pointer == i:

                screen.print(self.titles[i]+" <--")

            else:

                screen.print(self.titles[i])

The subroutine CalTurning is displayed under the calibration menu on the car. This subroutine will test if the car is turning correctly, and that the colour sensor can detect the different paths at a vertex. The result will be logged and printed to the screen. This subroutine uses the check line algorithm from the search section of the code.

    def CalTurning(self): # turns about a point and prints the list of directions possible

        self.screen.clear()

        directions = self.check\_line()

        self.screen.print(directions)

        evLogger.log(directions)

        time.sleep(10)

The CalTrackLine subroutine is another part of the calibration menu. Its use is for having the car navigate a single stretch of any maze and stopping once it has reached the end. The result that it has reached the end is then logged. This can be useful for testing how consistent the corner detection is. This piece of code is almost identical to the similar section in the search algorithm, with this subroutine stopping after a corner or dead end.

def CalTrackLine(self): # will carry on going down a red line until the line stops

        self.screen.clear()

        runLoop = True

        while runLoop == True:

            time.sleep(0.1)

            lineFound = True

            self.driver.drive(self.speed,0)

            if self.colsense.color() == Color.RED:

                pass

            if self.colsense.color() != Color.RED: # re-adjust to find the line

                evLogger.log("Lost Line")

                lineFound = False

                self.driver.drive(0,0)

                self.driver.turn(-30)

                rel\_angle = -30

                while rel\_angle<30:

                    self.driver.turn(8)

                    if self.colsense.color() == Color.RED:

                        lineFound = True

                        evLogger.log("Found Line")

                        break

                    if self.colsense.color() == Color.GREEN:

                        runLoop = False

                        lineFound = True

                        evLogger.log("Found End")

                        runLoop = False

                        break

                    rel\_angle += 8

                if lineFound == False:

                    runLoop = False

                    evLogger.log("End of Line Found")

This subroutine is used in the settings menu of the car. This will allow the user to set the speed of the motor between 100 and 300 mm/s. This gives the user options and **increases the usability** of the system.

**Validation:**

    def SetMotorSpeed(self): # increases or decreases the speed of the motor

        while Button.CENTER not in self.buttons.pressed(): # if the center button is pressed, take this as enter and exit the subroutine

            time.sleep(0.05)

            self.screen.clear()

            self.screen.print(self.speed) # print the current speed.

            if Button.UP in self.buttons.pressed() and self.speed <= 290: # increase the speed if the up button is pressed

                self.speed += 10

            elif Button.DOWN in self.buttons.pressed() and self.screen >= 110: # decrease the speed if the down button is pressed

                self.speed -= 10

        self.driver.settings(straight\_speed=self.speed)

        evLogger.log("driver speed set to {}".format(self.speed))

        time.sleep(5)

The SetLogType subroutine toggles the logger object between on and off. This gives the user the ability to save space if necessary. The screen is cleared, and the type of logging is displayed for a short while before returning to the main loop.

    def SetLogType(self): # toggles logging on/off

        self.screen.clear()

        evLogger.loggingActive = not evLogger.loggingActive

        self.screen.print("Logging toggled {}".format(evLogger.loggingActive))

        time.sleep(5)

The SetLogInterval subroutine is used to change the interval for the logging object. Whilst this feature is currently unused, it may be implemented later for tracking the current state of the car using another variable.

    def SetLogInterval(self):

        while Button.CENTER not in self.buttons.pressed(): # if the center button is pressed, take this as enter and exit the subroutine

            time.sleep(0.05)

            self.screen.clear()

            self.screen.print(evLogger.interval) # print the current speed.

            if Button.UP in self.buttons.pressed(): # increase the speed if the up button is pressed

                evLogger.interval += 0.1

            elif Button.DOWN in self.buttons.pressed(): # decrease the speed if the down button is pressed

                evLogger.interval -= 0.1

        evLogger.log("Logger interval set to {}".format(evLogger.interval))

        time.sleep(5)

The code can now shut down the OS once the main menu is exited. This means the user cannot change any settings that may be sensitive or delete any files.

        Car.screen.clear()

        Car.screen.print("Shutting Down...")

        os.system("sudo shutdown -h now")

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 108 | To test if the menu can write its information onto the screen. | Screen object | The information is outputted onto the screen | The screens are printing, and all the menu titles fit perfectly | Nothing need to be done, the desired result occurs |
| 109 | The pointer needs to be updating in real time to respond to the users’ actions. | Buttons on the ev3 | The pointer will increment and decrement with the button presses. | The pointer updates correctly. | No action needed; the system performs with the correct speed. |
| 110 | The menus should be able to link from one to another and execute subroutines. | The menus are created and linked, then navigated. | The menus will link correctly, and the screens should change with the pointer updated to 0. | The menus link correctly, and the pointer resets to 0 each time. | The code works as intended, so no action is needed. |
| 113 | The menu should be more friendly to navigate from a user’s approach. | Some menus will be created and linked. | The menus are easier and more responsive to navigate. | The visual system is still black and white and is hard to understand for the user. | The visual system needs to be redone to be more appealing to the user, or a detailed user guide needs to be created explaining each menu. |

### 3.3.3 Search Algorithm

The search algorithm has been significantly changed since the previous iteration. The search algorithm is now attached to the car object in the main python file. This makes it easier for the program to access.

The now RunSearch algorithm first clears the screen and waits 2 seconds to ensure the user can set everything up for the search to begin. The event logger then logs that the search is starting. An initial vertex is created, and the currently faced direction is set to 0, representing north. Moving from the relative directions to absolute directions means the car can be easily positioned. Finally, the loop is controlled by a variable called runLoop, set to True initially.

    def RunSearch(self):

        self.screen.clear()

        time.sleep(2) # waits 2 secs before starting the search

        evLogger.log("Starting Search")

        self.maze.add\_vertex(0, 0, [True,False,False,False]) # creates the initial vertex: A

        dirfacing = 0 # facing north relative to start

        runLoop = True

        while runLoop == True:

Inside the loop, the car moves forward until the colour sensor no longer detects red. This means that either the car has gone slightly off track, or the car has met a corner/ dead end. In the former case, the car will attempt to find the line by scanning the 60\* in front of the car. If this finds the line, then the loop breaks, and the search continues. If the end is found, then the whole loop is exited and the result is logged.

while runLoop == True:

            time.sleep(0.1)

            lineFound = True

            self.driver.drive(self.speed,0) # sets the motors to drive forward

            if self.colsense.color() == Color.RED: # go straight ahead

                pass

            if self.colsense.color() != Color.RED: # re-adjust to find the line

                evLogger.log("Lost Line")

                lineFound = False

                self.driver.drive(0,0)

                self.driver.turn(-30)

                rel\_angle = -30

                while rel\_angle<30:

                    self.driver.turn(8)

                    if self.colsense.color() == Color.RED:

                        lineFound = True

                        evLogger.log("Found Line")

                        break

                    if self.colsense.color() == Color.GREEN:

