

SMART TRAVEL APPLICATION

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Abstract

The traveling salesman problem (TSP) is an algorithm problem focused on optimization, and it has become an important part of certain fields such as logistics, manufacturing, telecommunications, robotics and more. This thesis pretends to use three different TSP algorithms (brute force, the nearest neighbor and a genetic algorithm) to address the issue of finding an optimal route for travelers, who wish to visit different destinations in Ireland following a distance-effective route. The approach is to develop a GUI based on Java, which will connect to the Google Maps API services in order to get the distances between each pair of locations, and by applying one of the algorithms mentioned earlier, the application will come back with a possible optimal solution.

Currently, a prototype consisting of a basic GUI and a Nearest Neighbor implementation has been developed for demo purposes. The input data is stored in a text file using a symmetric matrix, which then is processed by the application to generate a tour applying the Nearest Neighbor algorithm.

**Table of Contents**

[Chapter 1: Introduction 5](#_Toc475401483)

[Chapter 2: The Travelling Salesman Problem 6](#_Toc475401484)

[2.1 Introduction 6](#_Toc475401485)

[2.2 Graph Theory 6](#_Toc475401486)

[2.3 Classification of the TSP 7](#_Toc475401487)

[2.4 Type of Algorithms 8](#_Toc475401488)

[2.4.1 Exact solutions 8](#_Toc475401489)

[2.4.2 Approximation algorithms 8](#_Toc475401490)

[2.4.3 Heuristics 9](#_Toc475401491)

[2.4.4 Metaheuristics 9](#_Toc475401492)

[2.5 Nearest neighbor 9](#_Toc475401493)

[2.5 Genetic Algorithm 10](#_Toc475401494)

[2.6 Applications 11](#_Toc475401495)

[Chapter 3: Geolocation 12](#_Toc475401496)

[3.1 Introduction 12](#_Toc475401497)

[3.2 Global Positioning System 12](#_Toc475401498)

[3.3 Network-based technologies 13](#_Toc475401499)

[3.4 Google Maps API 13](#_Toc475401500)

[3.4.1 How Google Maps and its API work 13](#_Toc475401501)

[3.4.2 Coordinates 13](#_Toc475401502)

[Chapter 4: Methodology & Design 15](#_Toc475401503)

[4.1 Research Methodology 15](#_Toc475401504)

[4.2 Research Question 15](#_Toc475401505)

[4.3 Proposed Solution 15](#_Toc475401506)

[4.4 Project Scope 19](#_Toc475401507)

[4.5 User Description 20](#_Toc475401508)

[4.6 List of Application Features 20](#_Toc475401509)

[4.6.1 MUST HAVE 20](#_Toc475401510)

[4.6.2 SHOULD HAVE 20](#_Toc475401511)

[4.6.3 COULD HAVE 21](#_Toc475401512)

[4.6.4 WON’T HAVE 21](#_Toc475401513)

[4.7 Prototype 21](#_Toc475401514)

[4.8 User Stories 23](#_Toc475401515)

[5.1 Sprints 24](#_Toc475401516)

[5.2 Sprint schedule 24](#_Toc475401517)

[5.2.1 Sprint One 25](#_Toc475401518)

[5.2.2 Sprint Two 29](#_Toc475401519)

[References 32](#_Toc475401520)

# Chapter 1: Introduction

# Chapter 2: The Travelling Salesman Problem

## 2.1 Introduction

The Travelling Salesman Problem (TSP) is a classic algorithmic problem in the field of computer science focused on combinatorial optimization. According to Wang (Wang, 2014), the problem is described as follows: given a tourist map, a salesman wants to find the optimal Hamiltonian circuit (OHC), i.e., a circuit that visits each city once and exactly once and incurs the least distance, time or cost, etc. According to (Rego, et al., 2011), the TSP can be described as the problem of finding a minimum distance tour of n cities, starting and ending at the same city and visiting each other city exactly once.

## 2.2 Graph Theory

The TSP can be represented using graph theory. As mentioned in (Rego, et al., 2011), the problem can be defined on a graph G = (V,A), where V = {v1,...,vn} is a set of n vertices (nodes) and A = {(vi,vj)jvi,vj 2 V, i – j} is a set of arcs, together with a nonnegative cost (or distance) matrix C = (cij) associated with A. For example, given the graph shown in Figure 2.1, a possible TSP tour in the graph is 0-1-3-2-0. Therefore, the cost of the tour is 8+10+30+12 = 60.

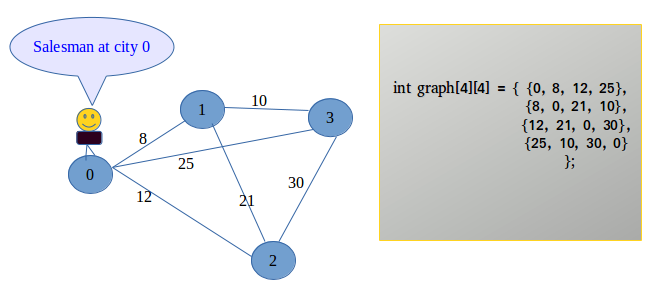


Figure 2.1 (Wikistack, 2016)

The TSP is classified as an NP-complete problem, and therefore there is not a polynomial-time algorithm able to solve all instances of the problem. Generally, the most efficient solution is not always provided due to the complexity of the problem; instead, different algorithms have been developed seeking an optimal solution with the lowest computational cost in terms of processing time and resources.

## 2.3 Classification of the TSP

According to (L. Applegate, et al., 2007), the different instances of the TSP can be classified in two categories. These are:

* Symmetric
* Asymmetric

In a symmetrical TSP, the distance between a pair of cities is the same in each direction, forming an undirected graph.

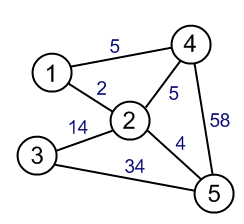


Figure 2.2 (Sheard, 2009)

Figure 2.2 is an example of a symmetrical TSP. Taking node 1 as the departing node, there is a distance of 5 going to node 4, and it is exactly the same distance if node 4 were the initial point and node 1 the end node. As observed in the image, this rule applies to the rest of the nodes, thus this instance falls into the Symmetric category. In (Wang, 2014) , it is described that, given a symmetrical TSP with *n* cities, the number of Hamiltonian Circuits can be calculated by using the following formula:

*(n – 1)! / 2*

This is the number of possible paths that can be followed to visit each vertex exactly once.

On the other hand, when the distance is variable between a pair of nodes based on the direction, that instance is considered asymmetrical. In the TSP in particular, traffic accidents, one-way roads, closed streets, etc. are a few examples of reasons as to how symmetrical instances can be transformed into asymmetrical problems.

Based on the formula used to calculate the HCs for a symmetrical TSP, it is deducible that, provided an asymmetrical TSP instance where the distance between each node I different base on the direction, the number of HCs can be calculated using the next formula:

*(n – 1)!*

## 2.4 Type of Algorithms

Since the early days of computers, mathematicians hoped that someone would develop better ways to solve large TSP problems, in other words, algorithms that would allow computers to solve them in a reasonable amount of time. Currently, there are different known approaches to produce an optimal solution, which are explained in the following sections.

### 2.4.1 Exact solutions

An exhaustive search of all possible paths would guarantee to find the shortest route or cheapest solution. An exhaustive search (also known as “brute force”) is the most common type of exact solution for the TSP. However, it is computationally intractable for all instances, only for small sets of locations. For larger problems, optimization techniques are usually needed to intelligently search the solution space and find near-optimal solutions (Sahalot & Shrimali, 2014).

### 2.4.2 Approximation algorithms

These types of algorithms are designed to find, as their name suggests, approximate solutions. Unlike [heuristics](https://en.wikipedia.org/wiki/Heuristic_(computer_science)), which normally only find reasonably good solutions reasonably fast, this type of algorithms aim for provable solution quality and provable run-time bounds (Lupsa, et al., 2010 ).

### 2.4.3 Heuristics

Algorithms that deliver either seemingly or probably good solutions, but which could not be proved optimal. While approximation algorithms are able to produce results that can be “measured” to see how close they are to the optimal solution, heuristics do not have this property (Glovera, et al., 2001). Examples of heuristics:

* Nearest neighbor
* Greedy
* Insertion heuristics

### 2.4.4 Metaheuristics

A metaheuristic is a high-level problem-independent algorithmic framework that provides a set of guidelines to develop heuristic optimization algorithms. As mentioned in (Gendreau & Potvin, 2005), a good metaheuristic implementation is likely to provide near-optimal solutions in reasonable computation times. Examples of metaheuristics:

* Tabu search
* Genetic algorithms

## 2.5 Nearest neighbor

The nearest neighbor algorithm, paraphrasing (Gendreau & Potvin, 2005), is a tour-construction procedure that aims to build an optimal route by taking at each step the node with the cheapest cost or shortest distance from the current node. One of the key points of this algorithm is simplicity given that its methodology is relatively easy in comparison with other algorithms. Figure 2.3 shows the steps performed in the nearest neighbor algorithm.

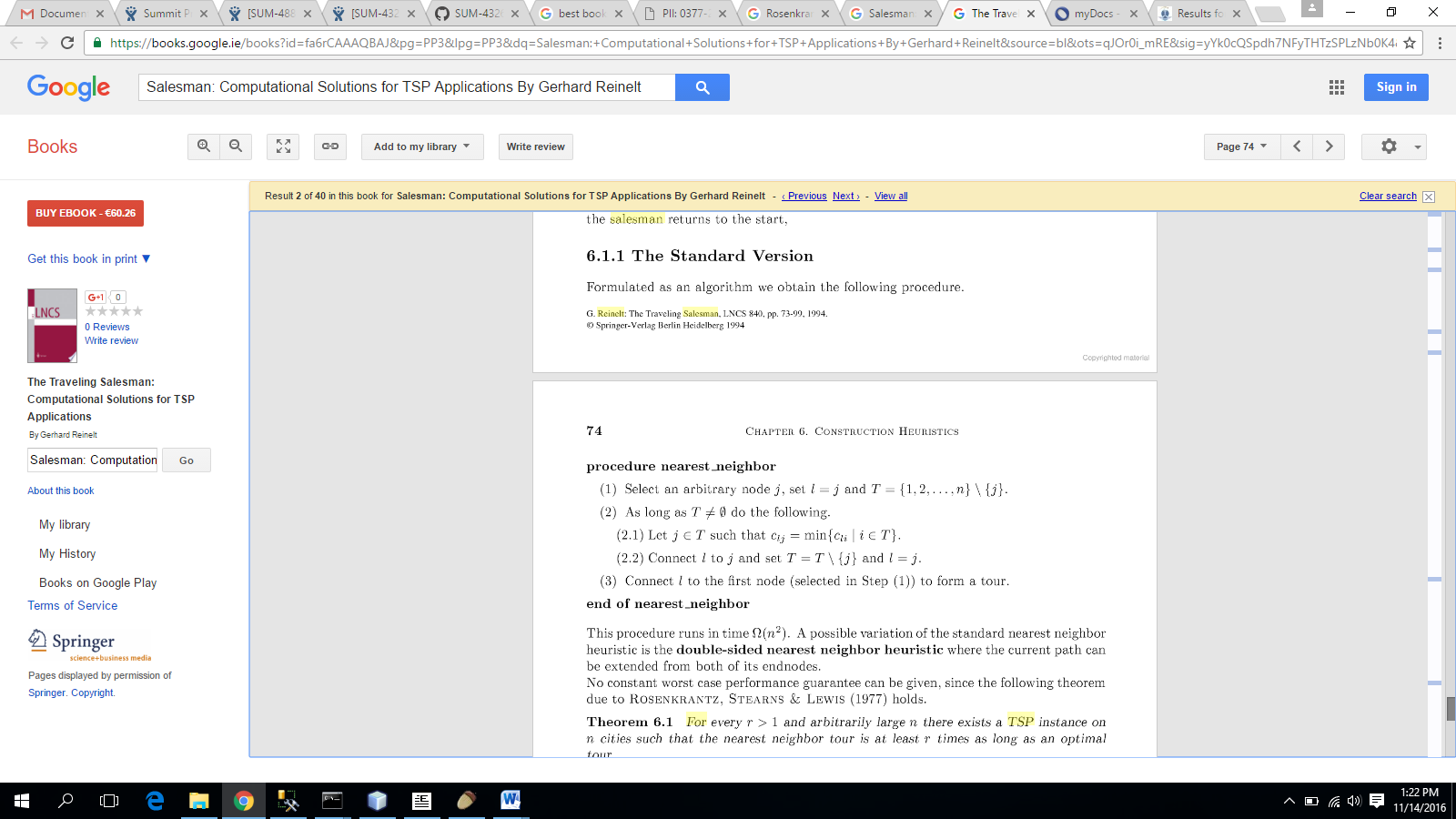


Figure 2.3 (Reinelt, 2003)

Putting the algorithm in terms of a sales man who needs to visit a set of cities, he would firstly select an aleatory starting point, and then he would visit the nearest city that has not been visited so far until all cities are visited. Finally, he returns to the starting point to complete the circuit. The complexity of this procedure is O(n2). Now, a possible modification is to consider all vertices as a starting point. The overall algorithm complexity is in turn O(n3), however, the resulting tour is generally better (Laporte, 1992).

## 2.5 Genetic Algorithm

Based on the natural process of evolution, a genetic algorithm attempts to mimic the concept of generating new populations with more fit individuals, which in the case of the TSP means new solutions that provide shorter tours. This local search algorithm starts by generating an initial population, and then genetic operators are applied to it in order to produce offsprings (new neighborhoods in this context) which are expected to be more fit than their ancestors. At each generation (iteration to produce a new offspring), every new individual represents a possible solution (chromosome). The iteration process continues until the stop criteria is reached, at this point the individual holding the best solution is considered the final result (Pezzellaa, et al., 2007). The different phases of the genetic algorithm are:

1. Initialization: the first population may be generated randomly or by using different methods such as heuristics, and it may be of any size. However, the problem to find a good initial population and the optimal size are complex problems given that these can vary depending on the problem to be evaluated (Diaz-Gomez & Hougen, 2007). Figure 2.4 shows some aspects to take into account when generating an initial population randomly.

