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# Introduction

The main aim of this project is to create an application that can:

* Implement a routing algorithm capable of dealing with an institute the size of the John Anderson campus.
* Visualise this route in a way that a user can easily understand.

In addition to this over the course of the project an investigation should be carried out into the feasibility of including route modifiers and location services into this application. For the purposes of this report Route Modifiers are defined as settings which depending on their values will give different routes for different users. An example of this would be to avoid stairs. Location services would be some way of automatically determining where the user is within the mapped section. This could then be used to either provide Dynamic Routing as they follow the path or to simply allow them to input their start location more easily.

# Project Planning and Organisation

This project took place over several months which meant that if time was not managed carefully important tasks may have been left incomplete. From this need a project plan was developed.

# Research

Before any development work could begin several key questions had to be answered about how the project should proceed: Would the application provide static or dynamic routing to the user? How would the Application be developed? How would the shortest path be found?

## Application Type

It was decided that the application should be able to be used on mobile devices as this offers the greatest levels of flexibility to the user. This means the user could use it throughout the day as they traverse the mapped area as opposed to having to plan their routes for the day in advance. With this requirement in mind there are two main types of application that would be possible a Web Application or a Native Application [1].

### Web Application

These applications are developed to be ran within a web browser. This means that they can be used across virtually any device including both mobile devices and more traditional computing platforms. They are designed and built as a website with special care taken to appear correctly on mobile devices. This means they can be accessed by navigating to a particular webpage on the phone.

### Native Application

Native applications are built specifically for the mobile operating system being targeted. This means if it is built for Android it cannot be used on iOS or vice versa. To use a Native application, they are first installed from an OS specific store (either the App Store for iOS or the Google Play Store for Android). They can then be launched from a home menu.

### Comparison of Native and Web Applications

To decide between Native and Web Applications they must be compared on a number of key features to the project. This reasoning can be seen in Table 1.

Table Comparison of Native and Web Applications on Key Issues

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Issue to compare | Native Application | Web Application | Which is better for this project | Reason |
| Portability | Can only be used on the OS it was designed for. | Can be used on virtually any Operating System that includes support for a web browser. | Web | If this was to be released it would be important for as many students to have access to it as possible. Although multiple Native Applications could be created it would be far easier to have one Web Application. |
| Performance | Developed specifically for each platform which means greater performance. | Lower performance. | Native | Performance may be an issue as the size of the map increases. Although this is also an issue for the choice of routing algorithm it makes sense to make the later choice easier. |
| Access to phone sensors | Virtually full access to all of the phone sensors. | More restricted access to phone sensors. | Native | This could be important for location services. Although Web applications have access to geolocation information [2] they do not appear to have access to information on Wi-Fi access points they are not currently connected to [3]. Native applications by comparison have access to this information [4]. |
| Programming Language | Uses Object Oriented languages (Java or Objective C) which makes Encapsulation, Abstraction, etc far easier than they would have been otherwise. | Uses JavaScript for the main bulk of work. This can be programmed in an object oriented fashion but it is much more difficult to do so. Does not enforce strict type-checking meaning errors can be made far more easily during development. | Native | It provides a better framework for producing an error free application more quickly. |

As can be seen from Table 1 Native applications have a number of advantages that are important to the project particularly for the study into Location Services feasibility. There are two major choices to be considered when developing a Native Application: Android and iOS.

### Android

These applications are developed specifically for the Android OS and are widely available for download in the Google Play Store. Android phones are produced by a range of manufacturers including Sony, Samsung and HTC.

### iOS

iOS applications are developed specifically for Apple’s mobile devices i.e. the iPhone and iPad. They are available for download on these devices through the App Store.