                        runLoop = False

                        lineFound = True

                        evLogger.log("Found End")

                        break

                    rel\_angle += 8

If the line cant be found, it is assumed that the current position is a corner. This means that the car will reposition itself to the original position, then start rotating through 360\*, detecting wherever a line is. This is then returned, and the absolute directions (NESW) are calculated using the current direction. The car then creates a vertex in this position, records the distance and the adjacency, before turning and continuing searching the maze.

if lineFound == False: # find out which directions are possible to turn.

                self.driver.turn(-30)

                directions = self.check\_line()

                self.screen.print(directions)

                abs\_directions = [False,False,False,False] # a list of the directions in NESW

                if "Left" in directions:

                    abs\_directions[(dirfacing-1)%4] = True

                if "Right" in directions:

                    abs\_directions[(dirfacing+1)%4] = True

                if "Back" in directions:

                    abs\_directions[(dirfacing+2)%4] = True

                self.driver.straight(50)

                self.maze.add\_vertex(dirfacing, self.driver.distance(), abs\_directions)

                self.driver.reset()

                self.driver.drive(0,0)

                if "Left" in directions:

                    self.driver.turn(-90)

                    evLogger.log("Found Corner")

                elif "Right" in directions:

                    self.driver.turn(90)

                    evLogger.log("Found Corner")

                elif "Back" in directions:

                    # problem here, as it doesnt know that the vertex

                    # before this vertex is going to be the next vertex.

                    # Hence, needs some condition to know it needs to

                    # navigate to another vertex that isnt complete.

                    self.driver.turn(180)

                    evLogger.log("Found Dead End")

Once the maze has been navigated, and the end has been found, the final vertex is added. Then, the final path is stored and logged with weights and labels. The search is then complete.

        abs\_directions = [False,False,False,False]

        abs\_directions[(dirfacing+2)%4] = True

        self.maze.end = chr(self.maze.label\_index)

        self.maze.add\_vertex(dirfacing, self.driver.distance(), abs\_directions)

        try:

            evLogger.log(self.maze.Dijkstras())

        except Exception as e:

            evLogger.log(e)

        evLogger.log("Search Complete") # logs that the search algorithm is done.

The checkline algorithm checks the space around the current vertex/corner to identify where the car can turn down. This subroutine then returns a list of relative directions to converted into absolute directions for use with Dijkstra’s and the graph traversal.

    def check\_line(self): # finds which directions are possible to turn.

        evLogger.log("Check Line algorithm")

        self.driver.drive(0,0) # stops the motors

        rel\_angle = 0

        possible\_dirs = []

        while rel\_angle<330:

            self.driver.turn(10)

            if rel\_angle > 0 and rel\_angle < 135 and "Right" not in possible\_dirs and self.colsense.color() == Color.RED:

                possible\_dirs.append("Right")

            if rel\_angle > 135 and rel\_angle < 225 and "Back" not in possible\_dirs and self.colsense.color() == Color.RED:

                possible\_dirs.append("Back")

            if rel\_angle > 225 and rel\_angle < 360 and "Left" not in possible\_dirs and self.colsense.color() == Color.RED:

                possible\_dirs.append("Left")

            rel\_angle+= 10

        return possible\_dirs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 105 | To test if the check line algorithm can detect a line in the range specified | - | - | - | This test has been scrapped, as the function no longer works the same, and the similar functionality is instead tested in test 114. |
| 106 | To test if the graph can store multiple unique vertices within a list during operation | A line with a single corner | That the car will create a vertex with the correct adjacency. | The car creates and stores vertices but overlaps some sections. | Logic needs to be put in place to “Fix” the graph. |
| 107 | To be able to trace out a simple maze | A simple maze is placed down on a surface. | The car can move through the maze without any hinderance. | The car navigates through the maze with some difficulty. The car will sometimes move round a corner slowly, without giving the chance to create a vertex. | The car needs to have a better method of detecting the end of a line, and perhaps reducing the angle to look for the continuing of the line. This will make the algorithm more efficient. |
| 114 | To produce a list of possible directions at any vertex. | A simple maze with 2 right hand turns, 2 left hand turns, 2 dead ends. | At each corner, the correct adjacency directions will be printed on screen. | The car detects the correct adjacency at each vertex and prints this to the screen. | The correct result occurs. This means no work needs to be done for now. |
| 115 | To test the smoothness of the turning within the search. | The car is put on a corner and must navigate it. | The car turns round the corner with minimal jittering. | The car mostly moves round the corner correctly but will always jitter when polling for the adjacency. | The algorithm needs to use another method of turning, such as turning for a certain amount of time without stopping, the continue with the program whilst polling for the red line. Being changed from 10 to 8 seems to be better. |

### 3.3.4 Logger Object

The logger object will be used to log events and to dump and retrieve objects.

The constructor method for the logger object assigns the name of the file that should be written to when logging, the interval of logging (not in use) and the initial start time. The object will then log that it has been instantiated.

class logger:

    loggingActive = True

    def \_\_init\_\_(self, filename="Log.txt") -> None:

        self.filename = filename

        self.interval = 0.1

        self.init\_time = time.time()

        self.log(index=0, lineStart="\n") # logs that it has initialised itself.

        self.ObjectID = "logger"

This subroutine is called when the class itself is called. This will be used for dumping the information about an object and later retrieving it. All the necessary information is collated and placed into a list, called properties across all objects, which is then returned.

def \_\_call\_\_(self):

        properties = []

        properties.append(self.filename)

        properties.append(str(self.interval))

        properties.append(str(self.init\_time))

        properties.append(self.ObjectID)

        return properties

The dump method collects the information about an object, and outputs (or dumps) them into a text file that can be read to retrieve the state of the object.

    def dump(self, args): # dumps an object into a text file

        #finding what increment is next and updating the file to store this increment.

        with open("increment.txt", "r") as openFile:

            for line in openFile: pass

            this\_increment = int(line) + 1

        with open("increment.txt", "w") as openFile:

            openFile.write(str(this\_increment))

        self.object\_increment = this\_increment

        for item in args:

            with open(str(this\_increment) + " " + item.ObjectID, "w") as Tomb:

                for i in range(len(item())):

                    if i == 0:

                        Tomb.write("{}".format(item()[0]))

                    else:

                        Tomb.write("\n{}".format(item()[i]))

                self.log("{} dumped".format(item.ObjectID))

The retrieve method takes all the information from the dumped files and returns an object by passing in the properties into a build method of the class.

    def retrieve(self, searchName, object, index=1): # retrieves an object from a text file

        with open(str(index) + " " + searchName, "r") as Tomb:

            properties = []

            for line in Tomb.readlines():

                properties.append(line.strip())

            return object.build(properties)

The log method hasn’t changed from the previous iteration, still logging the different changes and events in the system.

    def log(self, text="", index = -1, lineStart = ""): # used to log things.

        presets = ["Logger Initialised",

                   "Graph Initialised",

                   "",

                   ""] # creates a list of presets that can be accessed using an index.