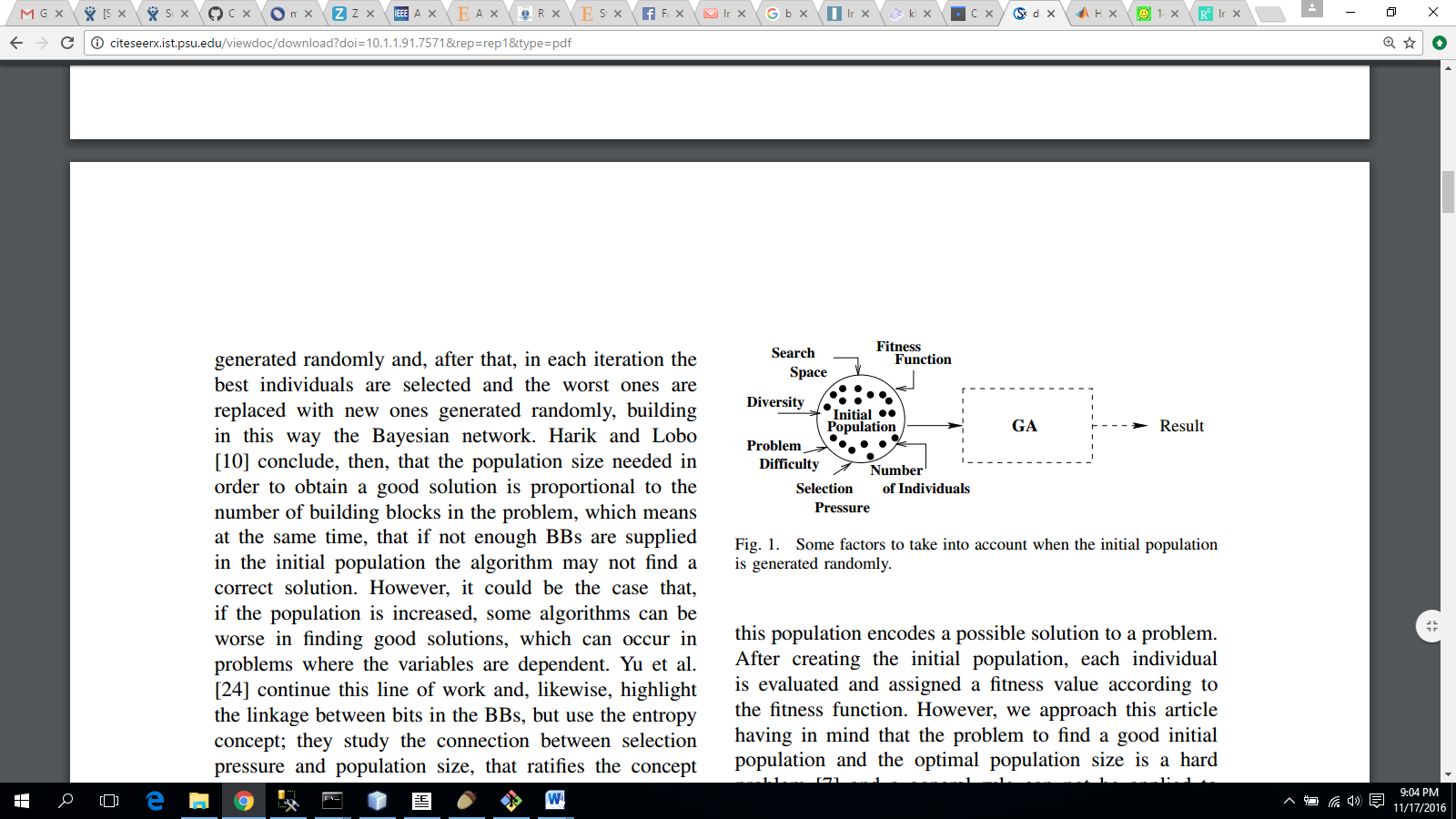


Figure 2.4 (Diaz-Gomez & Hougen, 2007)

1. Evaluation: each individual is evaluated to determine how well it fits the requirements of the problem. In terms of the TSP, the shorter the length of the tour the better.
2. Selection: process of selecting the best chromosomes among the population evaluated. There are different methods (binary tournament selection, roulette wheel selection, etc.) for this, but the idea is the same, make it so that fitter individuals are most likely to be included in the next generation (Alabsi & Naoum, 2012).
3. Crossover: aspects (genes) of the individuals selected are combined to generate new members. Methods such as Single Point, Two Points, and Uniform can be applied to do the crossover (Alabsi & Naoum, 2012).
4. Mutation: the intention here is to add a bit of randomness when generating new populations so that the algorithm does not get trapped in a local optimum. Examples of mutation algorithms are Flip Bit, Boundary, etc. (Alabsi & Naoum, 2012)
5. Stopping criterion: the evolution process is repeated until the terminating condition is reached. The number of iterations is commonly the most used stop criteria.

Figure 2.5 shows the pseudo code for a basic genetic algorithm

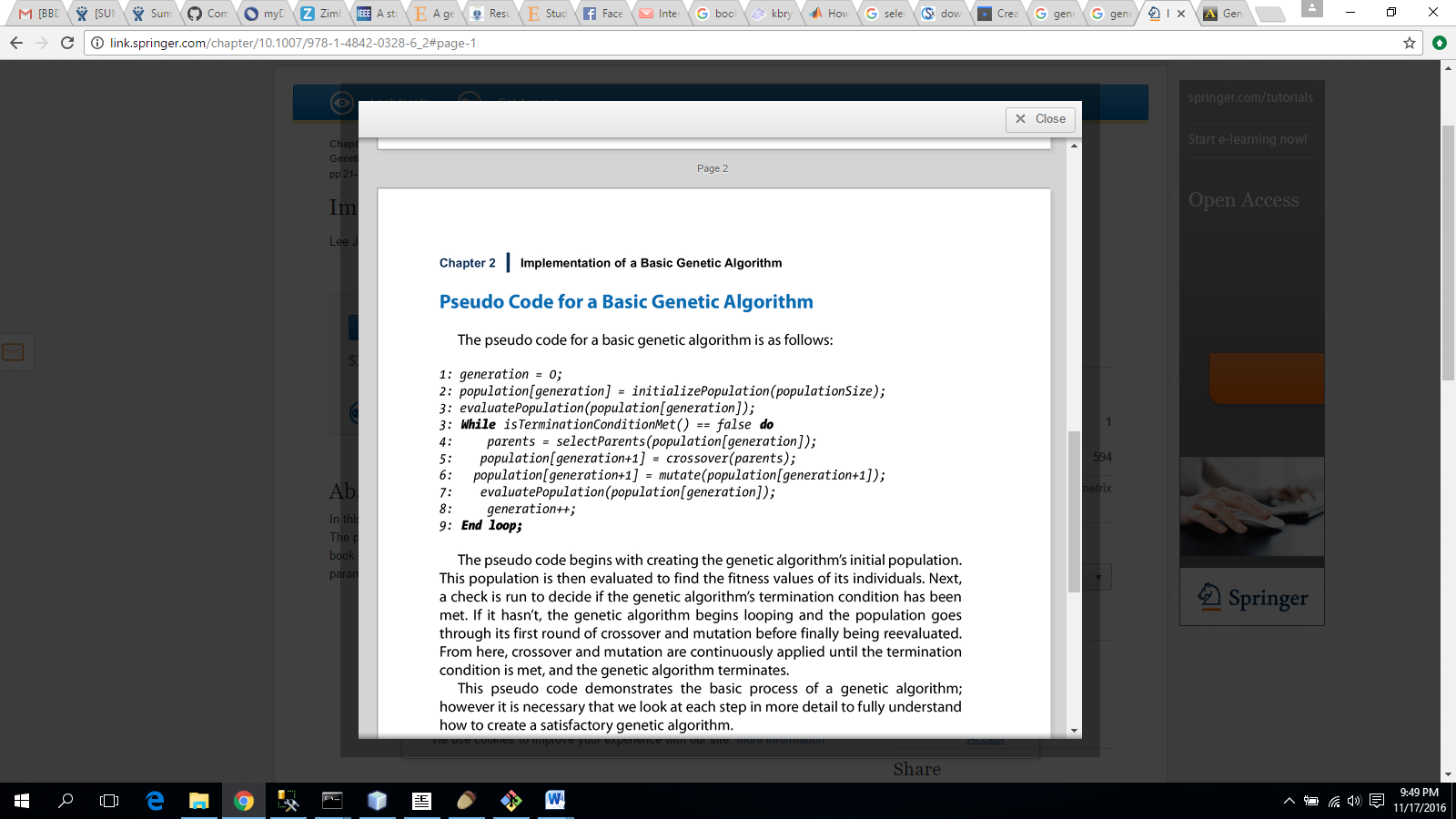


Figure 2.5 (Jacobson & Kanber, 2005)

## 2.6 Applications

The TSP has been used in several fields where optimization is required. Quoting (L. Applegate, et al., 2007), the TSP has seen applications in the areas of logistics, genetics, manufacturing, telecommunications, neuroscience, and robotics. The majority of the problems that are optimization-related may be good candidates for it.

# Chapter 3: Geolocation

## 3.1 Introduction

Geolocation essentially refers to the process of detecting the real-world geographic position on the Earth of a person or an object through a wireless technology. There are different ways to perform geolocation, but the most common techniques are those that rely on the Internet or satellites.

## 3.2 Global Positioning System

The U.S. Department of Defense developed the Global Positioning System (GPS) in the late 1960s and early 1970s as a merger of synergistic Navy and Air Force programs for timing and space-based navigation, respectively (McNeff, 2002). It consists of a constellation of 24 satellites, equally allocated in six orbital planes 20,200 kilometers above the Earth. According to (Djuknic & Richton, 2002), satellites transmit the information in two specially coded carrier signals: L1 frequency for civilian use, and L2 for military and government use. GPS receivers process the signals to compute position in 3D using latitude, longitude, and altitude, all this within a radius of 10 meters or better. Figure 3.1 shows how GPS works.

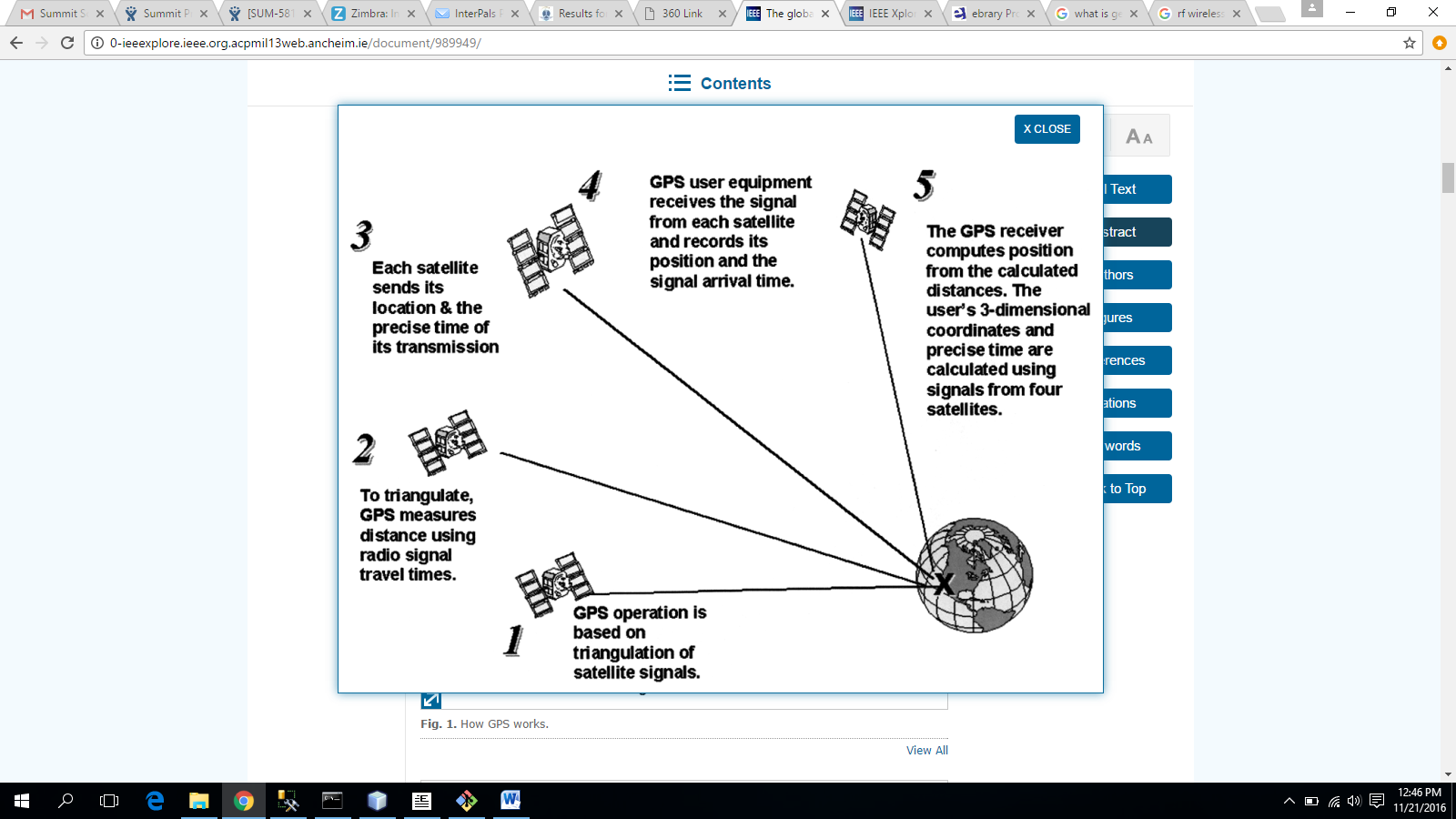


Figure 3.1 (McNeff, 2002)

There are a few things to consider when using GPS. It is important to notice that receivers need a clear view of the skies and signals from at least four satellites. This means GPS not work when the receiver is inside a building or other radio frequency-shadowed environments. Additionally, its power consumption and cost may not be suitable for all scenarios.

## 3.3 Network-based technologies

Technologies that rely exclusively on wireless networks often use time of arrival, time difference of arrival, angle of arrival, timing advance, and multipath fingerprinting to provide geolocation. These offer a shorter time-to-first-fix (TTFF) than GPS, a quick deployment and continuous tracking capability for navigation applications. However, network-based technics are far less accurate than GPS, and require expensive investments in base-station equipment (Djuknic & Richton, 2002).

## 3.4 Google Maps API

As mentioned in (Király & Abonyi, 2015), the Google Maps API is free and publicly available. It provides a fast and reliable web-service for defining user-friendly maps, computing traveling distances and time, and visualizing routes. Furthermore, it is the most popular mapping service nowadays.

### 3.4.1 How Google Maps and its API work

According to (Svennerberg, 2010), Google Maps is HTML, CSS, and JavaScript working together. The map tiles are images that are loaded in the background with Ajax calls and then inserted into a <div> in the HTML page. As the user navigates the map, the API sends information about the new coordinates and zoom levels of the map in Ajax calls that return new images. That is essentially how Google Maps works.