### Comparison of Android and iOS Applications

A number of issues should be considered before deciding on a platform to build the application for. Several of these are examined in

Table Comparison of Android and iOS Applications on Key Issues

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Issue | iOS | Android | Better for this project | Reason |
| Percentage of users worldwide | 13.9% [5] | 82.8% [5] | Android | Users are far more likely to own an Android phone and therefore be able to use the application. |
| Integration with mapping services | Wide support for many major mapping applications including Google [6] and Bing [7]. | Similar levels of support from the major mapping applications [8] [9]. | Tie | Both options offer similar levels of integration with popular mapping applications. |
| Availability | None. | Several devices of different sizes and features. | Android | Circumstances surrounding the project have dictated these are more easily available. |

For the reasons detailed above the application will be developed as an Android application.

## Static or Dynamic Routing

To determine whether the application should provide static or dynamic routing it is first important to understand what both involve.

### Static Routing

For the purposes of this report Static Routing will be defined as routing between two fixed points with the whole route available for the user to view. A popular example of this is google maps which can be seen in Figure 1.

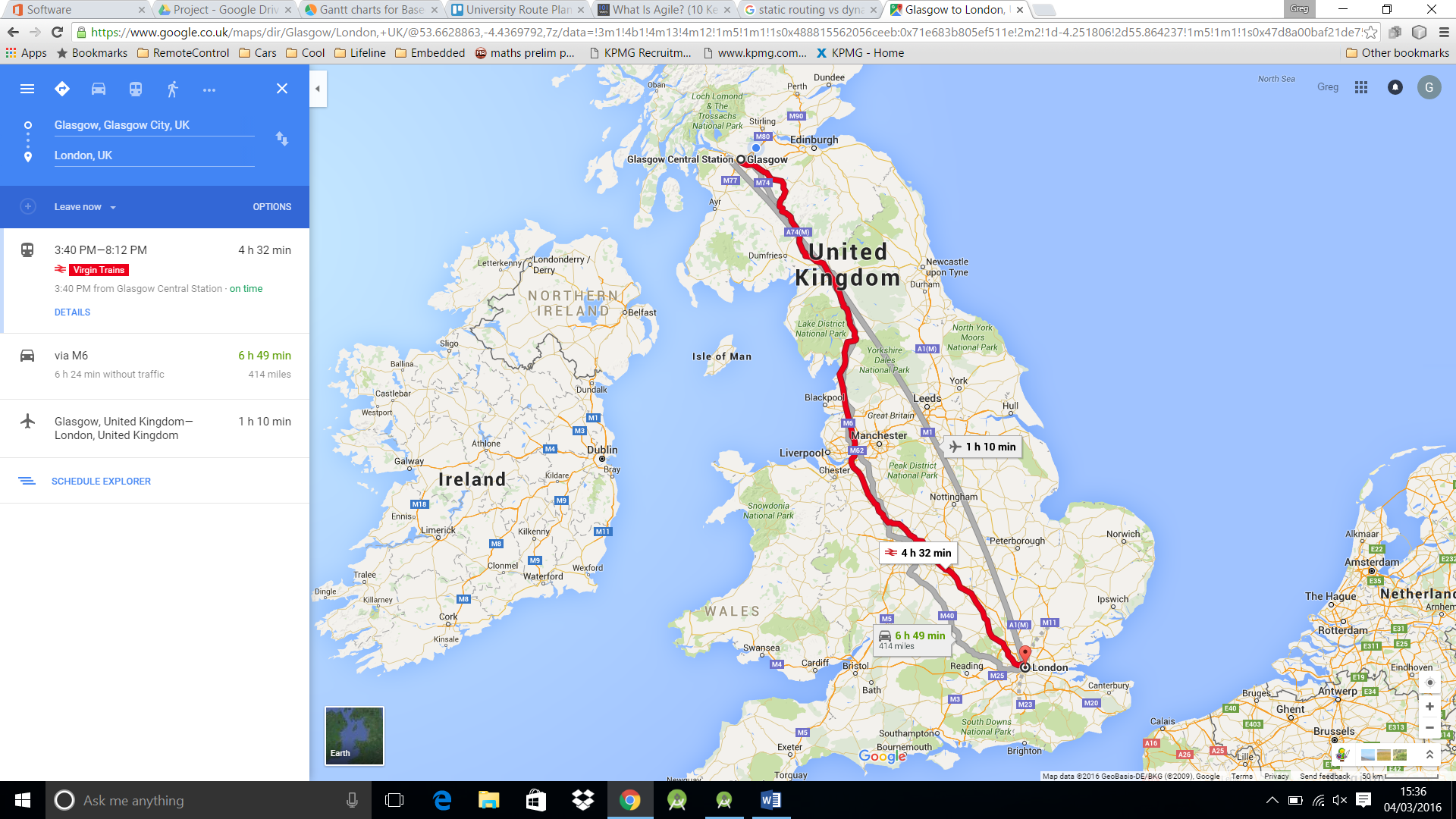


Figure Static Routing Example [10]

### Dynamic Routing

By comparison Dynamic Routing will be defined as routing from the user’s changing location to a fixed endpoint. This means as the user moves the route will automatically adjust to their new location. This is the type of routing used in Satellite Navigation systems or Google Navigation which can be viewed below in Figure 2.

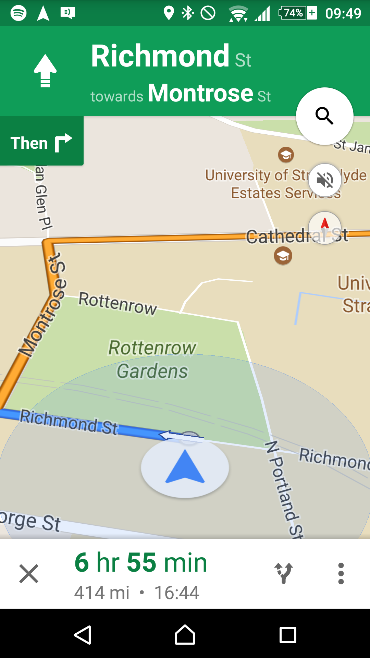


Figure Dynamic Routing Example

It is also common for the display to be more restricted showing only a short section of the route at a time i.e. where the user is to go next.

## Location Services

The main difference between the two types of routing is whether or not they the user’s location is utilised to improve the user interface or not. In order to decide between them then it is important to determine whether this is possible.

There are three main technologies which could be used to determine the user location: Global Positioning Service, Cellular Positioning and Wi-Fi.