        if index == -1:

            pass

        elif index < -1:

            text = "Log Index Does Not Exist"

        else:

            text = presets[index]

        if self.loggingActive:

            with open(self.filename, "a") as writer:

                writer.write(lineStart + "[{}]".format(round(time.time() - self.init\_time, 2)) + text + "\n")

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 116 | To test the logging capabilities of the logger object | A sample start-up of any module with sample log lines | A log file is created, and each event is logged and has the correct timestamp. | The log file is created, when an object is instantiated, the log file has a new line added with a time stamp. | Some timestamps have an incorrect rounded time, such as 58.77000000000001, as the rounding in python falls victim to floating points errors. The error is persistence and cannot be changed. |
| 117 | To test the object serialization of the logger object | A sample object will be created, serialized, then be retrieved, and tested. | The object is dumped and retrieved without any loss of data | The object is dumped and retrieved successfully. | No action needed, the correct output occurs. |

### 3.3.5 Iteration Review

This iteration was the final iteration to be carried out. As a result, this iteration must meet the most success criteria out of all 3 iterations.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria No. | Purpose | Met | Evidence | Improvement to meet criteria |
| 1 | Easy to read Menu titles | Yes | The titles are large text that are easy to read. | None |
| 2 | Easy to understand how to navigate the menu system | Partially | User questionnaires stated that whilst the system is somewhat usable, once several actions are needed, the usability declines and the system will become harder to navigate. | Add more colour and makes menus somewhat different. |
| 3 | Very little text displayed in the menu | Yes |  | None |
| 4 | Algorithm that can calculate a path within a maze consistently and efficiently | Yes | The algorithm executes quickly and efficiently, and when tested multiple times on larger mazes, has come out with the correct result every time. | None |
| 5 | Algorithm that can track out a maze efficiently and consistently. | Partially | The maze is tracked out efficiently, but sometimes the car will create a false corner where it veers off. | Use multiple colour sensors. |
| 6 | Space efficient object storing algorithms | Partially | Whilst the algorithm is not yet implemented into the objects to pack and retrieve, the algorithm still works efficiently with some test objects used. | Add call and retrieve functions to the graph object. |
| 7 | RAM used efficiently during operation | Yes | Very little memory is used during operation. | None |
| 8 | Algorithms will be quick to process data and output information | Yes | Each algorithm takes less than 100 ms to execute unless dependant on the car’s movement. These ones are subject to the battery’s charge and the material the car is on, as this will affect speed and hence algorithm speed. | None |
| 9 | Clear and abstracted user guide with pictures | Yes | In appendix. | Add colour. |
| 10 | The ability to stop the program | Yes | The quit option allows for the exiting of the program. | None |
| 11 | The ability to remotely read data from the system | No | - | Somehow improve the Bluetooth capability of the device. |
| 12 | The ability to remotely write data to a config file in the system | No | - | Somehow improve the Bluetooth capability of the device. |
| 13 | The ability for the car to be stand alone | Partially | The car can navigate a maze without any human interaction (after the button is pressed) but cannot automatically boot up into the correct program. | Use an autorun file that launches on boot. |

# 4 Evaluation

## 4.1 Post development testing

In this section, the tests created in the analysis section are used to black box test the system. This means that the tests will be including users that have no access to the code behind the system, so they don’t know what processes are running in the background. This will allow me to stress test the system and see how it responds to a typical client using the system.

Each test is given a test ID and explained, before presenting the wanted and actual outcomes of the test. This is followed by the actions to take in terms of perfective and corrective maintenance, which will be addressed and explored in a later section of the evaluation.

### 4.1.1 Car’s UI

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 01 | To test the usability of the menus built into the car. | Sample users use and navigate the menu. | The menu is easily usable. | The users reported that the system interface is easy to use for simple tasks but can become more unusable once several tasks are queued. | Improve usability by using colours and different font styles, as well as introducing a Desktop view for the car. |
| 02 | To test the systems overload capability and robustness. | Button inputs. | The system does not slow down significantly when many buttons are pressed. | The system does not slow down significantly when many buttons are pressed. | None |
| 03 | To test what happens if the pointer is incremented beyond 3. | - | The pointer will not be able to go beyond 3. | The pointer increments beyond 3, but does not show on screen | Could limit value to 3 |

### 4.1.2 Desktop UI

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 05 | Testing the usability of the menu system. | User testing | The user finds the system usable and can easily navigate the system | The system does not connect to any computer wirelessly. | Setup a way to connect consistently or at all |
| 06 | Testing the overloading capability of the system when taking many inputs. | Many button presses | The system remains stable and only executes one subroutine at a time. | The system does not connect to any computer wirelessly. | Setup a way to connect consistently or at all |
|  |  |  |  |  |  |

### 4.1.3 Search Algorithm

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 08 | To test how well the car can navigate a simple maze. | A small easy maze with a very little number of corners and no dead ends. | The maze is navigated successfully. | The maze is navigated successfully most of the time | Perfective maintenance needed to ensure the car stays on the track. Sometimes the car will veer off and identify a false corner. |
| 09 | To test how well the car can navigate a medium difficulty maze. | A medium maze with 4-5 corners and a dead end. | The maze is navigated successfully. | The maze is navigated successfully most of the time | Perfective maintenance needed to ensure the car stays on the track. Sometimes the car will veer off and identify a false corner. |
| 10 | To test how well the car can navigate a difficult maze, testing how robust the search algorithm is. | A difficult, large maze with many corners and dead ends. | The maze is navigated successfully. | The maze is navigated successfully most of the time | Perfective maintenance needed to ensure the car stays on the track. Sometimes the car will veer off and identify a false corner. |

### 4.1.4 Dijkstra’s Algorithm

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 11 | To test the efficiency of Dijkstra’s algorithm on a small, simple maze. | Test output 08 | The algorithm identifies and returns the best path. | The algorithm identifies and returns the best path. | None |
| 12 | To test the efficiency of Dijkstra’s algorithm on a medium maze with a dead end. | Test output 09 | The algorithm identifies and returns the best path. | The algorithm identifies and returns the best path. | None |
| 13 | To test how the algorithm deals with larger, more complex mazes with dead ends.  Understanding how robust the algorithm is. | Test output 10 | The algorithm identifies and returns the best path. | The algorithm identifies and returns the best path. | None |

### 4.1.5 Run All Algorithm.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 14 | To test if the car can navigate a simple maze, find the shortest path, and complete the shortest path. | Test 08 | The algorithm runs through the maze, solves it and then completes the maze. | The algorithm tracks out the maze and solves it, but does not run through the most optimal path | Perfective maintenance needed to complete the final run through of the maze. |
| 15 | To test if the car can navigate a medium maze with a dead end, find the shortest path, and complete the shortest path. | Test 09 | The algorithm runs through the maze, solves it and then completes the maze. | The algorithm tracks out the maze and solves it, but does not run through the most optimal path | Perfective maintenance needed to complete the final run through of the maze. |
| 16 | To test if the car can navigate a difficult maze with several dead ends, find the shortest path, and complete the shortest path. | Test 10 | The algorithm runs through the maze, solves it and then completes the maze. | The algorithm tracks out the maze and solves it, but does not run through the most optimal path | Perfective maintenance needed to complete the final run through of the maze. |