In terms of the API, it consists of JavaScript files that contain classes, methods and properties that users can call to tell the map how to behave and extract information from it.

### 3.4.2 Coordinates

It is widely known that coordinates are used to express locations in the world. There are several different coordinate systems. The one used in Google Maps is the Word Geodetic System 84 (WGS 84), which is the same system the Global Positioning System (GPS) uses. In this case, the coordinates are expressed using latitude and longitude. This is how locations are described and, therefore, expressed in Google Maps.

# Chapter 4: Methodology & Design

## 4.1 Research Methodology

The research methodology for this thesis involved investigating the traveling salesman problem and the different types of algorithms used to generate optimal solutions, focusing mainly on three particular instances: brute force, the nearest neighbor and genetic algorithms. After analyzing these three different algorithms, it was concluded that it should be feasible to use them in a route optimization solution to process a set of destinations and provide an optimal tour to visit them all.

Geolocation and the Google Maps API in particular, is the other area of research. After considering the power of Google Maps API, it was considered that it could be integrated to a GUI application to select different locations, and get their coordinates afterwards. This information can be then used as input for the three algorithms mentioned earlier.

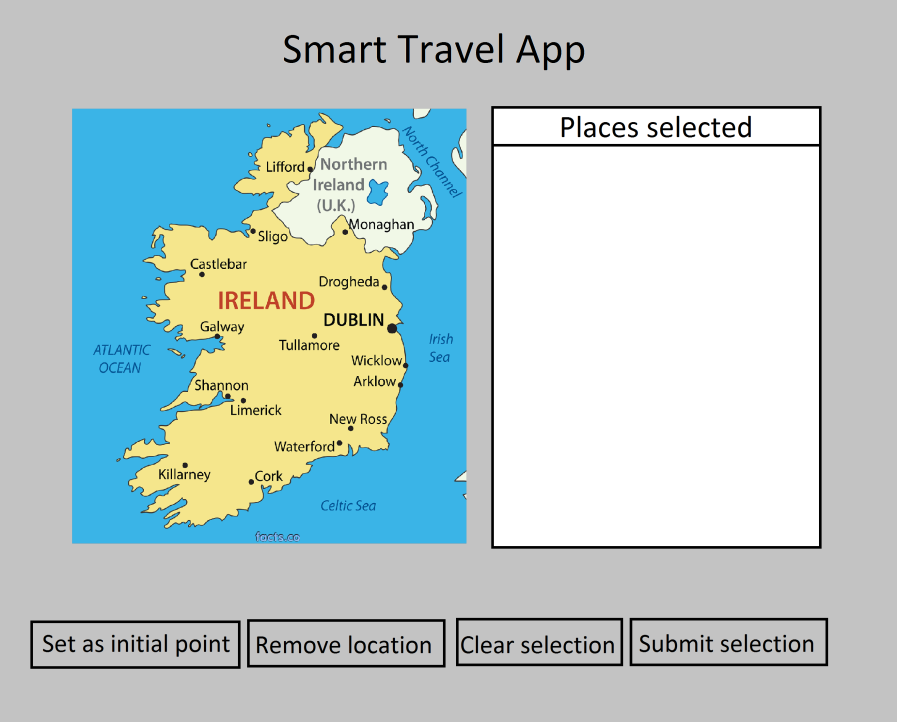
## 4.2 Research Question

An evaluation of implementing the Traveling Salesman problem utilizing the Google Maps API for route optimization.

## 4.3 Proposed Solution

The proposed solution is to develop a Java desktop application that will present a map of Ireland to the users, who will then be able to add destinations to be provided with a time-effective route. Screenshots are included in this section to describe how users will interact with the application and what it would look like.

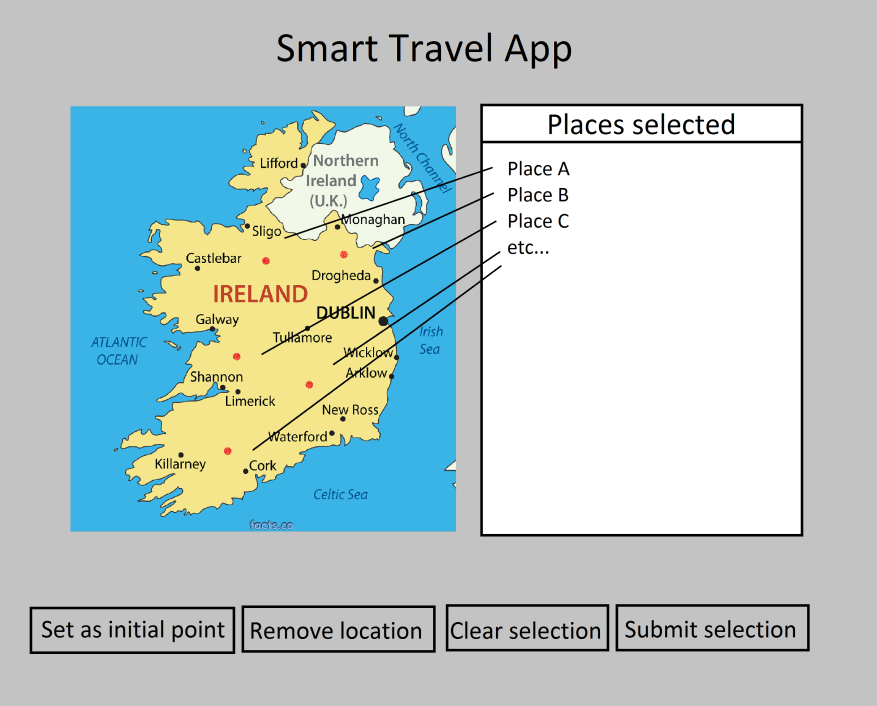
Screen presented to users



This is the screen displayed when the application is launched. It includes:

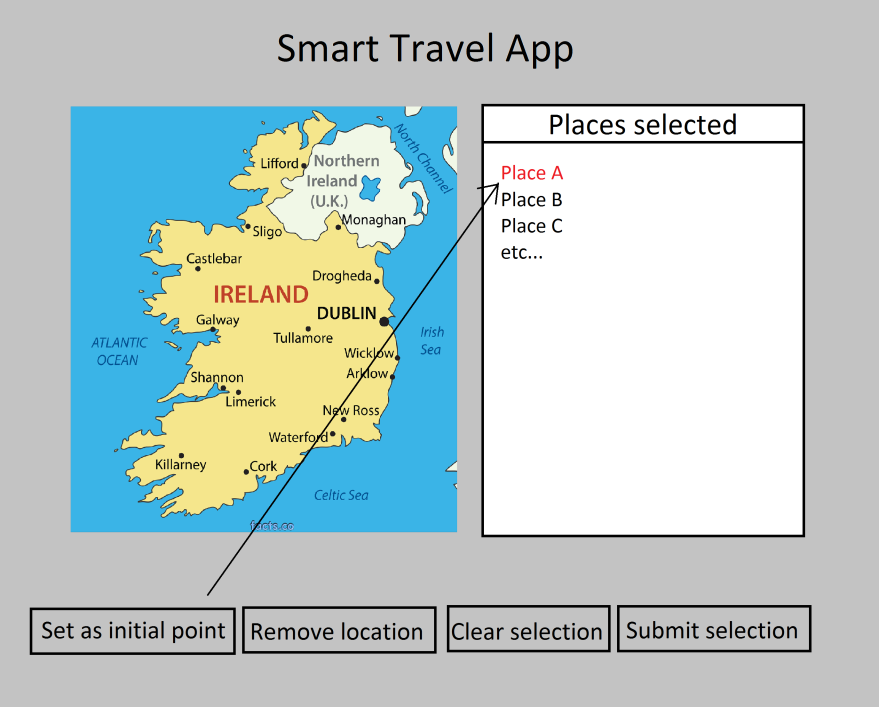
* Name of the app
* Map of Ireland
* List to hold selections
* Four buttons

Selecting a destination



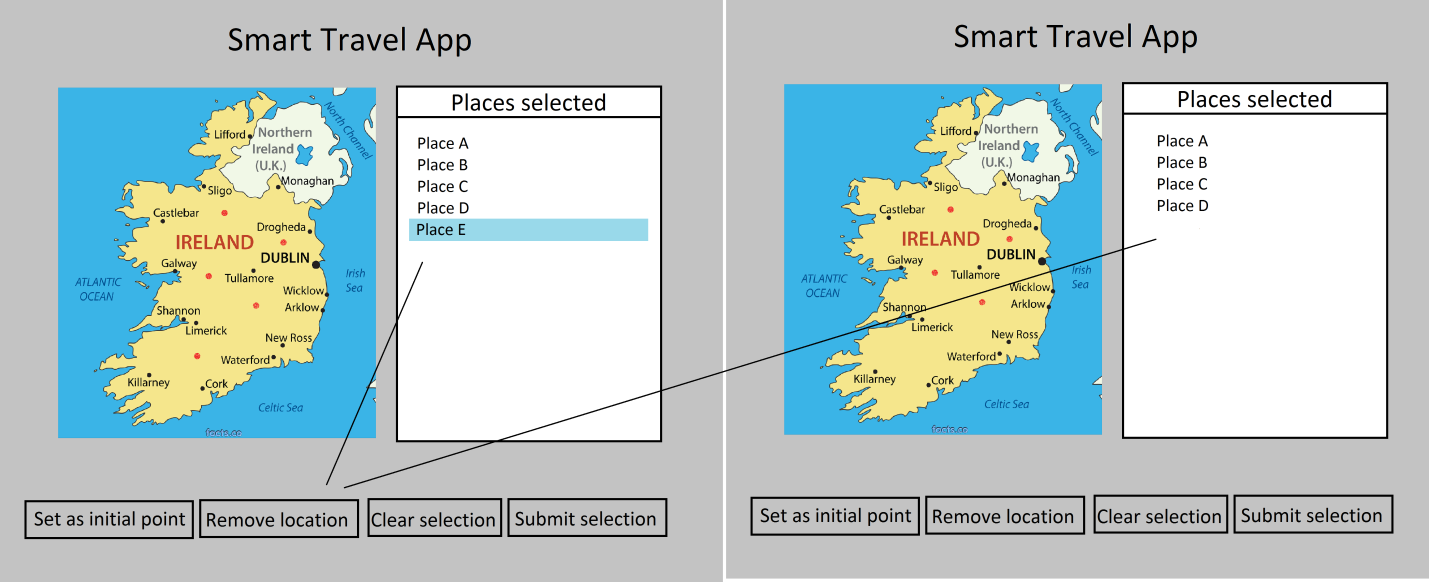
To add a destination to the list, users can simply click on the map and it will be added to the list on the right. This is how users will add all their destinations to the tour.

Selecting an initial point



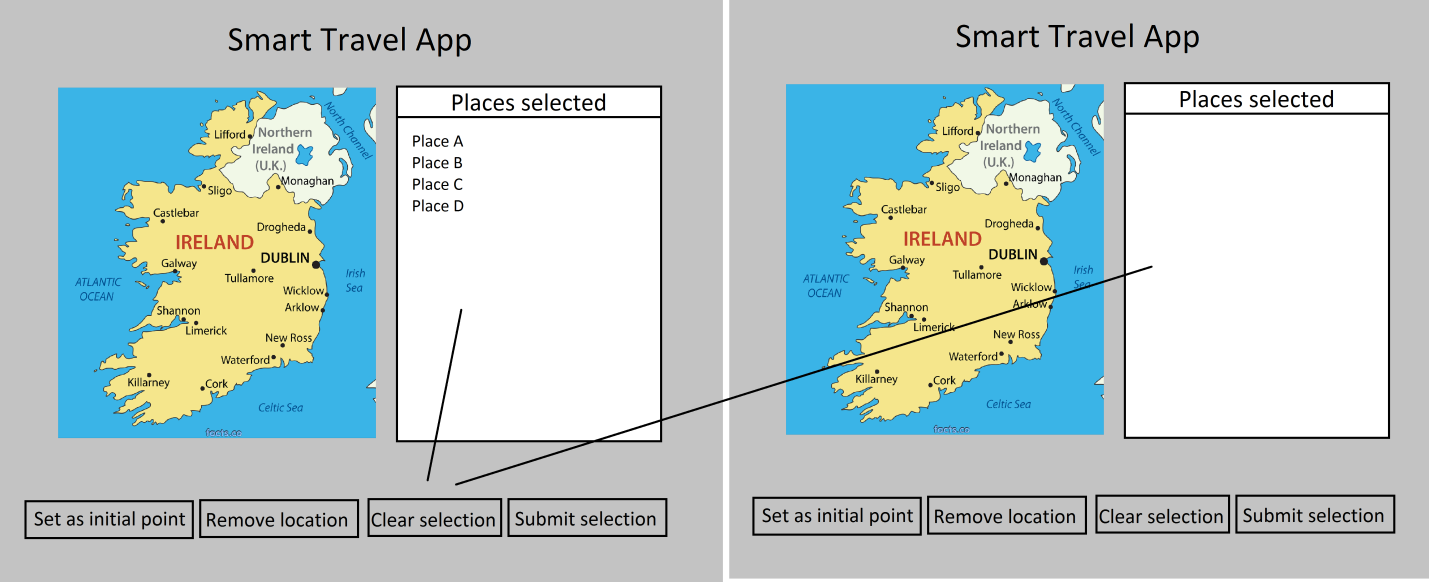
To set a destination as the starting point, users will need to select the location in the list, after users can click the Set as initial point button to make the selected location the starting point of the tour and the record will be displayed in red.