### Global Navigation Satellite System (GNSS)

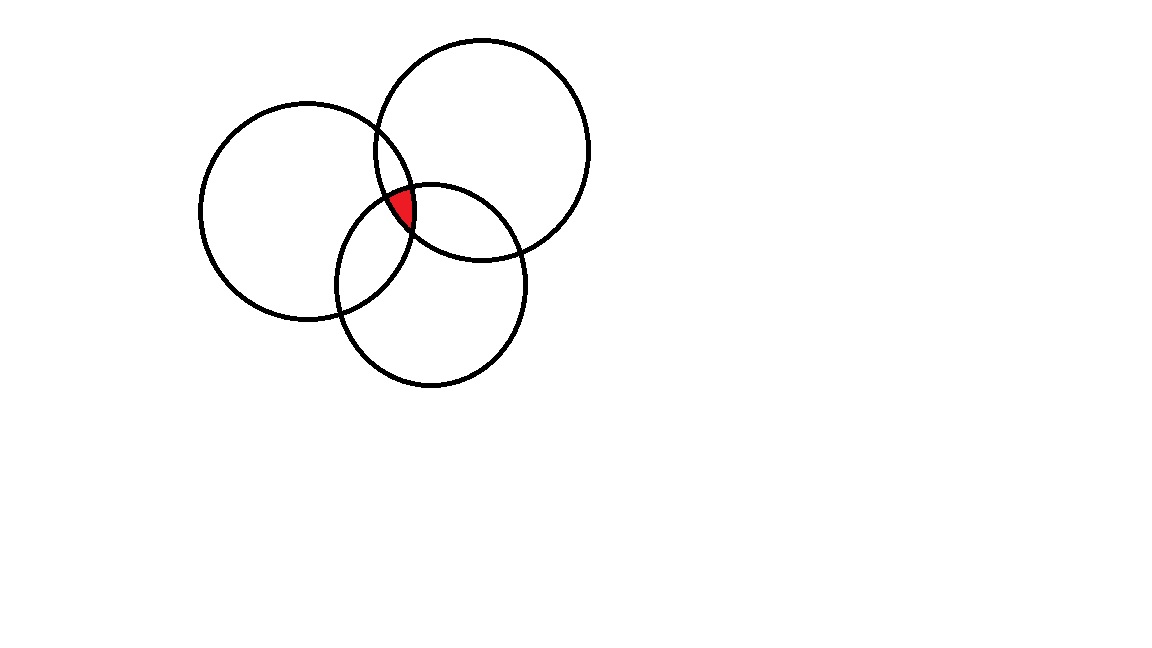
There are several of these systems currently in operation. The most famous of these being the U.S. funded Global Positioning Service (GPS) however there are others such as the Russian Federation’s GLONASS and soon the European Galileo [11]. These were devised as systems to enable users worldwide to calculate their current location. The GPS system for example comprises of twenty-four satellites continuously producing signals that tell a user where a satellite is and highly accurate timing information about when this signal was produced. All twenty-four satellites communicate on the same two frequencies using Code Division Multiple Access in order to avoid collisions. By listening to the signals generated by at least four of the satellites to discover their locations and calculating the time it has taken to reach the user and hence how far away they are from each the users own location can be calculated. [12]

The accuracy of GPS is roughly 3.5m on the horizontal plane without using additional information. There are other systems which can be used in conjunction with GPS to provide up to millimetre accuracy however 3.5m should be accurate enough for this project [13]. The accuracy of Galileo is expected to improve to the centimetre range [14] once it is completed in 2020 [15].

There are two main limiting factors however: the accuracy of the GPS receiver in the user’s phone and that much of the time the user will be indoors. The accuracy of the receiver in a typical mobile phone is roughly 2-3m under good multipath conditions or up to 10m under bad multipath conditions [16]. Multipath is when the signal may reach the receiver via many paths for example direct from the satellite compared to being reflected by a building in between the satellite and receiver. This means that the signal will degrade when near buildings due to the weak multipath suppression available on mobile phone antennae. The app will always be expected to be running in an urban landscape therefore meaning the GNSS location may have quite a low accuracy. Receiving GNSS signals indoors can become a challenge as the signal when received outdoors is already very weak when compared with the background noise and the signal can be 10-100000 times weaker when indoors [17]. This can make it difficult to receive the necessary signals from four satellites at once making it near impossible to reliably and quickly determine location indoors via this method.

### Cell Tower Based Location

Location can be calculated using cell towers in a similar way to that of GNSS. Essentially the phone sends a ping to the nearby cell towers and times how long it takes to receive a response. If the locations of the cell towers are known then an estimate of the phone’s location can be calculated using the respective distances from each cell tower [18]. An example of how this works can be seen below in Figure 2 Cell Tower Triangulation.



1

3

2

Figure Cell Tower Triangulation

In the figure above the arrows represent the calculated distance from the cell tower. With only one cell tower response this means the user could be anywhere in the surrounding circle. This is as the furthest the user could possibly be from the tower would be is a straight line from it (the radius of the circle) however there is no guarantee that is the path being taken. Instead it could be reflecting off of buildings or other materials meaning the user could be anywhere within the surrounding circle. With responses from more cell towers the location becomes more accurate. As can be seen in Figure 2 Cell Tower Triangulation with these responses the user could only be in the overlapping area from each circle.