### 4.1.6 Log File Algorithm

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 17 | To test the logging capabilities of the system | Boot up and shutdown. | Logs are made for system boot up and shutdown | The Logger object logs that the system has shutdown and any events in between. | None |
| 18 | To test how the logging handles an unexpected shutdown or exit. | Boot up and shutdown incorrectly. | Logs are made for system boot up and shutdown | The logger object does not log that the system is unexpectedly shutdown. | Perfective maintenance needed for the system to know when an unexpected shutdown occurs. |
| 19 | To test the storage and retrieval of an object. | Graph object stored and then retrieved. | The object is stored correctly, and data is retrieved correctly. | The logger object does not yet store or retrieve objects. | Perfective maintenance needed to implement a build and store function in the graph object. |

### 4.1.7 Motor Control

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test ID | Purpose | Data/Input | Expected Outcome | Actual Outcome | Action taken or Maintenance |
| 20 | For the car to follow a line for a set distance | - | The car moves along the path and stops at the end | The car follows the straight line. | None |
| 21 | For the car to turn and return each possible direction | Simple T path | The car correctly identifies which ways it can turn. | The car turns around and returns the correct adjacency of the current corner. | None |

## 4.2 Evaluation of the final solution

### 4.2.1 Measuring the Success of the Solution

| Criteria No. | Criteria | Evidence of Completion | Explanation of Evidence | Criteria Met |
| --- | --- | --- | --- | --- |
| 1 | Easy to read Menu titles | The questions answered by some sample users were gathered and noted down. | The title is obvious to any user that has read the user manual, and whilst the text might not be the most readable, the spacing between the lines of text allow the user to easily view which menu they are in and the different options available. | Yes |
| 2 | Easy to understand how to navigate the menu system | The questions answered by some sample users were gathered and noted down. | Whilst the menus are mostly usable when only a few operations are required, once the user starts to navigate back and forth between menus, the lack of direct menu linking negatively impacts the UX, returning to the main menu every time. | Partially |
| 3 | Very little text displayed in the menu | The minimum amount of text is used to describe each operation. | Some of the operation titles may be lengthy compared to the screen, but they are of minimal length to adequately describe the operation they execute. | Yes |
| 4 | Algorithm that can calculate a path within a maze consistently and efficiently | Tests 11, 12, 13 display how the car calculates the quickest path through a maze of varying sizes. | Dijkstra’s algorithm, whist not the most efficient, is efficient and reliable enough to use. The tests display this by returning the correct quickest path through each maze and executing the algorithm in a short time. | Yes |
| 5 | Algorithm that can track out a maze efficiently and consistently. | Tests 08, 09, 10 display how efficiently and consistently mazes of different sizes are navigated. | The car will navigate the maze without any problems most of the time, however occasionally the car will lose the line enough to believe that there is a corner beneath it and start to search for the line. | Partially |
| 6 | Space efficient object storing algorithms | Not tested on graph object. | Since the pickle library was not supported by the version of python available on the EV3 brick, the algorithms had to be built from the ground up to support the system. This meant that whilst the algorithm was lightly tested on some simple objects and classes, the graph object was not. Hence, I don’t know how efficient the algorithm will be on a full graph object. | Partially |
| 7 | RAM used efficiently during operation |  | This evidence is from a previous iteration, but since the algorithm has been tested since, and the result has been the same, there is no change in the evidence used. The total memory used is roughly half of the total memory available, allowing for many more objects to be created before the system RAM becomes full. | Yes |
| 8 | Algorithms will be quick to process data and output information |  | The time taken for algorithms that do not depend on the car’s movement are always quick and repeatable. However, the algorithms that rely on the speed of the car are sometimes unreliable when an error occurs with the car’s movement. | Partially |
| 9 | Clear and abstracted user guide with pictures | In appendix. | Whilst some colour would go a long way to develop the user guide, currently it is sufficient to be used by any client. The user guide displays the basic operations and gives a visual interpretation of each menu. | Partially. |
| 10 | The ability to stop the program | A quit option in the main menu. | The quit button can be navigated to and pressed, allowing the system to correctly save and shutdown. | Yes |
| 11 | The ability to remotely read data from the system | N/A | The inability to use Bluetooth with the EV3 led to the lack of development of any remote tools. As a result, this means that the system will need some perfective maintenance to implement this feature set. | No |
| 12 | The ability to remotely write data to a config file in the system | N/A | The inability to use Bluetooth with the EV3 led to the lack of development of any remote tools. As a result, this means that the system will need some perfective maintenance to implement this feature set. | No |
| 13 | The ability for the car to be stand alone | The menus and error reporting present in the car. | The Menus present in the car allow for the user to interact with the variables and subroutines of the car. The Error reporting allows for the user to understand when an error occurs. Both features allow for an improved UX. |  |

### 4.2.2 Usability

| Feature ID | Description | Evidence | Justification of success | Feature Met |
| --- | --- | --- | --- | --- |
| F1 | Make text large and readable with clear indication. | The text is sufficiently sized and spaced out to be acceptably readable. | Since the text has been spaced out reasonably on screen and the size is big enough to read comfortably, this feature is a success. The menu title is dynamically placed between menus, so the menu title is more readable. | Yes. |
| F2 | Easy to understand menu structure | User Questionnaires state that whilst functional, the menus are somewhat similar and so can be confusing to navigate back to the main menu before opening another menu. | Since the menus are somewhat usable, they can be considered a partial success. This means with some perfective maintenance they can be improved and made far more user friendly. | Partially |
| F3 | Easy to find and use instructions on how to use the system | Instruction Manual in appendix. | The Instructions are plain and simple, and easily accessible. Some colour may go a long way to engage the user more, but this can be done with perfective maintenance. | Yes |
| F4 | Visibility of current system state | self.screen.load\_image(self.image\_directory+"backward.png")  The screen loads an image to tell the user which direction it is moving. | The user will see exactly what the car is doing on the screen, allowing for a better UX. However, future maintenance may improve this feature by using text-to-speech. This will identify errors without looking at the screen. | Yes |
| F5 | Error catching and prevention | except Exception as e:       Car.screen.print("hmmm, this didnt work")       evLogger.log(e)       time.sleep(1)  The system catches any errors when running and outputs to the screen that something has occurred, and logs exactly what has occurred. | The system needed to have a basic error catching system to allow for some errors which are unavoidable. Since the screen will have a line of text telling the user that something has gone wrong, the user will know to investigate the log files | Yes |
| F6 | Any icons match the real-world design | N/A | There is no evidence for usage of icons that match the real-world designs such as motors or sensors. | No |
| F7 | Text has appropriate colouring. | N/A | All text is the same colour, so the sections can’t be easily defined by means of colour. Some perfective maintenance to include lines of code that change the colour of the text could be implemented. | No |

