

Travelling Salesman Project

Submitted By:

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INTRODUCTION:

The traveling salesman problem (TSP) is a classic problem in computer science and operations research. It involves finding the shortest possible route that visits a set of given cities and returns to the starting city. The TSP is an optimization problem that has numerous practical applications, including route planning for delivery services, optimizing circuit board design, and scheduling of DNA sequencing.

Aim:

The aim of this project is to implement and evaluate different algorithms for solving the TSP problem. We will explore various algorithms, including Christofides algorithm, 2-opt, 3-opt, genetic algorithm, and Simulated Annealing optimization, and compare their performance in terms of time and space complexity.

Approach:

To solve the travelling salesman problem, we have used Christofides algorithm.
To do that, we implemented the following steps:

1. Found MST T of a Graph
2. Isolated a set of Odd-Degree vertices S
3. Found Min weight perfect matching M of S
4. Combine T and M into Multigraph G
5. Generate Eulerian Tour of G
6. Generate TSP tour from Eulerian Tour

To get the nodes and data points, the "Solve" method takes a file name as input, reads the data from a CSV file, creates a Node object for each valid data point in the CSV file, and adds it to a list of Nodes using a "Nodes" class that is not defined in the code snippet. Specifically, for each valid data point in the CSV file, the method creates a "Node" object with a unique identifier (i.e., "City" followed by the city number), latitude, and longitude, and then adds it to the list of Nodes using the "addNode" method of the "Nodes" class.

The "main" method calls the "Solve" method with the input file name and then comments out a print statement that would have printed the ID, latitude, and longitude of each node in the list of Nodes.

For our project, we compared our Travelling salesman problem approach using 2 tactical and 2 strategic algorithms:

Tactical:

1. **2-opt:** The 2-Opt algorithm works by iteratively trying to improve the tour by swapping two edges in the tour to create a shorter tour. In this implementation, the algorithm repeatedly loops over all possible pairs of edges (i, j) and $(i+1, j+1)$ in the tour, and checks if swapping these edges would result in a shorter tour. If a swap would result in a shorter tour, the edges are swapped, and the algorithm continues to loop until no further improvements can be made.

The Distance class is used to compute the distance between two nodes in the tour, as in the 2-Opt implementation. The algorithm is similar to the 2-Opt algorithm, but with an additional loop that iterates over all possible triples of edges (i, j) , $(i+1, k)$, and $(j+1, k+1)$ in the tour. For each triple of edges, the algorithm creates a new route by performing two 2-Opt swaps on the edges, and checks if the new route is shorter than the old one. If it is, the old route is replaced with the new one and the algorithm continues to loop until no further improvements can be made.

The Distance class is used to compute the distance between two nodes in the tour, as in the 2-Opt implementation. The `measureDistance` method takes two Node objects as arguments and returns the distance between them as a double value.

2. **3-opt:** The algorithm is like the 2-Opt algorithm, but with an additional loop that iterates over all possible triples of edges (i, j) , $(i+1, k)$, and $(j+1, k+1)$ in the tour. For each triple of edges, the algorithm creates a new route by performing two 2-Opt swaps on the edges, and checks if the new route is shorter than the old one. If it is, the old route is replaced with the new one and the algorithm continues to loop until no further improvements can be made.

The Distance class is used to compute the distance between two nodes in the tour, as in the 2-Opt implementation.

Strategic:

1. Simulated Annealing:

The algorithm starts with an initial solution and iteratively modifies it by randomly selecting a new solution nearby. The new solution is evaluated and compared to the current solution. If the new solution is better than the current solution, it is accepted as the new solution. However, if the new solution is worse than the current solution, it is accepted with a certain probability that depends on the temperature and the magnitude of the change.

The temperature parameter represents the probability of accepting a worse solution. The algorithm starts with a high temperature, which allows it to explore regions of the solution space that would otherwise be neglected. As the algorithm progresses, the temperature decreases, causing the probability of accepting worse solutions to decrease as well. This allows the algorithm to converge towards the optimal solution.

2. Genetic Algorithm:

The basic idea behind genetic algorithms is to create a population of potential solutions to a problem, and then use principles of natural selection to evolve that population over time.

Each potential solution in the population is represented as a set of parameters or variables, which can be mutated and recombined to create new solutions. The fittest solutions in the population are selected to reproduce and pass on their traits to the next generation.