Cell Tower Triangulation could potentially be a more reliable method of geolocation as it even tends to work indoors, presuming there is a mobile phone signal, and even works better in more urban areas where this application would be expected to be used, due to the higher number of cell towers [18]. It does however have some drawbacks in that it requires an accurate knowledge of cell tower locations which are not typically available publically making this more difficult [19]. On average for example in the United States of America (USA) the average accuracy of a three tower triangulation is 0.75 square miles [20]. This is far too inaccurate for the purposes of this application.

### Wi-Fi Based Location

In much the same way cell towers can be used to calculate the user’s location so can Wi-Fi base stations. By using easily available data such as signal strength a rough estimate of distance from the base station can be calculated. If several base stations can be identified, then the user’s location can be calculated using triangulation.

### Current Android Solution

Android as an OS has several built in features for detecting the user’s current position and provides app developers with the opportunity to use this data. It currently uses a combination of all 3 of the location services previously mentioned [4]. The accuracy while outside is particularly high as can be seen in

TODO

This is likely due to the availability of a strong GPS signal in combination with cell tower and Wi-Fi location services. When inside however the provided location services are far weaker as can be seen in Figure 4.

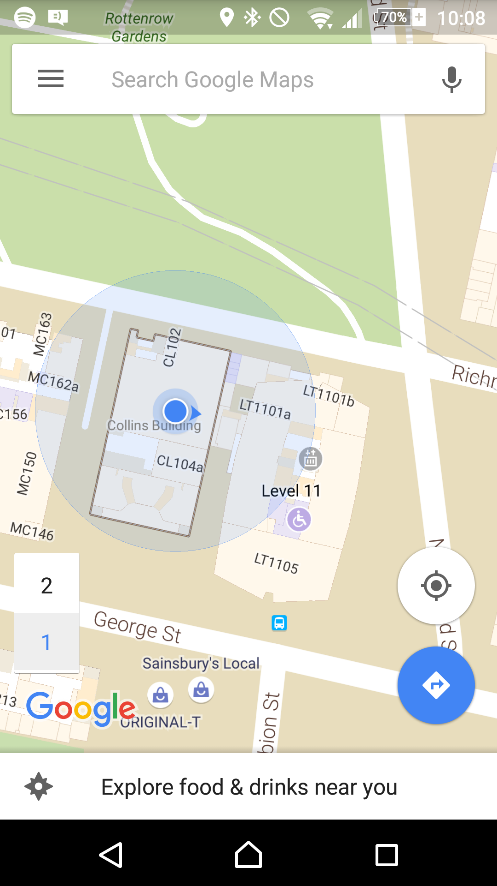


Figure Indoor Location Example

In Figure 4 again the reported location is shown with a small blue circle this can be compared to the actual location represented by the red circle to show that when indoors there can be a large margin of error. The larger blue circle represents the area in which google admits the location may fall within. Although technically the actual location does fall within this area the data is still almost unusable from the perspective of this app. The area of uncertainty shown above covers an entire building as well as significant amounts of two neighbouring buildings meaning this is unlikely to be useful when trying to navigate within one building. This large degree of uncertainty and inaccuracy is most likely due to a lack of a reliable GPS signal combined with a low knowledge of the exact Wi-Fi and Cell Tower locations. This should be improving however as google is trying to improve its knowledge of Wi-Fi locations using their massive user base. This is being done by taking the times when a user has a good knowledge of their own location using GPS to send google information on the surrounding Wi-Fi signals and strengths [21]. This could eventually theoretically provide strong indoor locations worldwide however is currently falling short of this. Even if it does improve using GPS as the starting point means height will always likely be a problem meaning differentiating between floors of a building could be difficult.

### Improved Suggestion

As previously stated it is believed that the main problem currently facing indoor location services is a knowledge of the locations of different Wi-Fi sources. Although steps are being made to try to improve this globally within a smaller area that is to be mapped such as a University campus this problem becomes far easier to deal with. Within this area the

locations could be found manually preferably by using documentation written during the installation of a Wi-Fi network however if not a Wi-Fi map could potentially be built up when the app is being built.