### 4.2.3 Maintenance issues and limitations

#### Limitations

|  |  |  |
| --- | --- | --- |
| Limitation | Description | How the solution could be developed to avoid this. |
| The usability of the menu.  (Test ID: 01) | The usability of the menus needs to be improved to be more accessible to newer users. Whilst the menus are simplistic, and a user guide has been made, test users still found it hard to navigate between different menus as the main menu had to be navigated to every time. | Add some colour to each menu to the menus are not monochromatic and more user friendly.  Add some way to link between menus, such as a shortcut button, to easily move between commonly used menus. |
| The ability to connect to the car remotely.  (Test ID: 05, 06) | The ability to use Bluetooth with the EV3 brick is one its advertised features. As such, I expected to be able to use it to remotely interface with the car. Unfortunately, the OS required to run python does not have good support. | Use a Bluetooth dongle with the car to alleviate any problems with the onboard receiver. Use some different OS with better Bluetooth support. Use another system altogether, such as NXT or SPIKE. |
| The car veering off track sometimes.  (Test ID: 08,09,10) | The car will sometimes move too far away from the track, making it believe that there is a corner beneath it. This will create an unnecessary vertex in the graph, and any distances will be skewed. | Use another sensor to determine if the car has veered off.  Ensure the maze meets certain specifications. |
| Not having the final completion of the best route of the maze  (Test ID: 14,15,16) | The car does not yet traverse the maze once the best path has been found. | Implement some code to drive back along the best path, or even to keep searching for more paths, back to the start and traverse the best-found path. |
| Not being able to know when an unexpected shutdown occurs.  (Test ID: 18) | The code does not know if there has been a system shutdown that has not saved data. | Use a file that determines if the car is currently doing a process and compare against that file every boot to determine if there has been a shutdown. |
| Not being able to store previous graphs.  (Test ID: 19) | Previous graphs can’t be selected and ran from any menu. The graphs data also can’t be stored in any capacity, so each time the maze must be searched. | Use the current Logger object to store the graph in a text file, using a call method with the graph to rebuild it from data. |

#### Corrective Maintenance

Corrective maintenance is used to repair and fix any components that fail during operation.

| Test ID | Maintenance Needed | Possible limitations of further maintenance |
| --- | --- | --- |
| 01 | Add colours to each of the menus to make them more appealing to users, and to increase usability. Using different font styles will also improve usability. | The screen might become to crowded, and if colours are not consistent, then the usability will be reduced. |
| 05/06 | There needs to be a desktop version of the UI developed that can interface directly with the car. | The Bluetooth capability of the system is largely limited by the OS, meaning the OS will need to be changed, potentially introducing new errors when copying code across. |
| 08/09/10 | The car will sometimes veer off track. This means that some sensors may need to be attached to allow the car to understand more often when there is a corner present. | The EV3 can only handle 1 sensor of each type, so another type of sensor needs to be used. This means the maze will need to be adjusted to consider this new sensor. |

#### Perfective Maintenance

Perfective maintenance addresses the missing functionality and usability of the system. This section looks at the criteria and functionality not yet met by the code and the project.

| Criteria/ functionality ID | Maintenance needed | Possible limitations of further maintenance |
| --- | --- | --- |
| 1 | Adding colour to each menu will allow for a better user experience. This will allow the user to understand and navigate each menu more easily. | Adding too much colour will reduce the usability of the system.  The system will need to be colour coded correctly and uniformly, with specific font and colour styles for each section and each menu title. |
| 2 | Some type of direct linking between menus to make navigation more natural. The more fluent the menus are, the easier it will be for the user to navigate the system and attain the required output. | If the menu is made too overly complicated, then the UX will be reduced. This will prevent the user from performing necessary tasks and using the system. |
| 5 | To make the search algorithm more reliable, another sensor will need to be added. This will give the car another point of reference to identify if a corner has been met or if the car has simply veered off the line. | The EV3 brick cannot support 2 sensors of the same type. So, using 2 colours sensors is not an option. This means a different type of sensor such as a light intensity sensor could be used. |
| 6 | The graph object needs to be set up with a couple of functions that can store and restore a graph into text format for the logger object to copy to a file. | The graph object will have many different vertices once complete. This means the logging object must know how many vertices are present before the graph can fully rebuild. |
| 8 | The reliability and robustness of the search algorithm needs to be improved to state that all algorithms will be quick to process data and output relevant information. | The car’s ability to track through the maze is completely dependant on the physical properties of the maze and the car, so whilst the maze might be fully current and valid, some slight imperfection in the starting position of the car might result in the failure to navigate the maze. |
| 9 | More colour is needed to allow for the user guide to connect with the user, and fully inform them of each aspect of the system, and how to use each menu. There also needs to be more pages with more information on future maintenance needed to keep the car working. | There is the potential for the user guide to become over complicated and colourful, detracting from its effectiveness. This means that the user could become more confused and unable to use the system after reading the guide. |
| 11 | The EV3 brick needs to be able to communicate via Bluetooth to setup remote controls within the system. This will allow for the EV3 to connect to a computer wirelessly, and have files changed whilst the system is running. | The EV3 Bluetooth support is non-existent with the OS chosen. This means that the OS will have to be changed or a receiver may have to be used to link the two together. |
| F2 | The user experience of the menus needs to be improved. This could be done by using more colour or a better font, but the whole experience and navigation needs to be much more natural and more fluent. This could be done by adding a return to previous menu option. | Increasing the amount of information in each menu will detract from the overall UX without some type of adjustment. If too much information is present on the screen, then the user may not be able to see it all. This means that the whole output system within each menu will need to be redone, potentially introducing new errors. |
| F6 | Icons with the system are not present. This means that some new icons such as starting up and shutting down need to be added, as well as the images of each component of the hardware. | The screen may not be big enough to display any image, so the images will need to be small enough to fit onto it. The images may also not be relevant, as the user will easily be able to see what is happening. This should only be improved once the desktop UI has been developed. |

# Appendix

## Easy Test Mat

The below test mat will be scales up. This means each edge will be roughly 50 in length.



## Medium Test Mat

The Below test mat will be scaled up. The Length AB should be 50 cm.



## Difficult Test Mat

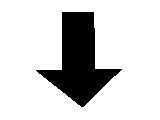
## Motor Control Test Mat

The motor control mat will need to be scaled up so that the length indicated is exactly one meter.