Removing one location from the list



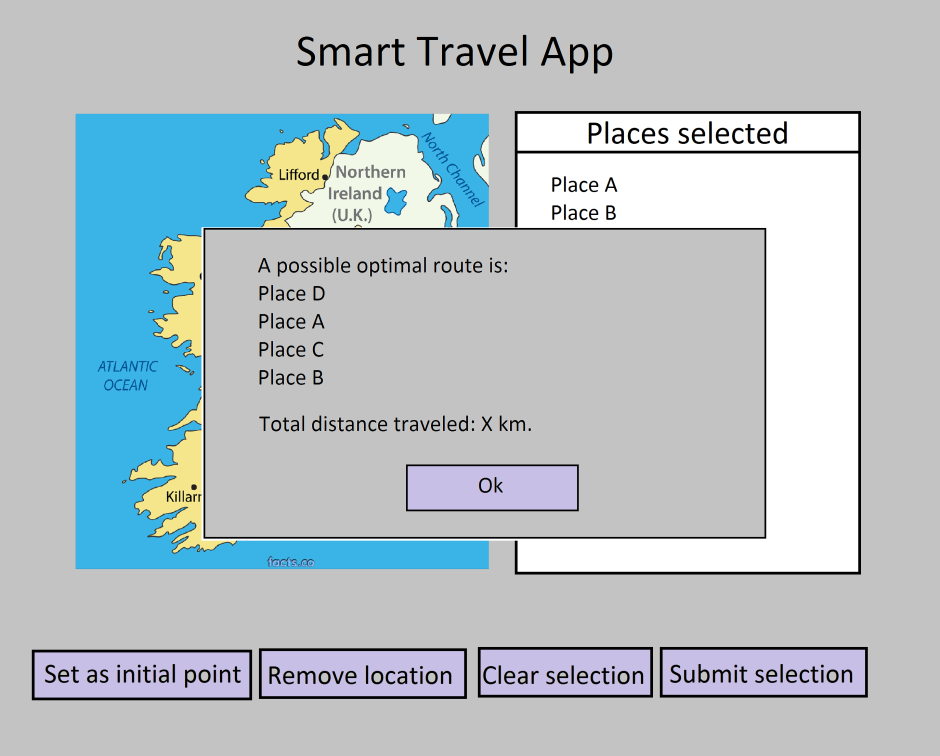
To remove a destination from the list, the user had to select it and then click the Remove location button. After this, the location will be removed from the list as shown in the screenshot.

Clearing entire selection



To clear the list of locations added to the tour, the user only needs to click the Clear selection button. All locations will be removed as shown in the screenshot.

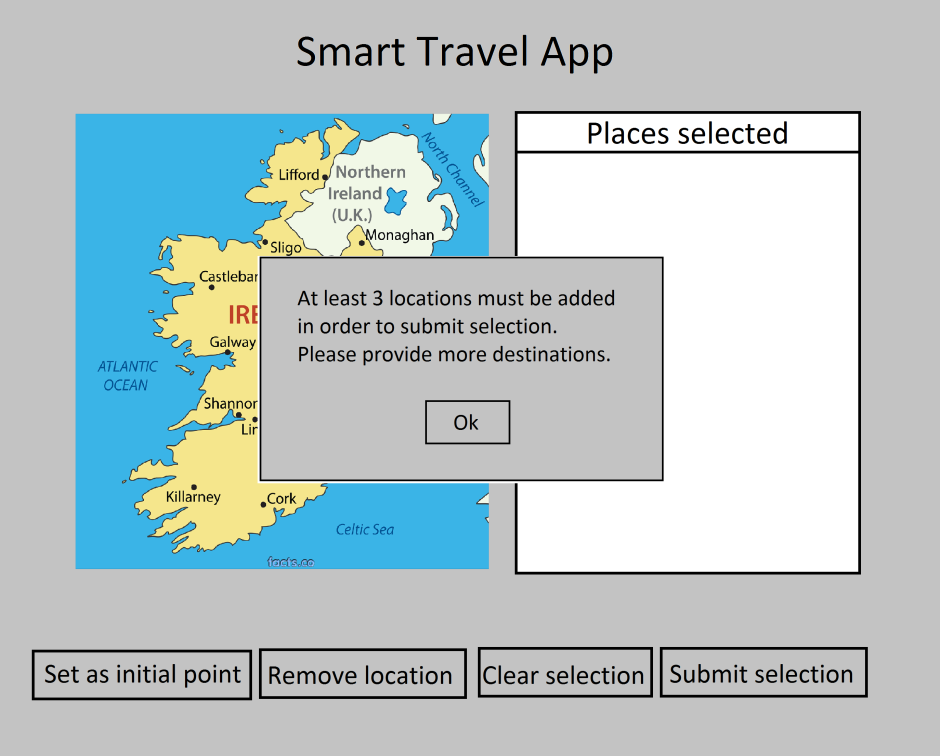
Displaying result



Finally, users will be able to submit their current selection to be processed. The result will be displayed in a pop up window and it will include all locations selected in the order provided after applying one of the algorithms, as well as the total distance of kilometers to travel.

An Ok button is added on the window so that the user can close it and proceed with a different selection.

Not enough destinations to process request



The minimum number of destinations required to process a request is 3. Otherwise an error message is displayed to let the user know more destinations are needed.

## 4.4 Project Scope

The objective of this project consists of developing a GUI application that will display a map of Ireland where users will be able to add destinations to finally be given a time-effective route. The routes will be generated by applying one of the following algorithms: brute force, nearest neighbor or a genetic algorithm. However, this will be completely hidden from users, as the algorithm selection will be made internally based on the number of locations selected so that the response can also be provided in a timely manner. The functionalities users will be able to utilize are:

* Add a location to visit by selecting it on the map
* Select a location as the starting point for the tour
* Remove a selected location from the list
* Clear entire selection
* Submit selection to be processed

## 4.5 User Description

The audience for this application is every traveler that desires to visit many places in Ireland without passing by the same destination twice following a time-effective path. They will be beneficiated by saving time, money and the effort needed to plan a travel route.

## 4.6 List of Application Features

All features are specified following the MoSCoW method, and classified as MUST HAVE, SHOULD HAVE, COULD HAVE and WON’T HAVE.

### 4.6.1 MUST HAVE

|  |  |
| --- | --- |
| **ID** | **MUST HAVE** |
| 001 | Implement Brute Force algorithm |
| 002 | Implement Nearest neighbor algorithm |
| 003 | Implement a Genetic algorithm |
| 004 | Display map of Ireland |
| 005 | Allow users to add destinations |
| 006 | Submit user selection and apply algorithm |
| 007 | Display results generated after applying an algorithm |
| 008 | Get coordinates of selected locations |
| 009 | Make HTTP requests through Google Maps API |

### 4.6.2 SHOULD HAVE

|  |  |
| --- | --- |
| **ID** | **Feature** |
| 010 | Use one of the 3 algorithms to calculate an optimal route |
| 011 | Clear existing selection |
| 012 | Not crash at any moment |
| 013 | Display total number of kilometers to travel |
| 014 | Delete one selection at a time |
| 015 | Read JSON result from Google Maps API calls |
| 016 | Display error message when user submits less than 3 locations |
| 017 | Allow users to set an initial point for tour |

### 4.6.3 COULD HAVE

|  |  |
| --- | --- |
| **ID** | **Feature** |
| 018 | Save results for future similar requests |
| 019 | Suggest popular places |

### 4.6.4 WON’T HAVE

|  |  |
| --- | --- |
| **ID** | **Feature** |
| 020 | Include maps of other countries |
| 021 | Database integration |

## 4.7 Prototype

The prototype consists of a basic user interface that allows to select a file containing a symmetric matrix, which represents the nodes (locations) for a TSP instance. It also displays two text fields, one to specify the number of nodes and another one to select the starting point for the tour.

|  |  |  |
| --- | --- | --- |
| **Task Number** | **Details** | **Status** |
| 1 | Nearest neighbor algorithm implementation | Complete |
| 2 | Generate/get test data | Complete |
| 3 | Create simple user interface to process test data | Complete |

**Test Data**

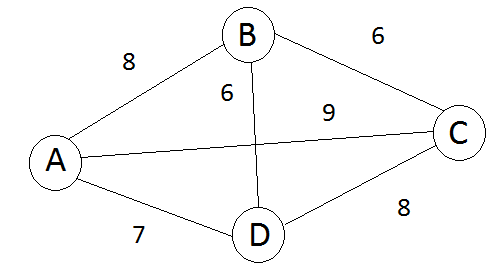
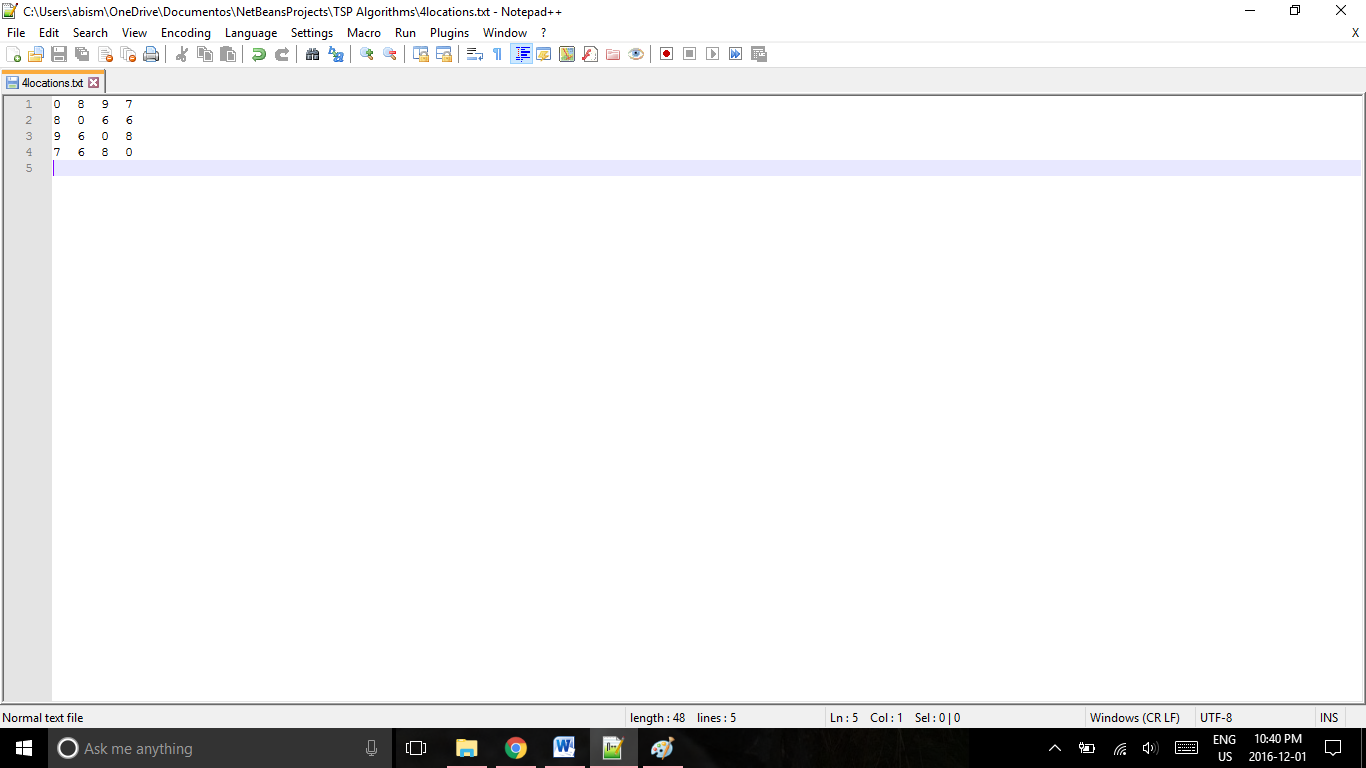
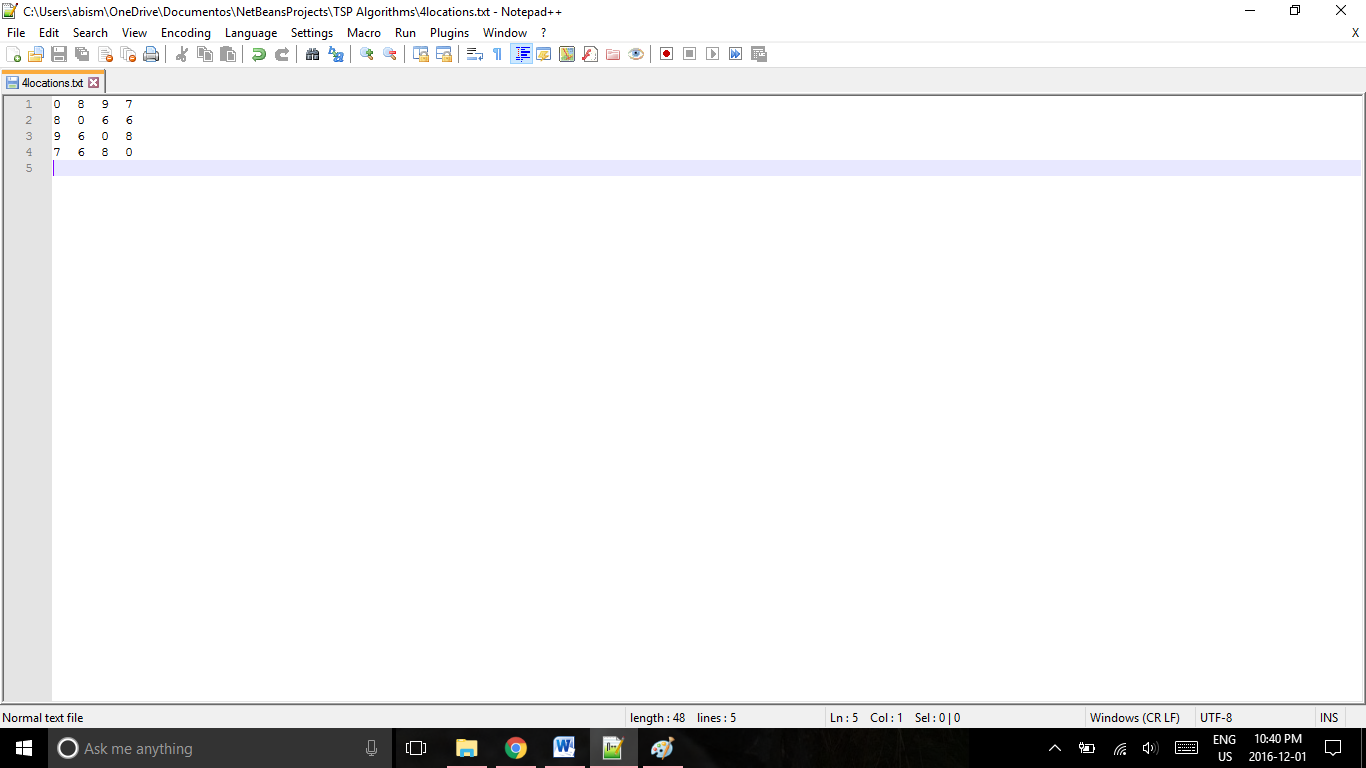
Test data is stored in a simple “.txt” file, which contains a symmetric matrix representing the different locations to visit for a particular instance. The number of columns/rows is equals to the number of vertices (destinations), and the edges (distances) are specified for each pair of vertices.