The process of genetic algorithms involves several steps, including initialization of the population, evaluation of fitness, selection of individuals for reproduction, recombination, and mutation of individuals to create new solutions, and termination criteria. The algorithm iteratively evaluates and evolves the population until a satisfactory solution is found or a stopping criterion is met.

At last, we will visualize our approach to the travelling salesman problem using the JFree Chart library and demonstrate the optimal path and its length in meters.

We will evaluate the performance of each algorithm by comparing its solution to known optimal solutions or by analyzing its time and space complexity.

We will use the following metrics to evaluate the performance of each algorithm:

1. **Solution quality:** We will compare the length of the routes found by each algorithm to known optimal solutions.
2. **Time complexity:** We will measure the time taken by each algorithm to find a solution.
3. **Space complexity:** We will measure the amount of memory used by each algorithm to find a solution.

PROGRAM

Classes Used:

Class: `SimulatedAnnealingOptimization.java`

Data structure: List of Node objects

- Represents the tour as an ordered sequence of nodes
- Node class encapsulates the information of each node, such as the coordinates

Algorithm: Simulated Annealing

- Based on a probabilistic technique to find a global minimum of a cost function
- Generates a neighboring solution by swapping two nodes in the tour
- Accepts the neighboring solution based on its cost and the current temperature
- Repeats this process for a fixed number of iterations, while gradually decreasing the temperature

Invariants:

- `RATE_OF_COOLING`: Determines how fast the temperature decreases; in this implementation, it's set to 0.95
- `INITIAL_TEMPERATURE`: The initial temperature of the system; set to 1000 in this code
- `ITERATIONS`: The number of iterations the algorithm will run for; set to 100,000 in this code

Class - `Genetic Algorithm.java`

Invariants:

1. `populationSize`: a constant representing the size of the population
2. `mutationRate`: a constant representing the probability of mutation
3. `tournamentSize`: a constant representing the number of chromosomes selected for tournament selection
4. `elitismCount`: a constant representing the number of fittest chromosomes carried over to the next generation
5. `generations`: a constant representing the number of iterations of the genetic algorithm.

Class – `optimization2opt.java`

Data Structures:

- `List<Node>`: The 'tour' variable is a List of Node objects, where each Node represents a city. The list stores the order in which the cities are visited in the tour.

Algorithms:

- 2-Opt Heuristic: The 2-opt heuristic is a simple local search algorithm for solving the TSP. It starts with an initial tour and iteratively improves it by swapping two edges in

the tour. The algorithm iterates through all possible pairs of non-consecutive edges in the tour, calculating the potential improvement in the tour length if the edges were swapped. If swapping the edges results in a shorter tour, the algorithm reverses the order of the nodes between the edges and marks the tour as improved. The process continues until no more improvements can be made.

Invariants:

- Each city is visited only once: In the 2-opt algorithm, the tour is iteratively updated, but the cities remain the same. The algorithm only modifies the order in which the cities are visited. This ensures that each city is visited only once.
- Tour improvement: The 2-opt algorithm only swaps edges if it results in a shorter tour. This means that after each iteration, the length of the tour will either remain the same or decrease, ensuring that the tour is never worse off after an iteration.
- Termination: The algorithm terminates when no improvements can be made to the tour. In other words, when no edge swaps can further decrease the tour length, the algorithm stops iterating and returns the final tour.

Class – optimization3opt.java

Data structures used:

List<Node>: A list of Node objects, where each Node represents a location or point on the route. The Node class is not provided in this code snippet, but it likely contains coordinates and possibly other relevant information for each point.

Algorithms used:

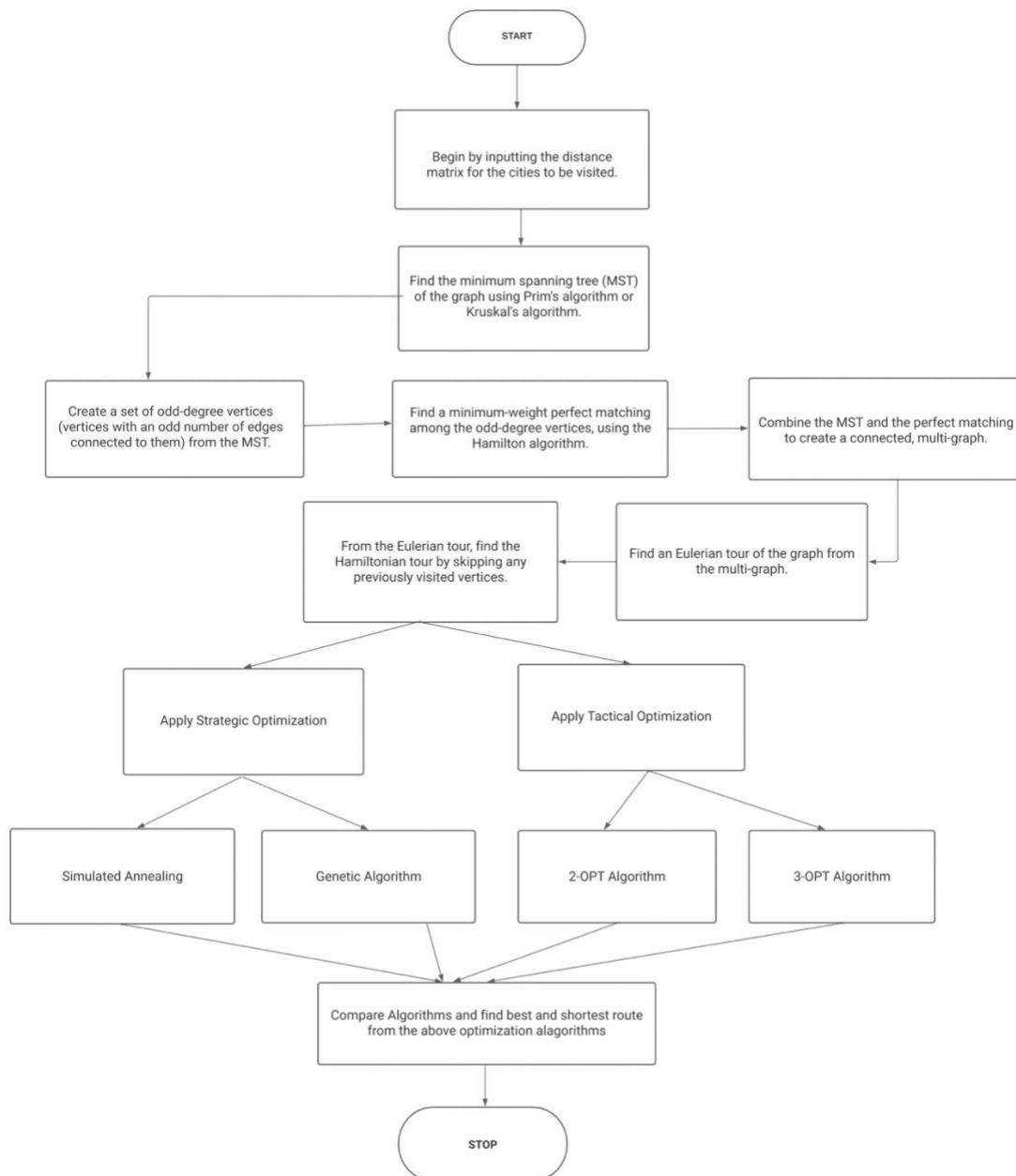
3-Opt optimization: The main algorithm used in this code is the 3-Opt optimization. It iteratively swaps segments of the route to find a shorter overall distance. The process continues until no further improvements can be made, and the final optimized route is returned.

Invariants:

- The start and end points of the route remain unchanged: The algorithm preserves the original start and end points of the route, ensuring that the optimized route begins and ends at the same locations as the original route.
- Route connectivity: The optimized route will always be a connected path, as the algorithm only swaps segments without breaking the connections between points.
- All points visited: All nodes from the original route are included in the optimized route, ensuring that the algorithm does not skip any points when optimizing the route.