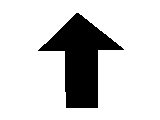


## Images

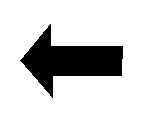
### Backward



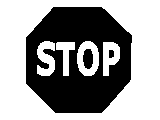
### Forward



### Left/Turning



### Stop



## Graphical user interface Description automatically generatedInstruction manual



Diagram

Description automatically generated

Diagram

Description automatically generated

A picture containing diagram

Description automatically generated

Diagram

Description automatically generated

A picture containing table

Description automatically generated

## Final Code

### Main.py

#!/usr/bin/env pybricks-micropython

#This is the Second menu prototype, which will include running subroutines from the menu

#This version will include the OOP approach

import Logger

import Graphing

# Imports

import os

import time

from pybricks.hubs import EV3Brick

from pybricks.ev3devices import (Motor, TouchSensor, ColorSensor,

                             InfraredSensor, UltrasonicSensor, GyroSensor)

from pybricks.parameters import Port, Stop, Direction, Button, Color

from pybricks.tools import wait, StopWatch, DataLog

from pybricks.robotics import DriveBase

from pybricks.media.ev3dev import SoundFile, ImageFile

# This program requires LEGO EV3 MicroPython v2.0 or higher.

# Click "Open user guide" on the EV3 extension tab for more information.

class math: # allows me add math functions to class, and easily replace math.inf

    inf = float("inf")

class Menu: # used for the different submenus in the UI

    def \_\_init\_\_(self, name, titlesList:list, subroutines=[]) -> None:

        self.name = name

        self.titles = titlesList

        self.subroutines = subroutines

        self.ObjectID = "menu"

    def draw(self, screen, pointer): # draws onto the ev3 screen

        screen.draw\_text(170-(len(self.name)\*10), 5, self.name)

        screen.print("")

        for i in range(len(self.titles)):

            if pointer == i:

                screen.print(self.titles[i]+" <--")

            else:

                screen.print(self.titles[i])

class car:

    def \_\_init\_\_(self):

        self.ev3 = EV3Brick()

        self.screen = self.ev3.screen

        self.buttons = self.ev3.buttons

        self.motorA = Motor(Port.A)

        self.motorD = Motor(Port.D)

        self.driver = DriveBase(self.motorD,self.motorA,31,190) # wheels have diameter of 31mm and a drivebase width of 190mm

        self.colsense = ColorSensor(Port.S4) # Left out as wont work right now, FIX THIS!!!!!

        self.speed = 200

        self.driver.settings(straight\_speed=self.speed) # sets the cars speed to 200mm /s

        self.maze = Graphing.Graph("Z", self.screen) # creates a graph with final vertex Z

        self.image\_directory = "Images/"

        self.ObjectID = "car"

    def CalTurning(self): # turns about a point and prints the list of directions possible

        self.screen.clear()

        self.screen.load\_image(self.image\_directory+"left.png")

        directions = self.check\_line()

        self.screen.print(directions)

        evLogger.log(directions)

        time.sleep(10)

    def CalTrackLine(self): # will carry on going down a red line until the line stops

        self.screen.clear()

        runLoop = True

        while runLoop == True:

            time.sleep(0.1)

            lineFound = True

            self.driver.drive(self.speed,0)

            if self.colsense.color() == Color.RED:

                self.screen.load\_image(self.image\_directory+"backward.png")

            if self.colsense.color() != Color.RED: # re-adjust to find the line

                evLogger.log("Lost Line")

                lineFound = False

                self.driver.drive(0,0)

                self.driver.turn(-30)

                rel\_angle = -30

                while rel\_angle<30:

                    self.driver.turn(8)

                    if self.colsense.color() == Color.RED:

                        lineFound = True

                        evLogger.log("Found Line")

                        break

                    if self.colsense.color() == Color.GREEN:

                        runLoop = False

                        lineFound = True

                        evLogger.log("Found End")

                        runLoop = False

                        break

                    rel\_angle += 8

                if lineFound == False:

                    runLoop = False

                    evLogger.log("End of Line Found")

    def SetMotorSpeed(self): # increases or decreases the speed of the motor

        time.sleep(0.5)

        while Button.CENTER not in self.buttons.pressed(): # if the center button is pressed, take this as enter and exit the subroutine

            time.sleep(0.05)

            self.screen.clear()

            self.screen.print(self.speed) # print the current speed.

            if Button.UP in self.buttons.pressed() and self.speed <= 290: # increase the speed if the up button is pressed

                self.speed += 10

            elif Button.DOWN in self.buttons.pressed() and self.screen >= 110: # decrease the speed if the down button is pressed

                self.speed -= 10

        self.driver.settings(straight\_speed=self.speed)

        evLogger.log("driver speed set to {}".format(self.speed))

        time.sleep(5)

    def SetLogType(self): # toggles logging on/off

        self.screen.clear()

        evLogger.loggingActive = not evLogger.loggingActive

        self.screen.print("Logging toggled \n{}".format(evLogger.loggingActive))

        time.sleep(5)

    def SetLogInterval(self):

        time.sleep(0.5)

        while Button.CENTER not in self.buttons.pressed(): # if the center button is pressed, take this as enter and exit the subroutine

            time.sleep(0.05)

            self.screen.clear()

            self.screen.print(evLogger.interval) # print the current speed.

            if Button.UP in self.buttons.pressed(): # increase the speed if the up button is pressed

                evLogger.interval += 0.1

            elif Button.DOWN in self.buttons.pressed(): # decrease the speed if the down button is pressed

                evLogger.interval -= 0.1

        evLogger.log("Logger interval \nset to {}".format(evLogger.interval))

        time.sleep(5)

    def RunAll(self): # runs both of the subroutines: hence will search the maze, then will traverse the maze back and run the complete solved maze

        self.RunSearch()

        self.RunSolved() # needs to run the maze that has just been solved.

    def RunSearch(self):

        self.screen.clear()

        time.sleep(2) # waits 2 secs before starting the search

        evLogger.log("Starting Search")

        self.maze.add\_vertex(0, 0, [True,False,False,False]) # creates the initial vertex: A

        dirfacing = 0 # facing north relative to start

        runLoop = True

        while runLoop == True:

            time.sleep(0.1)

            lineFound = True

            self.driver.drive(self.speed,0) # sets the motors to drive forward

            if self.colsense.color() == Color.RED: # go straight ahead

                self.screen.load\_image(self.image\_directory+"backward.png")

            if self.colsense.color() != Color.RED: # re-adjust to find the line

                evLogger.log("Lost Line")

                lineFound = False

                self.driver.drive(0,0)

                self.driver.turn(-30)

                rel\_angle = -30

                while rel\_angle<30:

                    self.driver.turn(8)

                    if self.colsense.color() == Color.RED:

                        lineFound = True

                        evLogger.log("Found Line")

                        break

                    if self.colsense.color() == Color.GREEN:

                        runLoop = False

                        lineFound = True

                        evLogger.log("Found End")

                        self.screen.load\_image(self.image\_directory+"stop\_1.png")

                        break

                    rel\_angle += 8

            if lineFound == False: # find out which directions are possible to turn.