Example:

For an instance with four vertices (A, B, C and D) similar to the one below, the test file would look like this:

Actual file

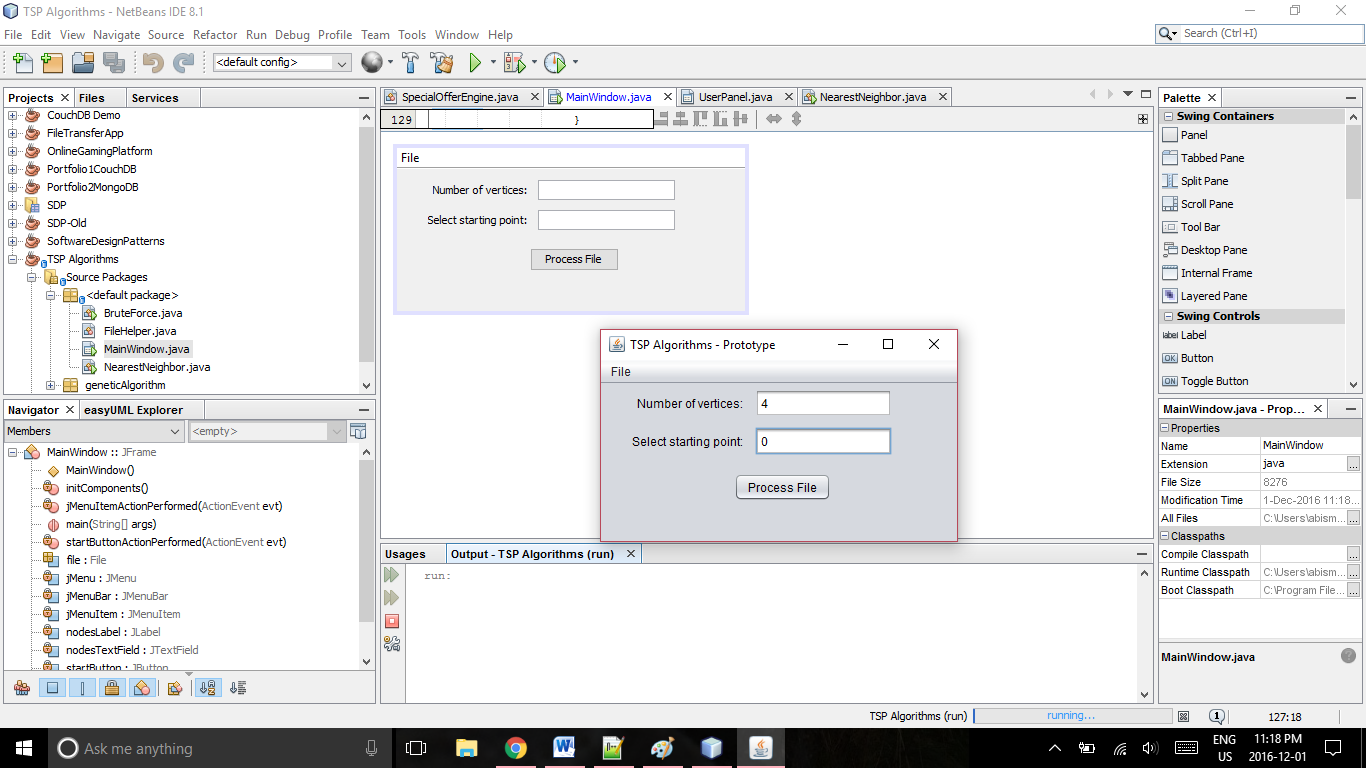
A B C D



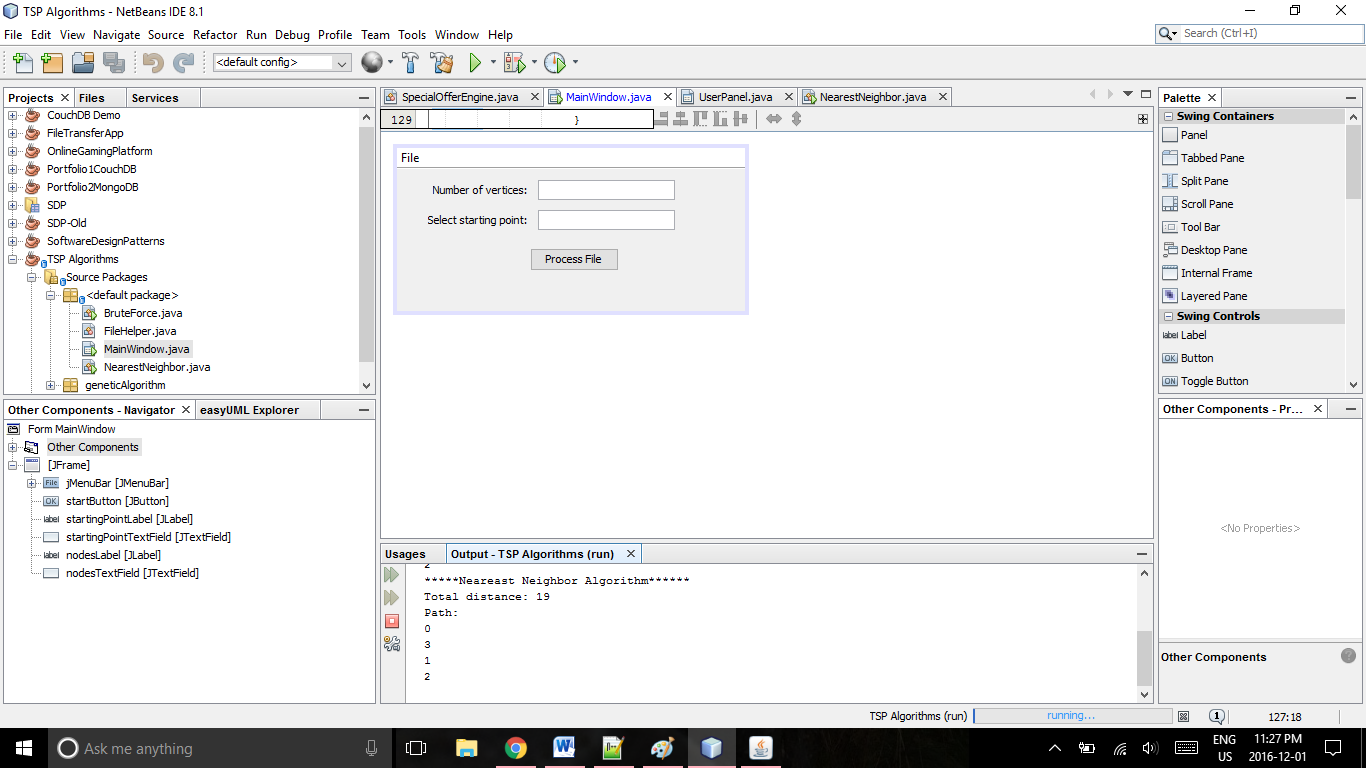
A B C D

**User interface**

The user interface has a File menu, where users need to select what test data file to process. After doing so, the number of nodes and starting point must be specified. Note the number of vertices must match the number of vertices included in the sample date.



Once the test file has been selected and the required information provided, the user may click Process File. Continuing with the example of the four vertices (A, B, C and D) and using vertex A as the starting point, the output should be similar to:



## 4.8 User Stories

//TO DOChapter 5: Implementation

The implementation of this project will be carried out using an Agile methodology. Sprints with defined tasks will be used to formalize this process. Each sprint will have a set of tasks that should be completed during the current sprint. Note that sprints may be modified as required.

## 5.1 Sprints

Each sprint will be 2 weeks long, and will have established goals to be fulfilled after the sprint has ended. However, sprints may be modified accordingly under certain circumstances such as unfinished work, blocking tasks, etc.

## 5.2 Sprint schedule

There will be seven sprints in total. The sprint schedule is displayed below:

|  |  |  |
| --- | --- | --- |
| **Sprint Number** | **Start Date** | **Finish Date** |
| 1 | 23/01/2017 | 03/02/2017 |
| 2 | 06/02/2017 | 17/02/2017 |
| 3 | 20/02/2017 | 03/03/2017 |
| 4 | 06/03/2017 | 17/03/2017 |
| 5 | 20/03/2017 | 31/03/2017 |
| 6 | 03/04/2017 | 14/03/2017 |
| 7 | 17/04/2017 | 28/03/2017 |

### 5.2.1 Sprint One

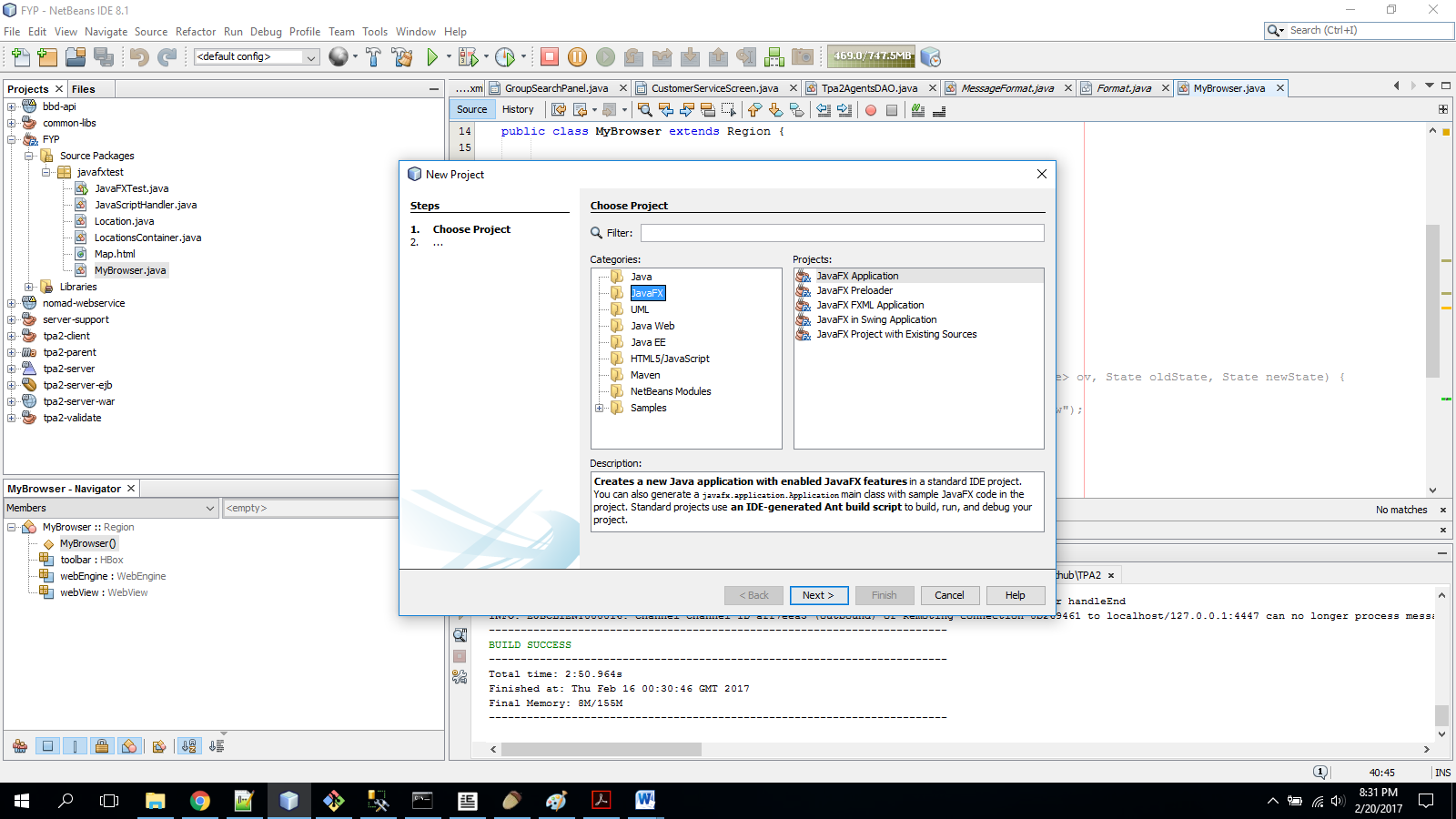
Integrate the Google Maps JavaScript API service and Java to be able to include an interactive map within a Java-based application.

#### 5.2.1.1 Google Maps JavaScript API and Java integration

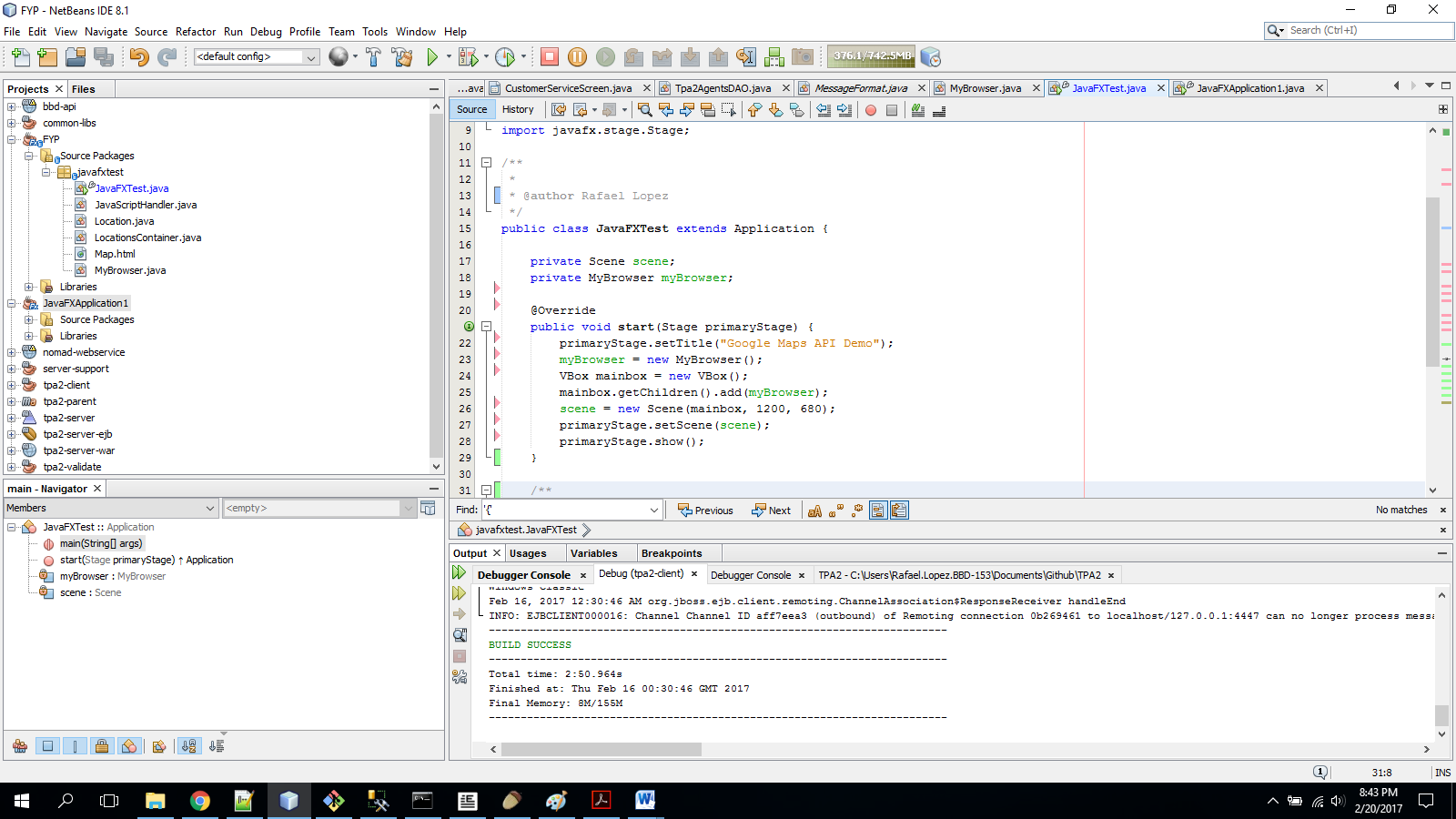
|  |  |
| --- | --- |
| **Task** | **Status** |
| Get Google Maps JavaScript API key | Complete |
| Create Java application that will contain the map | Complete |
| Load and display map within the Java application | Complete |
| Set up map to display Ireland when loaded | Complete |
| Test application to make sure users can zoom-in/out and drag the map around | Complete |

The first sprint required to combine Java and the Google Maps JavaScript API service in order to display a map that will then allow users to select locations. Getting a key for the Google service was relatively easy; the developer simply needs to request one through the Google Maps API website.