FLOW CHARTS

Travelling salesman problem flow chart



OBSERVATIONS AND GRAPHICAL ANALYSIS

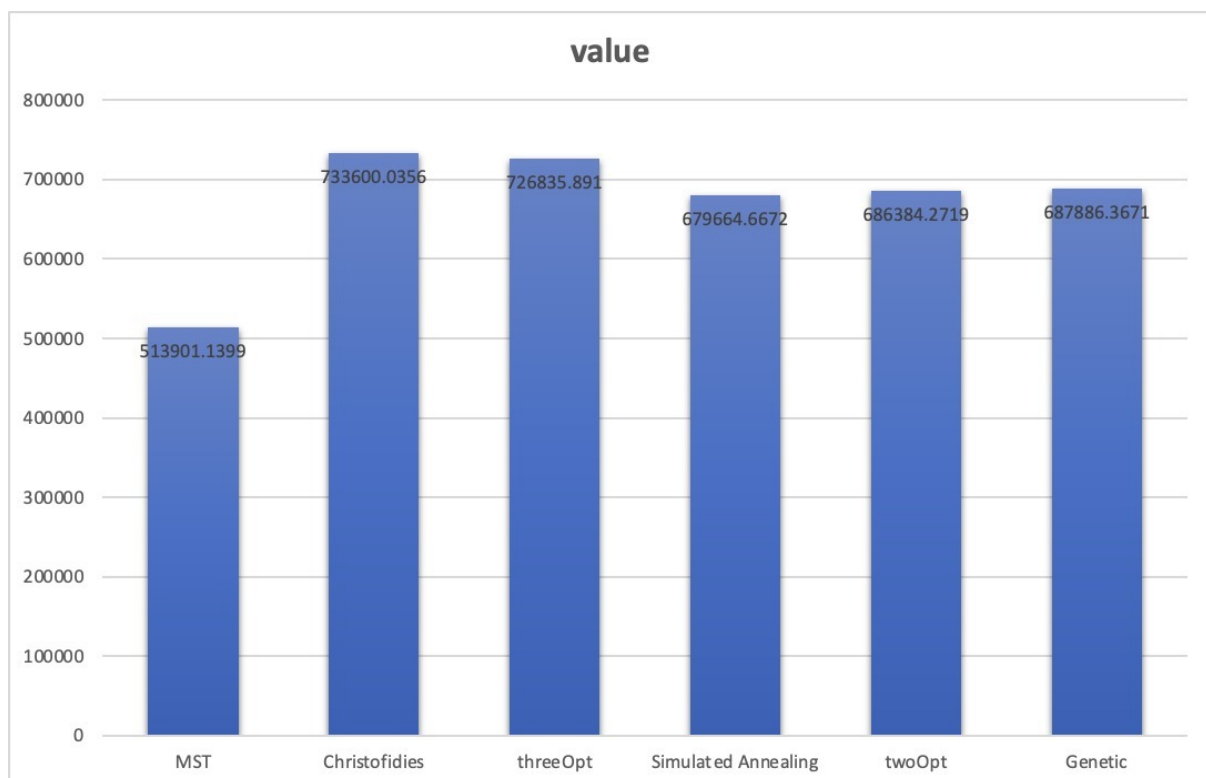
After running the Christofedes algorithm for the travelling salesman problem, the total distance we get is for the Hamiltonian tour is 740185.9793176028 meters. The MST for the Travelling salesman problem that we get is 513901.1398729172 meters

On running the optimization algorithms, we get the following distances and ratio with the optimal solution:

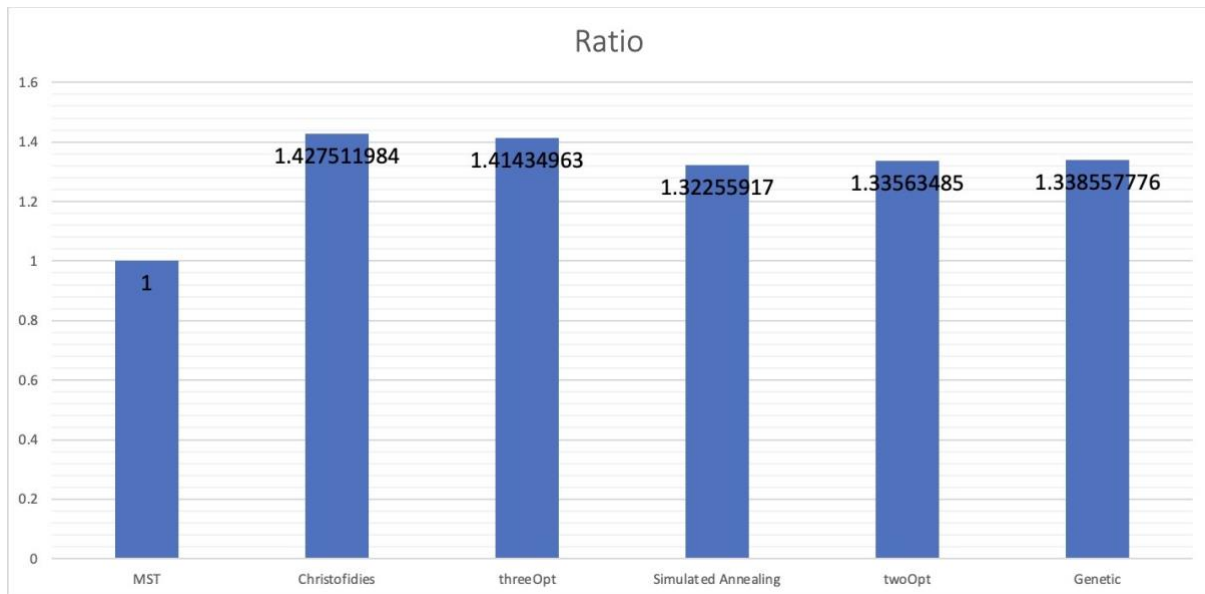
	Distance (meters)	Ratio (Tour /MST)
1. Hamiltonian Tour -	740185.9793176028	1.44
2. MST -	513901.1398729172	1
3. Genetic Algorithm -	83511.2772255736	0.162
4. Simulated Annealing -	689302.0676620142	1.341
5. 2-opt -	697206.2713367345	1.356
6. 3-opt -	739264.9301606393	1.438