                self.driver.turn(-30)

                self.screen.load\_image(self.image\_directory+"left.png")

                directions = self.check\_line()

                self.screen.print(directions)

                abs\_directions = [False,False,False,False] # a list of the directions in NESW

                if "Left" in directions:

                    abs\_directions[(dirfacing-1)%4] = True

                if "Right" in directions:

                    abs\_directions[(dirfacing+1)%4] = True

                if "Back" in directions:

                    abs\_directions[(dirfacing+2)%4] = True

                self.driver.straight(50)

                self.maze.add\_vertex(dirfacing, self.driver.distance(), abs\_directions)

                self.driver.reset()

                self.driver.drive(0,0)

                if "Left" in directions:

                    self.driver.turn(-90)

                    dirfacing -= 1

                    evLogger.log("Found Corner")

                elif "Right" in directions:

                    self.driver.turn(90)

                    dirfacing += 1

                    evLogger.log("Found Corner")

                elif "Back" in directions:

                    # problem here, as it doesnt know that the vertex

                    # before this vertex is going to be the next vertex.

                    # Hence, needs some condition to know it needs to

                    # navigate to another vertex that isnt complete.

                    dirfacing += 2

                    self.driver.turn(180)

                    evLogger.log("Found Dead End")

        abs\_directions = [False,False,False,False]

        abs\_directions[(dirfacing+2)%4] = True

        self.maze.end = chr(self.maze.label\_index)

        self.maze.add\_vertex(dirfacing, self.driver.distance(), abs\_directions)

        try:

            evLogger.log("Dijkstra's")

            evLogger.log(self.maze.Dijkstras())

        except Exception as e:

            evLogger.log(e)

        evLogger.log("Network")

        for item in self.maze.Permanent:

            evLogger.log("{},{}".format(item.label, item.adjacencyLabels))

        evLogger.log("Search Complete") # logs that the search algorithm is done.

    def check\_line(self): # finds which directions are possible to turn.

        evLogger.log("Check Line algorithm")

        self.driver.drive(0,0) # stops the motors

        rel\_angle = 0

        possible\_dirs = []

        while rel\_angle<330:

            self.driver.turn(10)

            if rel\_angle > 0 and rel\_angle < 135 and "Right" not in possible\_dirs and self.colsense.color() == Color.RED:

                possible\_dirs.append("Right")

            if rel\_angle > 135 and rel\_angle < 225 and "Back" not in possible\_dirs and self.colsense.color() == Color.RED:

                possible\_dirs.append("Back")

            if rel\_angle > 225 and rel\_angle < 360 and "Left" not in possible\_dirs and self.colsense.color() == Color.RED:

                possible\_dirs.append("Left")

            rel\_angle+= 10

        return possible\_dirs

    def RunSolved(self): # will take any of the previously solved mazes, and execute the path.

        pass

class main: # will hold the main section of the program. useful for dropping in different main loops

    def \_\_init\_\_(self) -> None:

        self.active = True

        self.ObjectID = "main"

    def runMain(self): # the main section of the code is here vvv

        Car = car()

        MainMenu = Menu("Main", ["Run Menu", "Calibration Menu", "Settings Menu", "Quit"])

        RunMenu = Menu("Run", ["Run All", "Run Search", "Run Solve", "Main Menu"])

        CalMenu = Menu("Calibration", ["Track Line", "Turning", "Main Menu"])

        SetMenu = Menu("Settings", ["Motor Speed", "Logging Type", "Logging Intervals", "Main Menu"])

        MainMenu.subroutines = [RunMenu, CalMenu, SetMenu, self.Exit]

        RunMenu.subroutines = [Car.RunAll, Car.RunSearch, Car.RunSolved, MainMenu]

        CalMenu.subroutines = [Car.CalTrackLine, Car.CalTurning, MainMenu]

        SetMenu.subroutines = [Car.SetMotorSpeed, Car.SetLogType, Car.SetLogInterval, MainMenu]

        currentMenu = MainMenu

        pointer = 0

        while self.active:

            Car.screen.clear()

            currentMenu.draw(Car.screen, pointer)

            if Button.DOWN in Car.buttons.pressed():

                pointer += 1

                time.sleep(0.05)

            if Button.UP in Car.buttons.pressed():

                pointer -= 1

                time.sleep(0.05)

            if Button.CENTER in Car.buttons.pressed():

                try: # will try to run the subroutine in the current menu

                    if isinstance(currentMenu.subroutines[pointer],Menu):

                        currentMenu = currentMenu.subroutines[pointer]

                        pointer = 0

                    else:

                        currentMenu.subroutines[pointer]()

                except Exception as e:

                    print("hmmm, this didnt work")

                    evLogger.log(e)

            time.sleep(0.2)

        # close the log file here

        Car.screen.clear()

        Car.screen.print("Shutting Down...")

        os.system("sudo shutdown -h now")

    def Exit(self):

        self.active = False

evLogger = Logger.logger()

MyMain = main() # creates the main object

MyMain.runMain() # runs the main section of the code

### Logger.py

import time

class logger:

    loggingActive = True

    def \_\_init\_\_(self, filename="Log.txt") -> None:

        self.filename = filename

        self.interval = 0.1

        self.init\_time = time.time()

        self.log(index=0, lineStart="\n") # logs that it has initialised itself.

        self.ObjectID = "logger"

    def \_\_call\_\_(self):

        properties = []

        properties.append(self.filename)

        properties.append(str(self.interval))

        properties.append(str(self.init\_time))

        properties.append(self.ObjectID)

        return properties

    def dump(self, args): # dumps an object into a text file

        #finding what increment is next and updating the file to store this increment.

        with open("increment.txt", "r") as openFile:

            for line in openFile: pass

            this\_increment = int(line) + 1

        with open("increment.txt", "w") as openFile:

            openFile.write(str(this\_increment))

        self.object\_increment = this\_increment

        for item in args:

            with open(str(this\_increment) + " " + item.ObjectID, "w") as Tomb:

                for i in range(len(item())):

                    if i == 0:

                        Tomb.write("{}".format(item()[0]))

                    else:

                        Tomb.write("\n{}".format(item()[i]))

                self.log("{} dumped".format(item.ObjectID))

    def retrieve(self, searchName, object, index=1): # retrieves an object from a text file

        with open(str(index) + " " + searchName, "r") as Tomb:

            properties = []

            for line in Tomb.readlines():

                properties.append(line.strip())

            return object.build(properties)

    def log(self, text="", index = -1, lineStart = ""): # used to log things.

        presets = ["Logger Initialised",

                   "Graph Initialised",

                   "",

                   ""] # creates a list of presets that can be accessed using an index.

        if index == -1:

            pass

        elif index < -1:

            text = "Log Index Does Not Exist"

        else:

            text = presets[index]

        if self.loggingActive:

            with open(self.filename, "a") as writer:

                writer.write(lineStart + "[{}]".format(round(time.time() - self.init\_time, 2)) + text + "\n")

### Graphing.py

class math: # allows me add math functions to a class, and easily replace math.inf

    inf = float("inf")

class Vertex():

    def \_\_init\_\_(self, label):

        self.label = str(label)