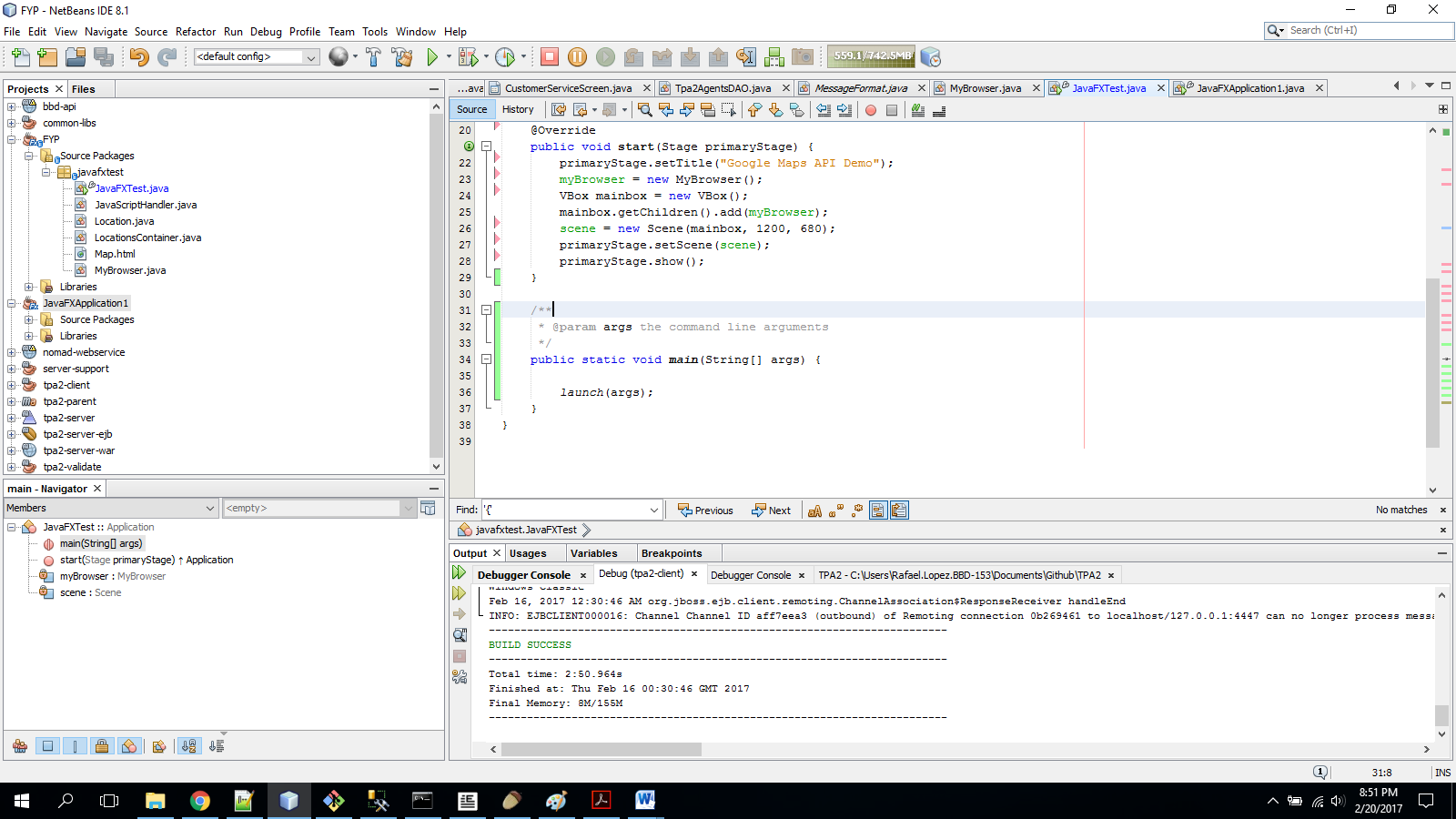
The next step was to find a way to combine Java and Google Maps to produce an application that would act as a container for the map. After some research, it was determined that JavaFX was the simplest solution for this scenario mostly because it comes with WebView, which according to Oracle’s description, is a web component that uses WebKitHTML technology to make it possible to embed web pages within a JavaFX application. Additionally, JavaScript running in WebView can call Java APIs, and Java APIs can call JavaScript running in WebView (Oracle, 2013). With all this in mind, JavaFX is a perfect fit for this case. Creating a JavaFX project is similar to creating a regular Java application in NetBeans, the only difference is that JavaFX must be selected instead of Java when creating the project as displayed in the image below.



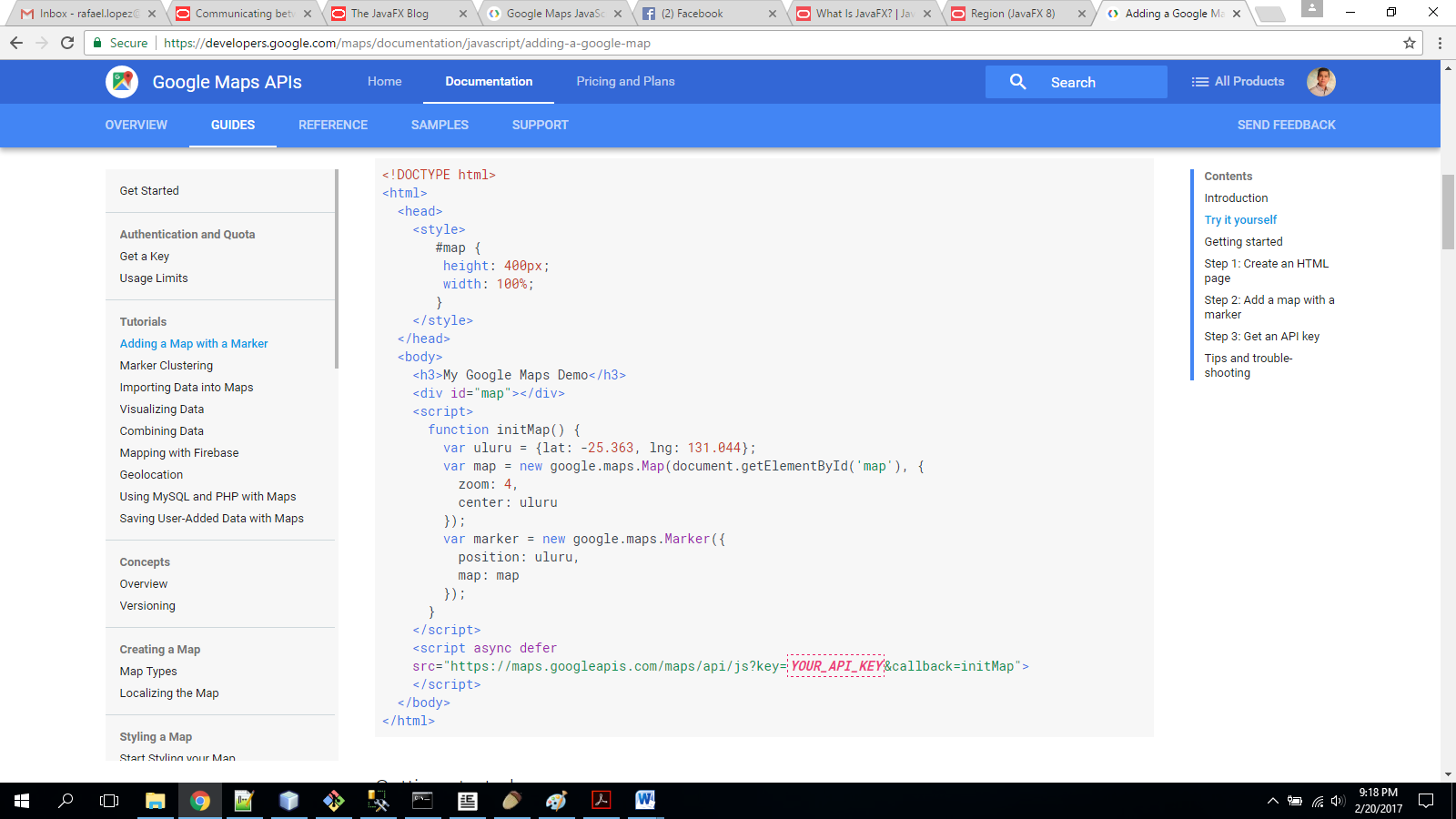
After creating the JavaFX project, the default class added by NetBeans will extend “Application”, and will have a start() method, which must be overwritten as it is the method that gets called when the application is launched. This is the method where the properties (window size, title, etc.) are usually set up for the application.



Furthermore, the main method will call the inherited launch() method, which is used to load a standalone application. By calling it, the start() method previously discussed is called in consequence.



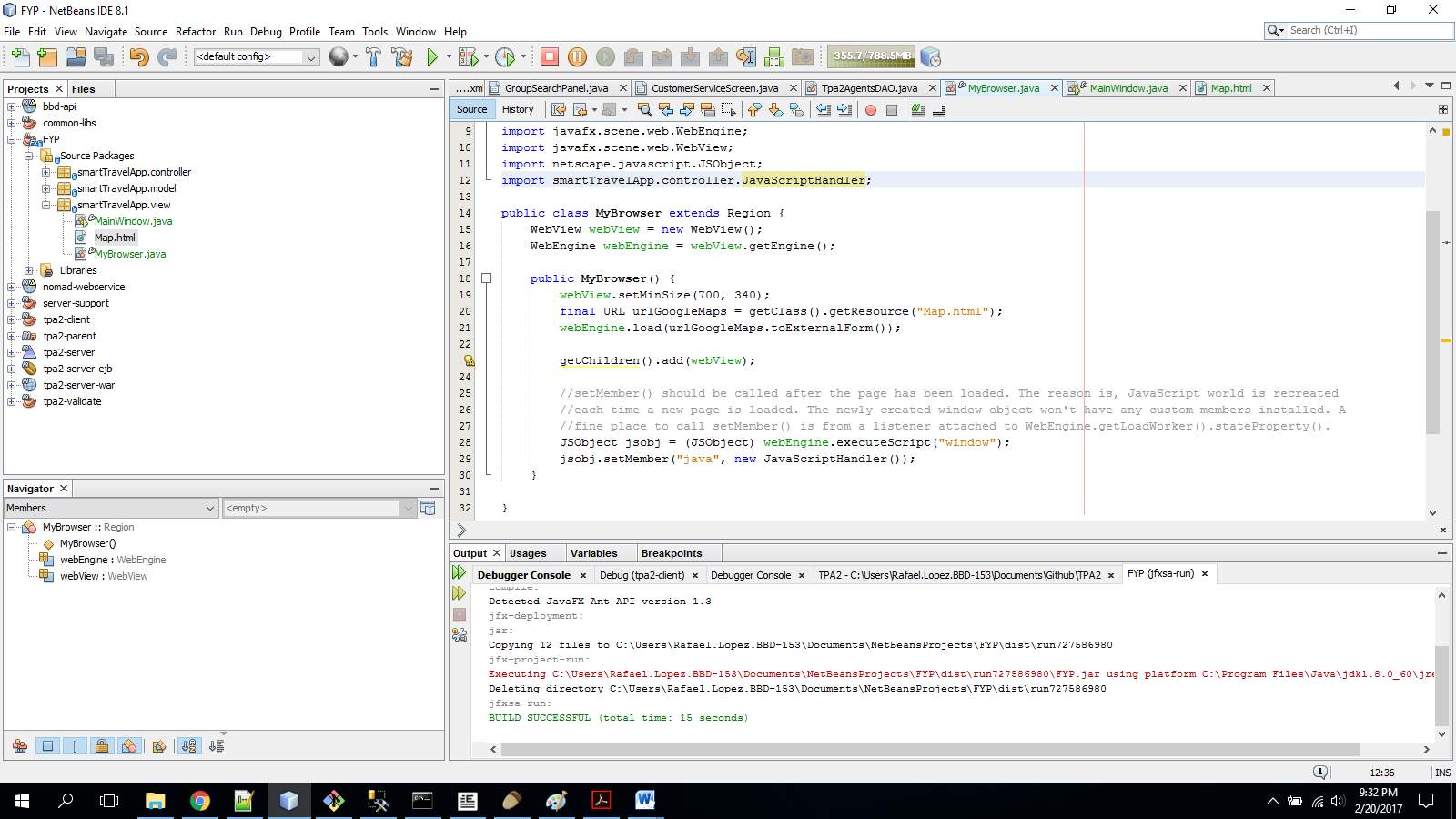
Next, loading and displaying a map within the JavaFX application is achieved through the load() function defined in the WebEngine class. First, an HTML page called Map.html was created where the Google Maps JavaScript API service was used to add an interactive map. The code for this HTML page is similar to this:



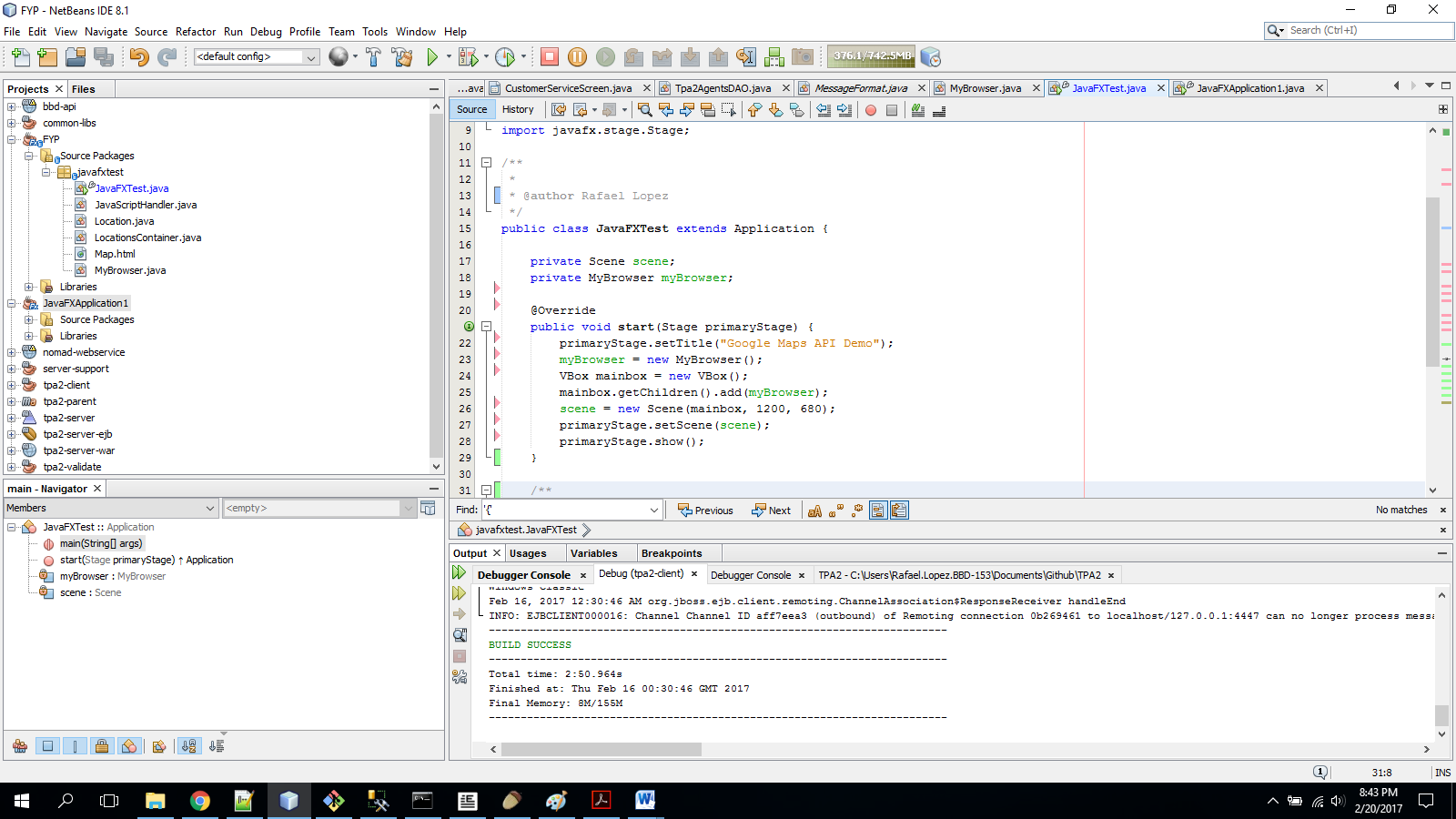
(Google, 2017)

There are two script tags defined, one is to define the initMap() function, which initializes and adds the map when the web page is loaded (here is where the latitude and longitude values are specified so that the map shows Ireland when loaded). The second script loads the Google Maps API from the specified URL. In addition, the callback parameter executes the initMap() function after the API is completely loaded. Finally, the key parameter contains the API key obtained after completing the first task of this sprint.

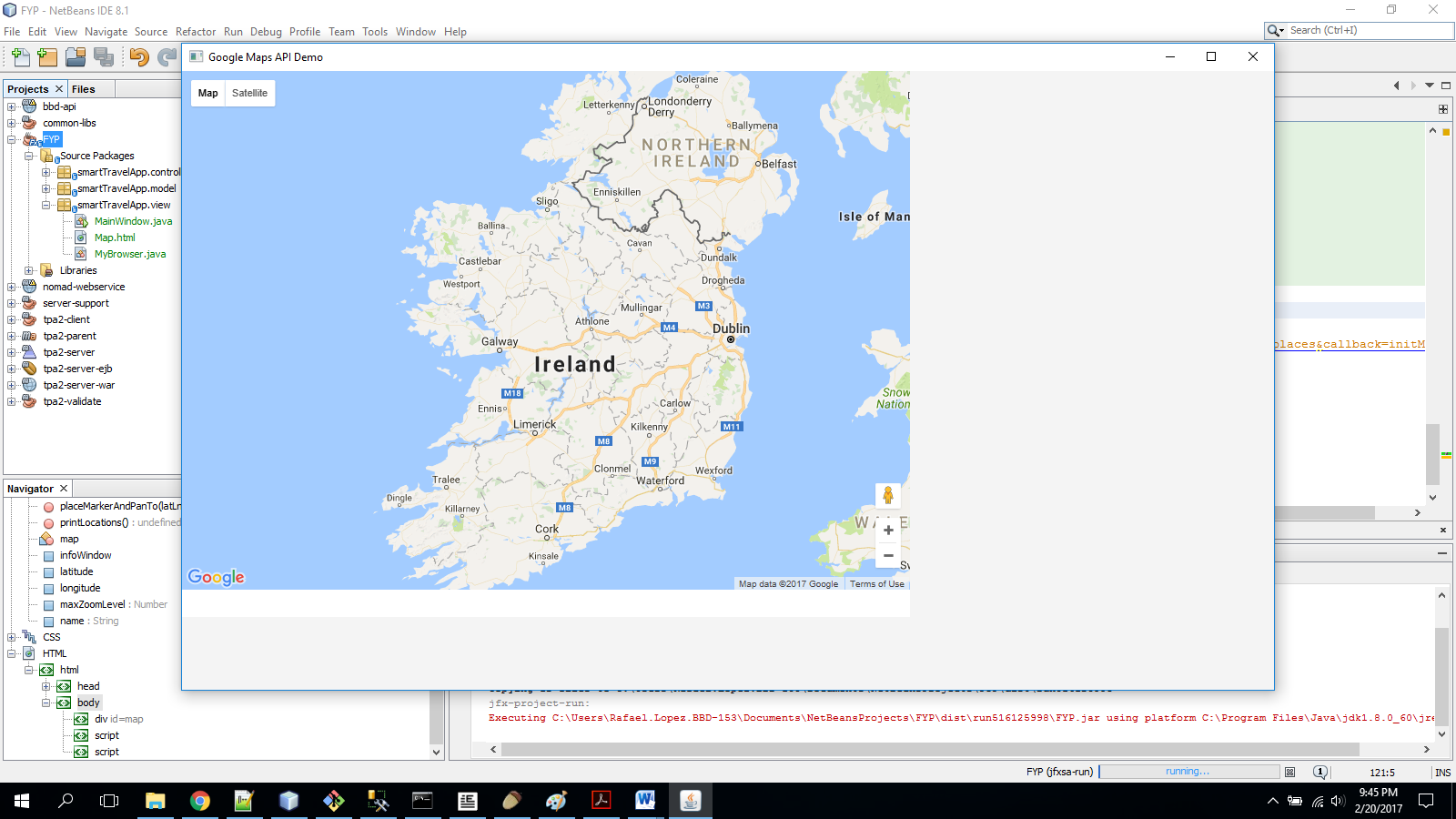
After creating the HTML page that will contain the map, a new class called MyBrowser was defined, which extends Region, the base class for all JavaFX Node-based UI Controls and all layout containers (Oracle, 2015). Then a URL object was defined to specify the url for the HTML webpage. This object is passed to the load() function previously mentioned so that the map can be displayed.



Once the map was added to MyBrowser, an instance of this class was created in the main class and attached to the main scene so that when the application was loaded it would display the HTML page showing the map.



The result was this:

  
The zoom and dragging functionalities were tested. They worked as expected.

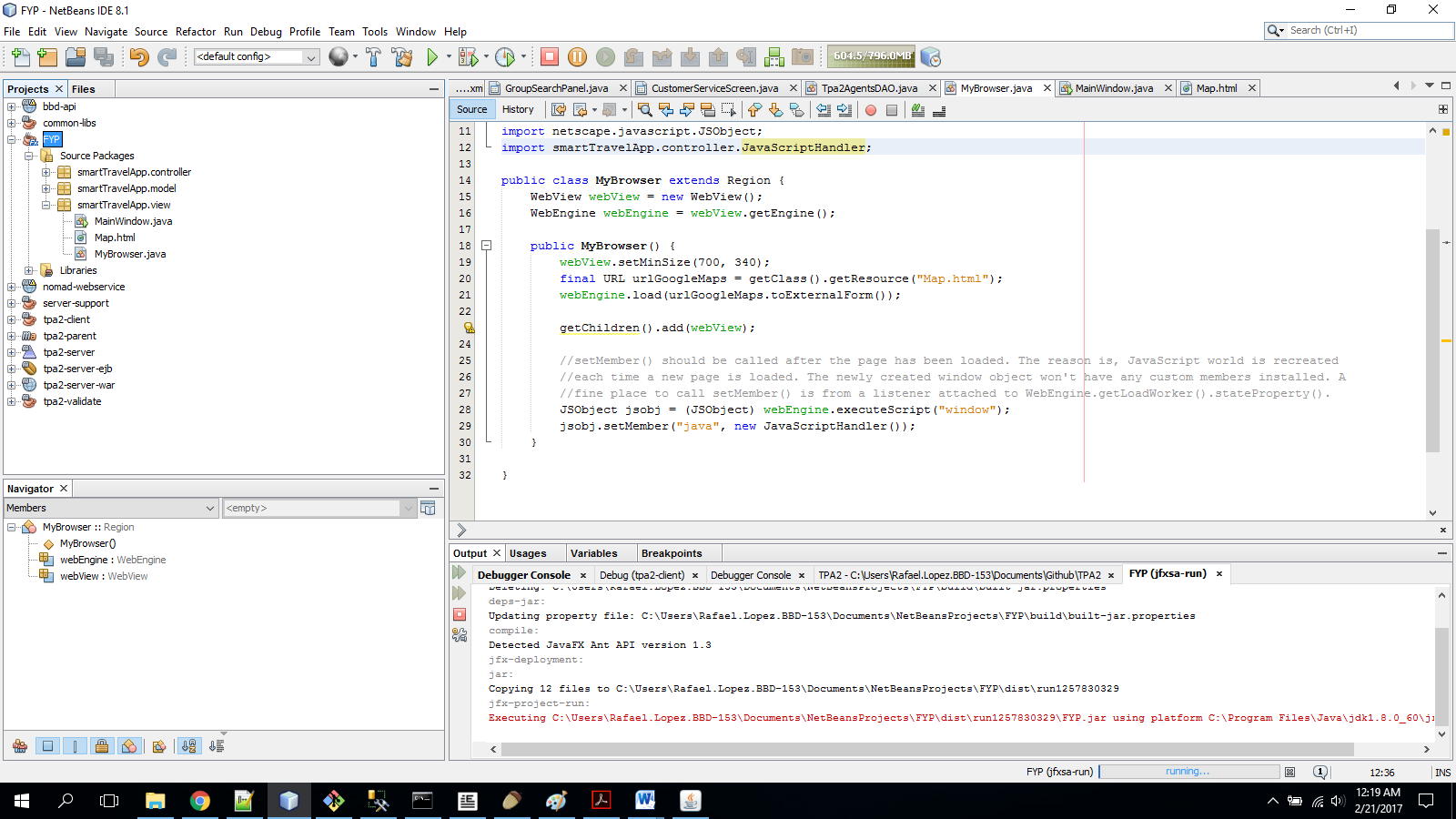
### 5.2.2 Sprint Two

Integrate the Google Maps JavaScript API service and Java to be able to include an interactive map within a Java-based application.

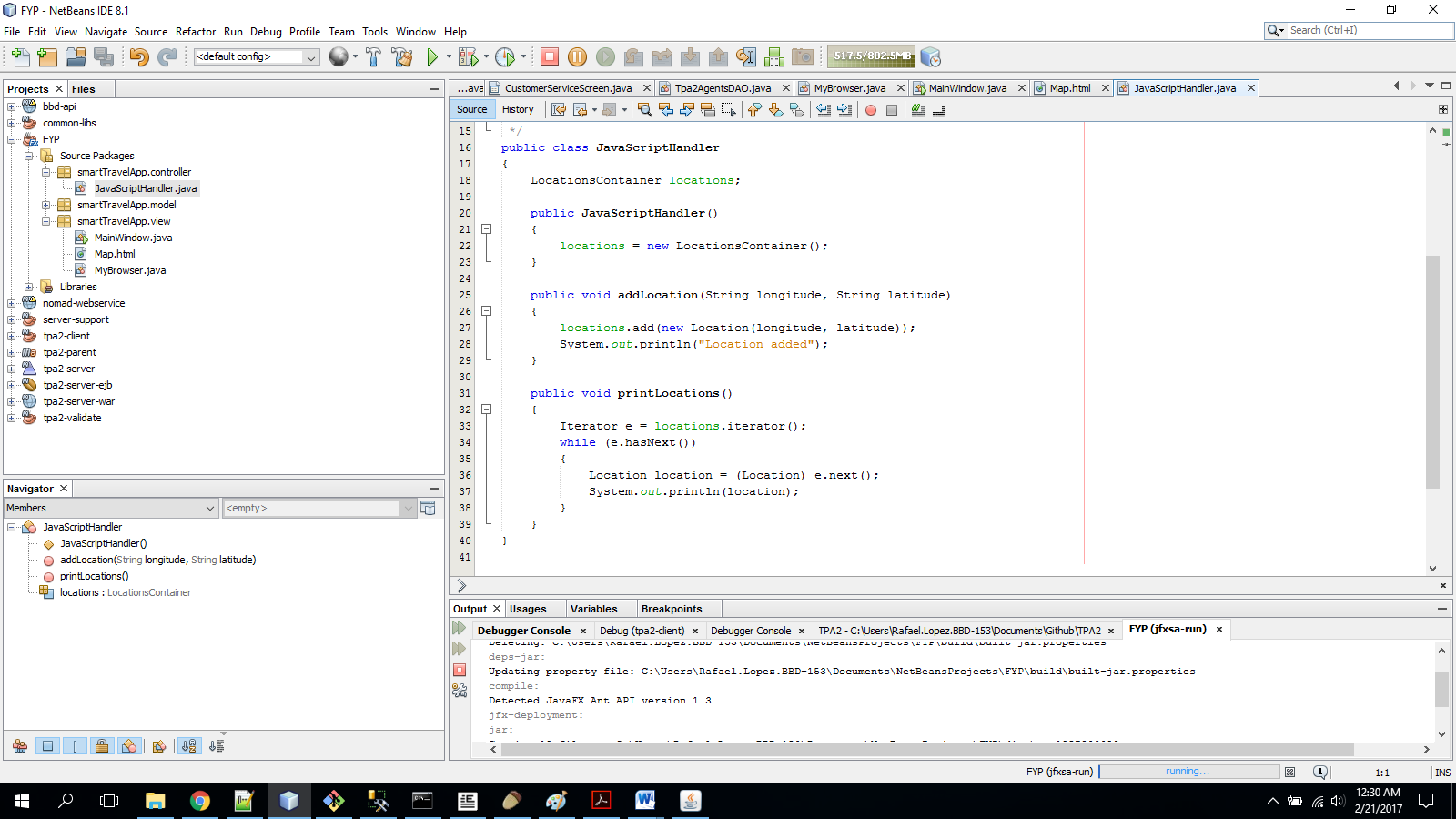
#### 5.2.2.1 Establish communication between both sides HTML and JavaFX to be able to perform Java method calls.