This shows that simulated annealing optimization is the best optimization algorithm and will retrieve the shortest path.

A comparison of tour length of different algorithms:



A comparison of tour ratio (tour length/ MST) of different algorithms:



RESULTS AND MECHANICAL ANALYSIS

Output received:

MST and Christofedes algorithm

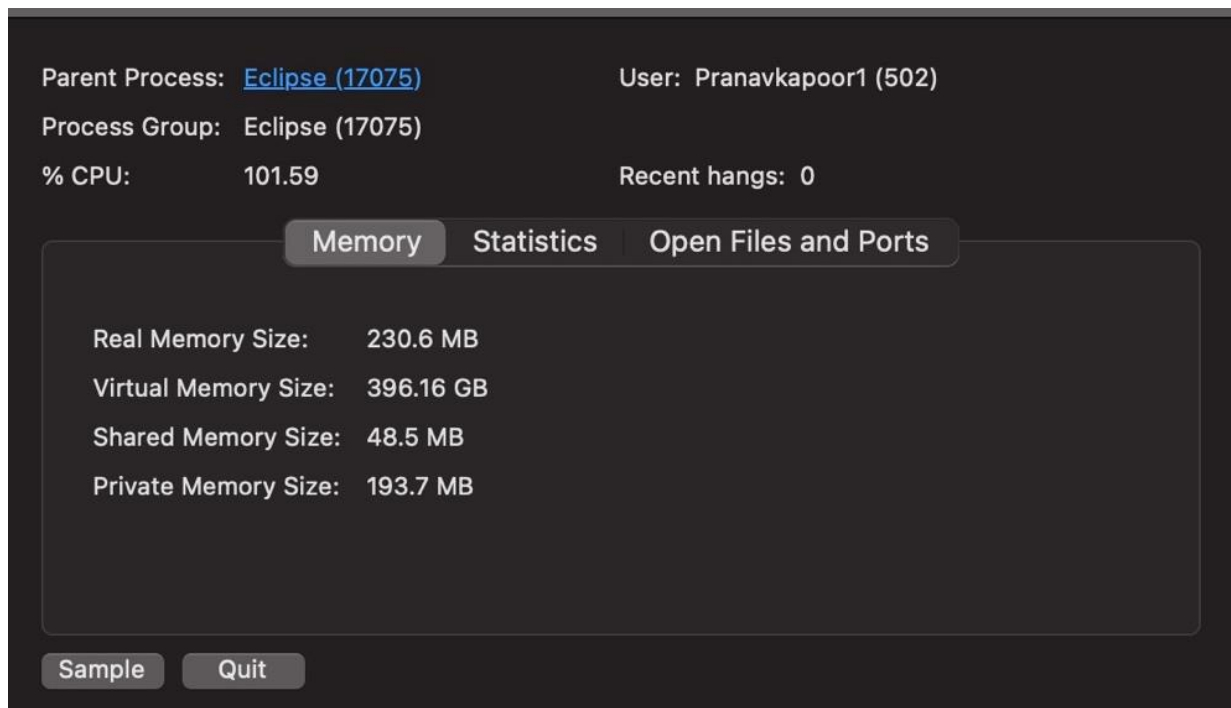
```
MST
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43aa0,09298,5aad7,6a7d5,af729,9fe9a,09a87,31838,5fe33,50990,cf0b9,99bdc,ec311,4521a,c59bd,5da55,48feb,6616d,41072,7a64e,63890,b50ca,5fe9b,814da,3849e,7713f,b61cf,e71b5,e0000,19884,b465f,b559f
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--- Tour Distance 513901.1398729172 meters
Ratio
--- Ratio 1.0 meters

TSP- using Christofides
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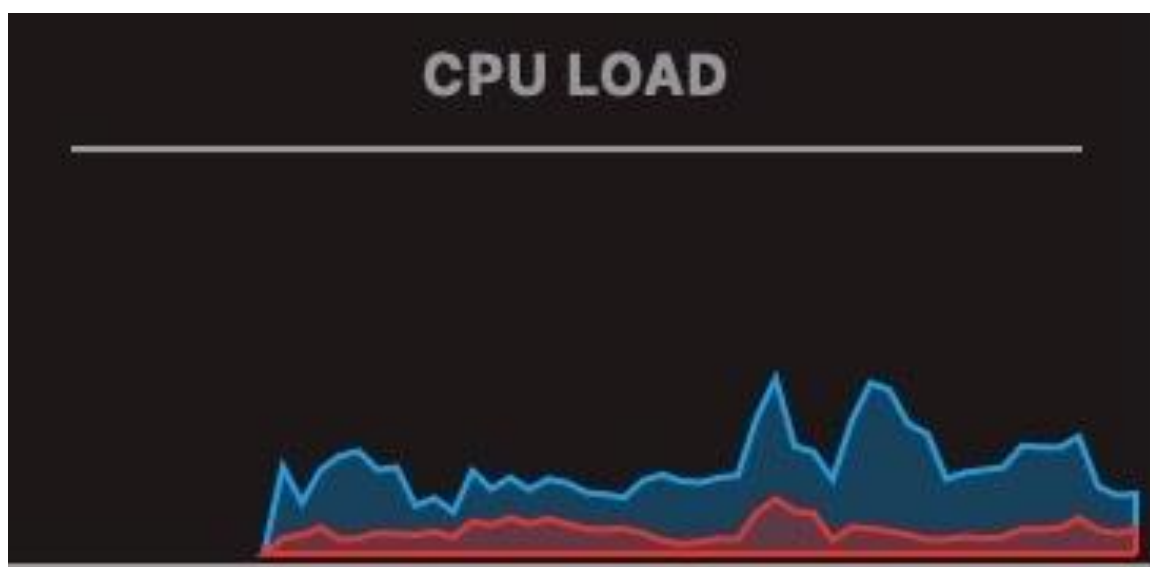
```