        # North, East, South, West

        self.adjacencyLabels = ["","","",""] # dictionary of the adjacent verticies

        self.adjacencyWeights = [math.inf, math.inf, math.inf, math.inf] # has all the connected arc weights set to infinity

        self.adjacencyPot = [False,False,False,False] # currently, no directions are possible

        self.totalweight = math.inf

        self.permanent = False

        self.previousVertex = ""

        self.previousDir = 0

    def update\_adjacency(self, input = [[],[],[],[]]):

        for i in range(0,4):

            try:

                if len(input[i]) == 2:

                    self.adjacencyLabels[i] = str(input[i][0])

                    self.adjacencyWeights[i] = int(input[i][1])

            except:

                print("one of your values isn't the correct type")

    def \_\_call\_\_(self):

        properties = []

        properties.append(self.label)

        for i in range(len(self.adjacencyLabels)):

            properties.append("{},{}".format(self.adjacencyLabels[i], self.adjacencyWeights[i]))

        return properties

    def build():

        pass

class Graph():

    def \_\_init\_\_(self, end\_label, screen):

        self.network = []

        self.label\_index = 65 # 65 in unicode is A, works as an offset

        self.end = end\_label

        self.nullVertex = Vertex("\*")

        self.finalPath = ""

        self.finalLength = math.inf

        self.Permanent = []

        self.screen = screen

    def \_\_call\_\_(self):

        properties = []

        for item in self.network:

            properties.append(item())

        properties.append("{};{}".format(self.end, self.label\_index))

        properties.append("{};{}".format(self.finalPath, self.finalLength))

        return properties

    def add\_vertex(self, direction, distance, possibleDirs):

        if self.find\_vertex(self.network, self.label\_index).label == "\*":

            Vert = Vertex(chr(self.label\_index))

            if chr(self.label\_index) == "A": # if the vertex is the initial vertex

                Vert.adjacencyPot[0] = True

            else: # if the vertex is any other vertex in the maze

                # updating the previous vertex

                previous\_vertex = self.find\_vertex(self.network, chr(self.label\_index - 1))

                adjacency = [[],[],[],[]]

                adjacency[direction%4] = [chr(self.label\_index),distance]

                previous\_vertex.update\_adjacency(adjacency)

                # updating the new vertex

                prev\_label = chr(self.label\_index - 1)

                adjacency = [[],[],[],[]]

                prev\_dir = (direction+2)%4 # calculates the direction that the link should be made

                adjacency[prev\_dir] = [prev\_label,distance]

                Vert.update\_adjacency(adjacency)

                Vert.adjacencyPot = possibleDirs

            self.network.append(Vert)

        self.label\_index += 1 # increments the label by 1 e.g A -> B

    def Dijkstras(self):

        self.fixGraph()

        Queue = []

        for item in self.network:

            Queue.append(item)

        for item in Queue:

            print("\n{}:### {}".format(item.label, item.adjacencyLabels))

        Queue[0].totalweight = 0 # sets the initial vertex weight to 0

        end\_vertex = self.find\_vertex(Queue, self.end)

        while end\_vertex in Queue: # the main loop which checks all the vertices

            self.bubble(Queue) # sorts the queue

            current\_vertex = Queue.pop(0) # similar to the dequeue in static languages

            current\_vertex.permanent = True

            self.Permanent.append(current\_vertex)

            for i in range(0,4): # iterates from 0 to 3, stops when at 4

                dirVertex = self.find\_vertex(Queue,current\_vertex.adjacencyLabels[i]) # finds the vertex in the direction

                if dirVertex.totalweight > current\_vertex.totalweight + current\_vertex.adjacencyWeights[i]:

                    dirVertex.totalweight = current\_vertex.totalweight + current\_vertex.adjacencyWeights[i]

                    dirVertex.previousVertex = current\_vertex.label

                    dirVertex.previousDir = i

        # Output the final path to follow

        self.finalPath = self.findPath(self.Permanent, self.end)

        return self.finalPath

    def findPath(self, final\_list, curlabel, output = ""): # traces the path back to the start

        dirList = ["Left", "Right", "Rear", "Front"]

        curVertex = self.find\_vertex(final\_list, curlabel)

        output += "\n{},{},{}".format(curVertex.label, curVertex.totalweight, dirList[curVertex.previousDir])

        if curVertex.label == "A":

            return output

        else:

            return self.findPath(final\_list, curVertex.previousVertex, output)

    def find\_vertex(self, Queue, label):

        if len(Queue)>0:

            for item in Queue:

                if item.label == label:

                    return item # returns the vertex

        return self.nullVertex

    def bubble(self, queue): # sorts the vertices by weight from start

            swaps = 1

            while swaps > 0:

                swaps = 0

                for i in range(0, len(queue)-1):

                    if queue[i].totalweight > queue[i+1].totalweight:

                        queue[i], queue[i+1] = queue[i+1], queue[i] # swaps the two values round

                        swaps += 1

            return queue # returns the sorted version of queue

    def fixGraph(self): # fixes the graph so that vertices are not 'hopped' over

        for vert\_i in self.network:

            for vert\_j in self.network:

                for i in range(0,4):

                    if vert\_i.label != vert\_j.label and vert\_i.adjacencyLabels[i] == vert\_j.adjacencyLabels[i] and len(vert\_j.adjacencyLabels[i])>0:

                        if vert\_i.adjacencyWeights[i] <= vert\_j.adjacencyWeights[i]:

                            firstVert = vert\_j

                            secondVert = vert\_i

                            thirdVert = self.find\_vertex(self.network, firstVert.adjacencyLabels[i])

                        elif vert\_j.adjacencyWeights[i] <= vert\_i.adjacencyWeights[i]:

                            firstVert = vert\_i

                            secondVert = vert\_j

                            thirdVert = self.find\_vertex(self.network, firstVert.adjacencyLabels[i])

                        print(firstVert.label, secondVert.label, thirdVert.label)

                        firstVert.adjacencyLabels[i] = secondVert.label

                        firstVert.adjacencyWeights[i] = firstVert.adjacencyWeights[i] - secondVert.adjacencyWeights[i]

                        secondVert.adjacencyLabels[(i+2)%4] = firstVert.label

                        secondVert.adjacencyWeights[(i+2)%4] = firstVert.adjacencyWeights[i]

                        thirdVert.adjacencyLabels[(i+2)%4] = secondVert.label

                        thirdVert.adjacencyWeights[(i+2)%4] = secondVert.adjacencyWeights[i]

#G1 = Graph("G")

#G1.add\_vertex(0,0, [True,False,False,False])

#G1.add\_vertex(0,4,[False,True,True,True])

#G1.add\_vertex(-1,4,[False,True,False,False])

#G1.add\_vertex(1,8,[True,False,False,True])

#G1.add\_vertex(0,4,[False,True,True,True])

#G1.add\_vertex(-1,4,[False,True,False,False])

#G1.add\_vertex(1,8,[False,False,False,True])

#print(G1.Dijkstras())

#print("\n\nnetwork values#################")

#for item in G1.network:

    #print("\n{},{},{}".format(item.label, item.previousVertex, item.totalweight))