## Routing

In order to build an application that will provide a route for the user between their chosen start and destination a graph representing the area to be mapped must be built. Once the graph has been built a method for finding the shortest path between two nodes in that graph must be found to indicate the route that the user should follow.

### Representing a Graph

There are three main ways of representing a graph within a computer system Edge List, Adjacency Matrix and Adjacency List [22].

#### Edge List

Consists of a list of all of the edges in the system. This is a fairly easy to understand representation of a graph however can be difficult to traverse during path finding algorithms. By indexing the information by edges rather than nodes it can make moving from one node to another more difficult. Each time it is needed to check what edges are connected to the current node it is necessary to move through all of the edges checking whether or not that node is attached to that particular edge.

#### Adjacency Matrix

Consists of a Matrix with the nodes along both axes and the weight of the edge connecting them at the point where they meet. An example of this can be seen in Figure 5 and Figure 6.

Figure Example Graph

4

C

6

5

D

1

A

B

2

2

E

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E |
| A | Null | 2 | 4 | Null | 1 |
| B | 2 | Null | Null | Null | 2 |
| C | 4 | Null | Null | 6 | Null |
| D | Null | Null | 6 | Null | 5 |
| E | 1 | 2 | Null | 5 | Null |

Figure Example Adjacency Matrix

Adjacency matrices are typically used in very densely populated graphs i.e. those with a lot of edges per nodes. This is as the number of edges does not affect the storage space required for this implementation however if the graph is sparser with each node having far fewer edges than there are other nodes this method becomes increasingly inefficient with almost the entire matrix being filled with null values to represent no edge.

#### Adjacency List

This is a method in which each node has a list of the nodes it is connected to. By storing the data in this way it makes routing algorithms far simpler as it is very easy to quickly determine which nodes are connected to the one that is currently being examined. Naturally this does not support edge weights however this functionality can be added via a slight modification. By storing a list of edges for each node this provides all of the benefits of an Adjacency List however also allows for weights to be added to the connections allowing for a representation of a weighted graph.

### Path Finding

Once the graph representation has been constructed an algorithm for finding the shortest path must be implemented. There are many algorithms that have been developed for finding the shortest path between two nodes in a graph and each have their own areas of expertise depending on the type of graph.

#### Breadth-First Search

This algorithm starts at one of the two nodes it is to find the route between. From there it then moves out to all of the surrounding nodes and assigns them a value of one. It then takes each of the nodes with a value of one and assigns all of the surrounding nodes with a value of two. This continues until it reaches the desired node. It is guaranteed to find the path between the two in the fewest number of hops however does not take into account edge weights.

By not taking into account differing edge weights it would make constructing a graph representing the campus to be mapped far more difficult. This is as each of the nodes would have to take roughly the same amount of time to walk between to produce an acceptable route. This becomes particularly difficult when adding lifts to the routes as waiting on lifts could potentially take several minutes. Waiting times like this mean either all of the nodes would have to be particularly far apart, which is likely not possible in a corridor with many rooms coming off of it, or there would have to be conceptually many nodes the user would move between while waiting on a lift which is essentially just adding weights in a very inefficient way.

#### Dijkstra’s Algorithm

The main problem with breadth first is that it doesn’t allow for different weights on the edges. Dijkstra’s Algorithm by comparison will always find the shortest path in a weighted graph. It works by essentially starting at one of the two nodes that the path is between and marking it as examined. Each of the nodes that it is connected to then have a number representing the weight of the edge taken to reach them assigned to them. From there the node with the lowest number associated with it is marked as examined and all the nodes it is connected to have their numbers updated to be the sum of the weight to the examined node plus the new edge unless they already have an associated number which is less. This continues until the destination node is marked as examined at which point the shortest path between them has been discovered.