|  |  |
| --- | --- |
| **Task** | **Status** |
| Invoke Java methods from the HTML/JavaScript end | Complete |
| Add a button to add a location to the tour | Complete |
| Obtain coordinates of a selected place on the map | Complete |
| Store places’ information on the Java side | Complete |
| Add a button to print all current selected location | Complete |

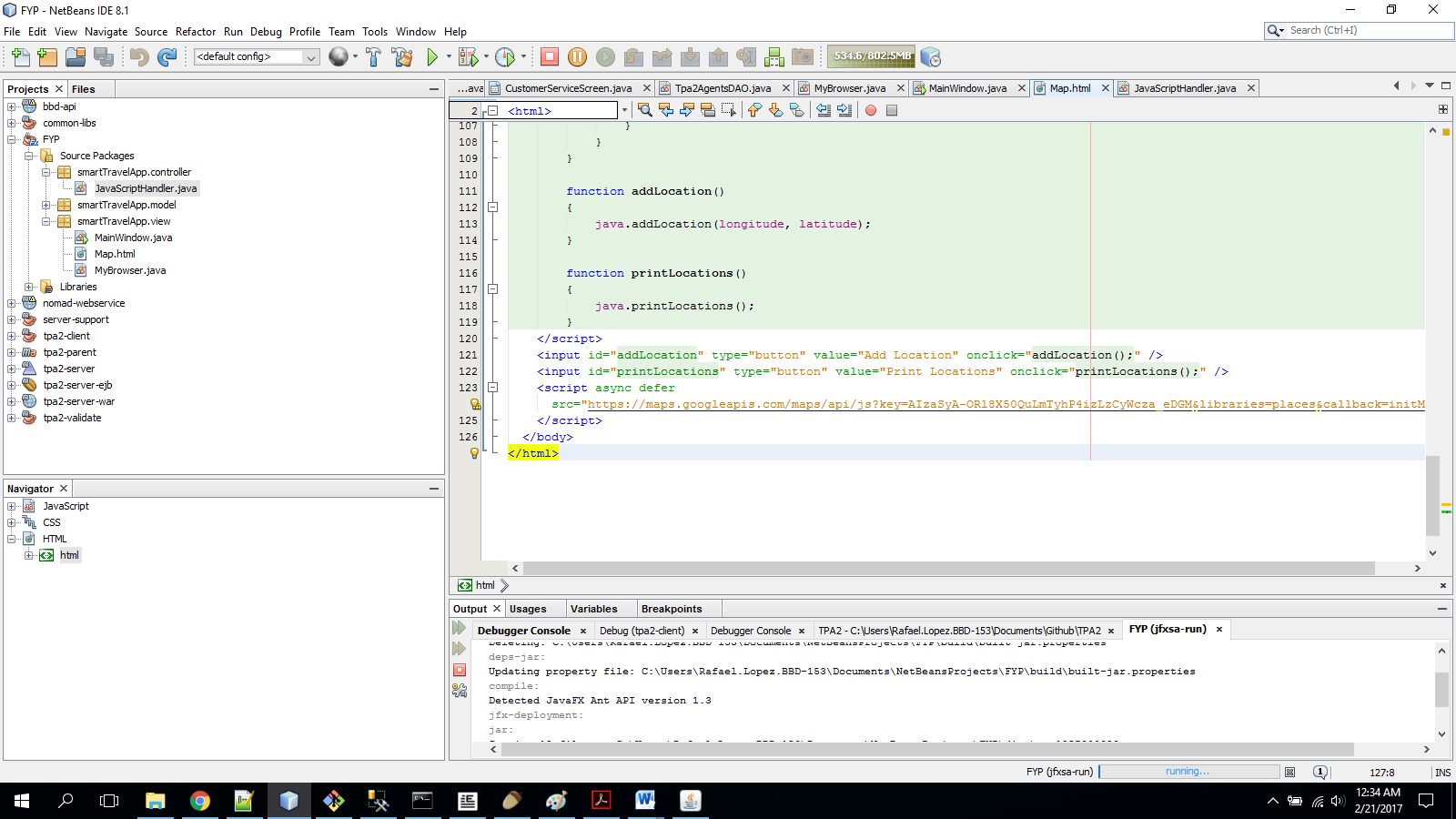
The most challenging part of the second sprint was to be able to establish a way to communicate between HTML/JavaScript and Java. This part was accomplished by using the WebEngine class and its method called executeScript(), along with the JSObject class and its method setMember(). Note that it is necessary to get a WebEngine instance by calling the getEngine() method in the WebView class. Additionally, the parameter passed into the executeScript() method represents the context in which the script will be executed, for this particular scenario “window” represents the HTML page displaying the map. Finally, the setMember() method requires two parameters, a name for the JavaScript property to be accessed and the actual value. The code is displayed in the following image.



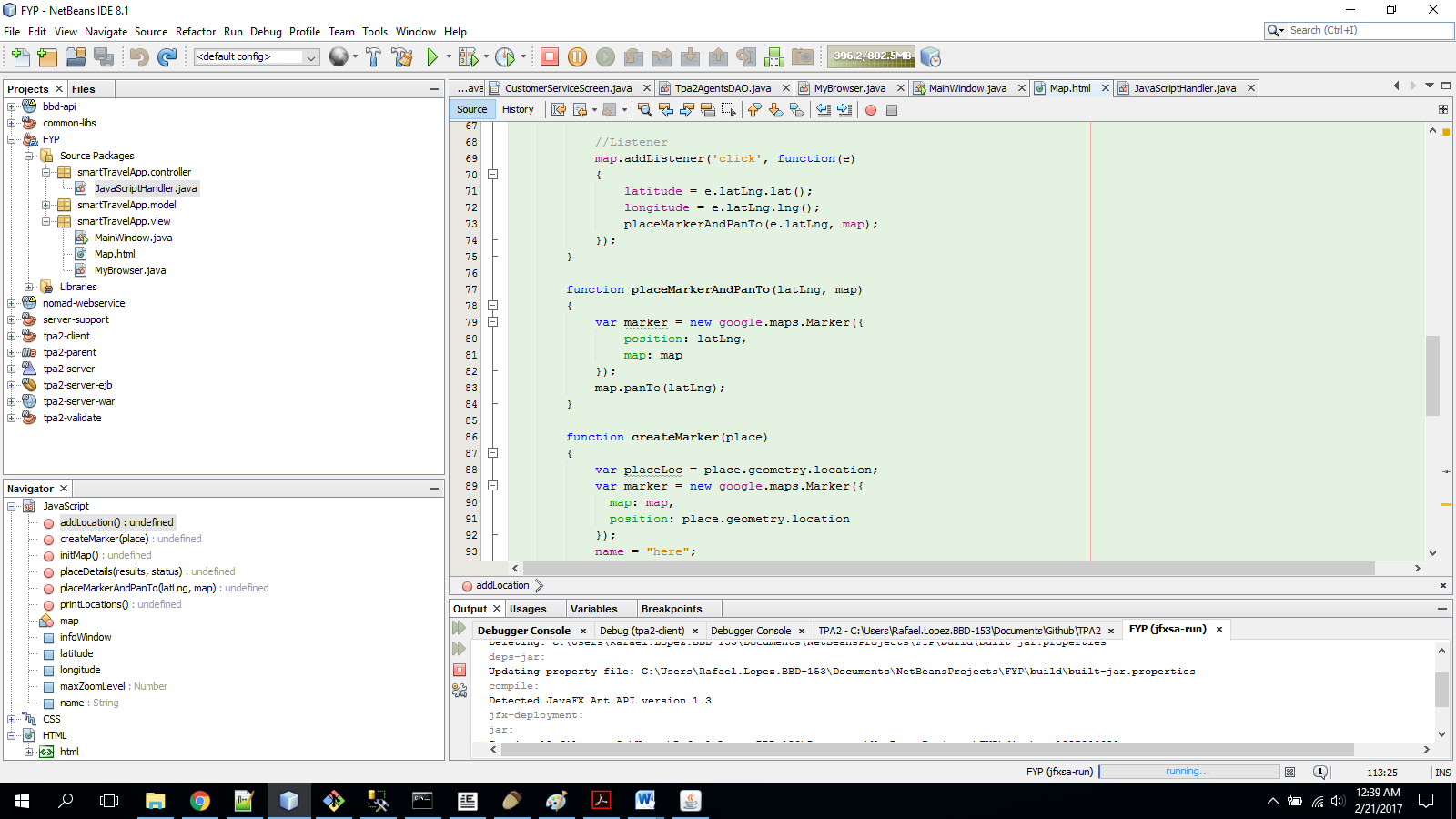
Note that a JavaScriptHandler reference is sent in as the JavaScript value to be accessed from the HTML/JavaScript side. This is a customized class will contain all the methods required to do the information processing from the map such as adding locations, deleting all locations selected, etc. At this stage, it only contains two methods, one to add locations and one to print all selected locations.



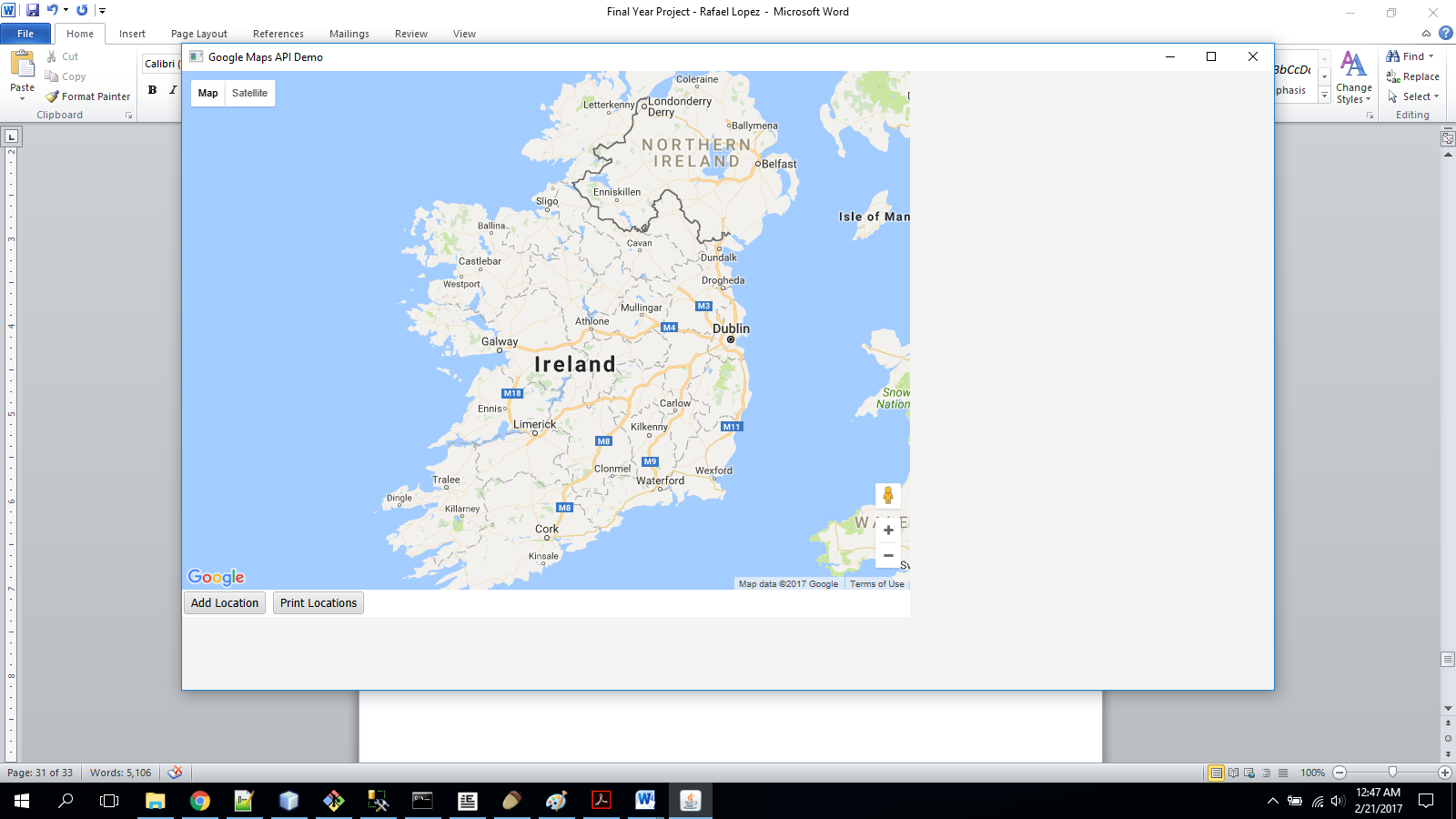
Once it was possible to make Java calls from the HTML/JavaScript side, the next step was to add two buttons, one to add locations and another one to print them all. Both are HTML buttons and call JavaScript functions that then call the Java methods.



One of the important goals of this sprint was to be able to click on the map and get the coordinates of the selected location. This was accomplished by placing a listener on the map to catch events generated by clicking on it, and then storing the longitude and latitude into two variables that are used as parameters to the addLocation() method declared in JavaScriptHandler. From Google documentation: a UI 'click' event typically passes a MouseEvent containing a latLng property denoting the clicked location on the map (Google, 2017).



After finishing sprint two, the application looked like this:



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