#### A\* Algorithm

The A\* Algorithm is essentially a modification of Dijkstra’s algorithm that allows the shortest path to be found more quickly. It does this by adding a heuristic value to the comparison when deciding which node to examine next. An example of a possible heuristic value for this case would be the straight line distance between each node and the current destination. This means that when choosing which node to examine next it would add both the difficulty in reaching that node and how physically far away from the destination the node is. This means that instead of spreading out equally in all directions like in breadth-first or towards the easiest direction like in Dijkstra’s it would instead spread towards the destination quicker than in other directions. The algorithm relies on the fact that the heuristic function always returns a value less than or equal to the length of the shortest path from that node to the destination. Calculating a heuristic value like this can be fairly simple for some applications for example a single level mapping application could use straight line distance fairly easily. However, a multi-level mapping application such as this would face difficulties in implementing such a system. Calculating the straight line distance for example would be impossible without detailed knowledge of the heights of each building. Even if the straight line distance could be calculated it would likely be a very poor heuristic value as it could lead the search algorithm to move towards the destination node even if the quickest route would be to move in the opposite direction towards a stair case. It would still find the quickest route but in this case it would likely be less efficient than Dijkstra’s despite the additional effort required to include the heuristics.

## Software Engineering

To develop a system of this scale and ensure it is easy to maintain and extend it is important to try to use good software engineering practices throughout. This should make development and testing easier by making the software more flexible and forgiving of change.

### Architectural Style

An architectural style is the highest level programming choice to be made. It is concerned with how data and functionality should be separated. For example, the Main Program/Subroutine shared data style in which all of the data is available throughout the program and the functionality is broken up into subroutines which can be called when needed to. For this project the architectural style is for a large part dictated by the decisions that have already been made. By choosing to develop for android this means the programming language that will be used is Java. As java is best suited to the Object-Oriented architectural style this is the main style that will be used throughout the project. However due to the way the Android OS and support libraries have been built up there will also be aspects of Event-Based Implicit Invocation included throughout.

#### Object-Oriented

This particular architectural style relies on splitting the program into objects, instances of classes, which each have access to their own particular data and can perform their own actions. Objects can then communicate via method calls between them. This leads to greater levels of abstraction meaning a change to one section of code will not dramatically alter other sections within the program. An instance of this could be if one class requests the quickest route between two nodes from another the second object could be changed internally, to represent the graph differently or use a different path finding algorithm, but it wouldn’t affect the first class in any way provided the nodes to be passed in and the route returned still obeyed some kind of standard definition. The best way to create a standard definition is by creating an interface. An interface is a list of the publically available method calls that other classes can use to communicate with any classes implementing that interface.

#### Event-Based Implicit Invocation

Event Based Implicit Invocation is similar to the Object Oriented style in many ways. However, instead of communicating between components via method calls an object can register for updates based on a particular event. This is best exemplified during use of the User Interface (UI) objects provided in the Android Software Development Kit(SDK). When a UI object is created a class which implements the provided interface can register for updates about events such as it being touched or swiped. Then when the user next touches or swipes on that UI object the registered object will be notified with relevant information such as the location of the touch.

### Programming Style

A good Programming Style will provide a high-level guide to how the program should be laid out and how both functionality and data will be separated. There are many different programming styles however since re-usability was a major factor in choosing which to adopt it was decided model-view-controller would be adopted.

Model-View-Controller divides data and functionality into the three main sections mentioned in its’ name. The Model should deal with everything programmatically for example in this project that would be the graph and path finding algorithms amongst other matters. The view should determine how that information is provided to the user for example this could be a map or simply a list of instructions. It is important that out-with the defined interface for communicating that these components do not rely on each other. This means the view could be changed entirely without any changes at all being necessary in the model. The Controller deals with user input and determines how that should affect the model. An instance of this in the project could be if the user selects a new room in some way it is the controller’s responsibility to alert the model to this change in state. Again outside the well-defined interfaces the controller should be able to be changed entirely without affecting either the model or the view.

By using this programming style it means components even at a particularly high level are particularly interchangeable. This is important in case at some point during development something changes dramatically. A possible reason for this would be if instead of using Google Maps it was decided university blueprints would be more accurate this would mean only the view would need to be changed leaving two thirds of the code with no need to be changed despite this rather large change.

### Design Patterns

Design Patterns are essentially proven solutions to a commonly recurring problems. Throughout programming certain problems such as how to change algorithms during runtime appear again and again and through use of these design patterns we have a way to deal with them effectively. Below is an overview of each of the design patterns which have been used throughout the project.

#### Observer Pattern

The Observer Design Pattern is essentially a lower level version of the same principles the Event-Based Implicit Invocation Architectural Style was based on. Essentially with it one component allows others implementing a specific interface to register with it for updates. Whenever this first object determines itself to have changed in some way it notifies all of those listening for updates. Using the Observer Pattern allows for two components which hold similar data to remain consistent while also staying loosely coupled. This design pattern can be seen most clearly in the sample UML diagram shown in Figure 7.

Observer

Update()

Update(State)

Concrete Subject

getState()

Subject

addObserver(Observer)

notify()

Concrete Observer

Figure Observer Design Pattern UML

The main advantage to this design pattern is that it very strongly decouples the concrete subject from the concrete observer allowing any changes to the concrete observer to be made easily. The main disadvantage however is that it can make debugging potential problems more difficult as the flow of code becomes less obvious. There are two versions of the Observer pattern: the push model and the pull model. They both follow the same basic structure however with one major difference. The push model gives the Observer the information it requires when it is notified. By comparison the pull model simply alerts the Observer that something has happened. This means the Concrete Observer requires a reference to the Concrete Subject in order to determine what has changed and react accordingly. These differences can be seen clearly in Figure 7 with the aspects only in the push model shown in blue and those only in the pull model shown in red. The push model has the added advantage of also cleanly decoupling the Concrete Observer from the Concrete Subject.

# Design

## Initial High- Level Design

As previously discussed the high level design should follow the Model-View-Controller programming style. To do this successfully it is important to outline exactly what each subsystem will be responsible for in this design and how they will communicate. For a full overview the high level UML diagram is shown in Appendix 1 Initial High Level UML Diagram.

### Responsibilities

The model will deal with the state of the program i.e. what the currently selected start and end nodes are, where the user is currently looking, what errors have occurred and what the current route is. It will also be the only subsystem to deal with the data as a graph and will therefore be responsible for route finding.

The view will deal with how the current state of the program will be displayed to the user for example what rooms will be displayed, how the route will be given and what inputs will be taken from the user.

The controller will deal with reacting to user input and changing the model accordingly. When it is informed of some form of user input from the view it will decide in which way this user input will affect the model.

### Communications

The communications between each of the three subsystems can be seen in Table 3.

Table High Level Communications

|  |  |  |  |
| --- | --- | --- | --- |
|  | Model | View | Controller |
| Model | n/a | Using the observer design pattern in the push variation. | n/a |
| View | n/a | n/a | View will hold a reference to Controller through the IController interface. This will allow |
| Controller | Controller will hold a reference to the Model through the IModel interface. | n/a | n/a |

By using the Observer pattern to communicate between the model and view it keeps these two sub-systems independent from one another. The controller to view and controller to model communications will pass through interfaces this will aid decoupling however not to the same extent as the Observer pattern does between the model and view. This is as instead of just passing through the data and allowing the other object to with it what it wants the components now call specific methods. This is a compromise that has to be made however because the links between the view to controller and controller to model are too complex to be broken down into an observer pattern.

## View Design

## Model Design

## Controller Design

## Software patterns

# Appendices

## Appendix 1 Initial High Level UML Diagram

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