Device metrics



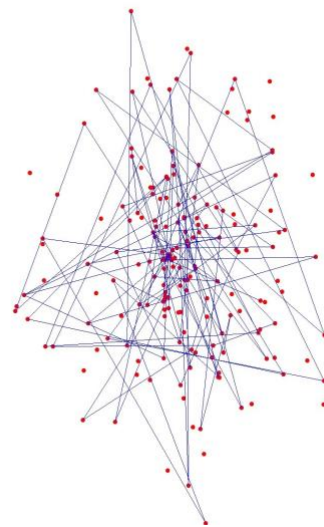
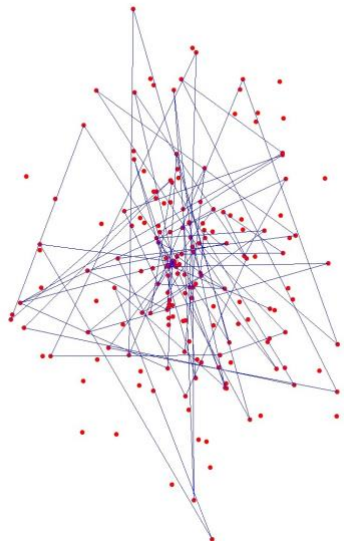
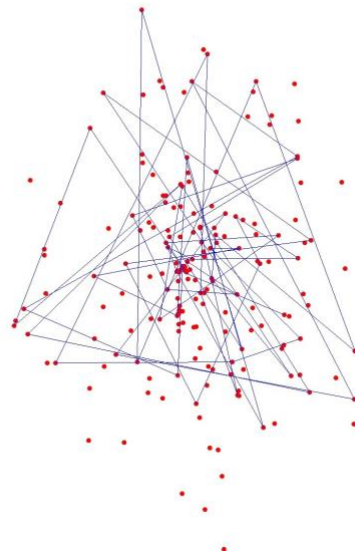
CPU % = 101.59%

Threads: 40

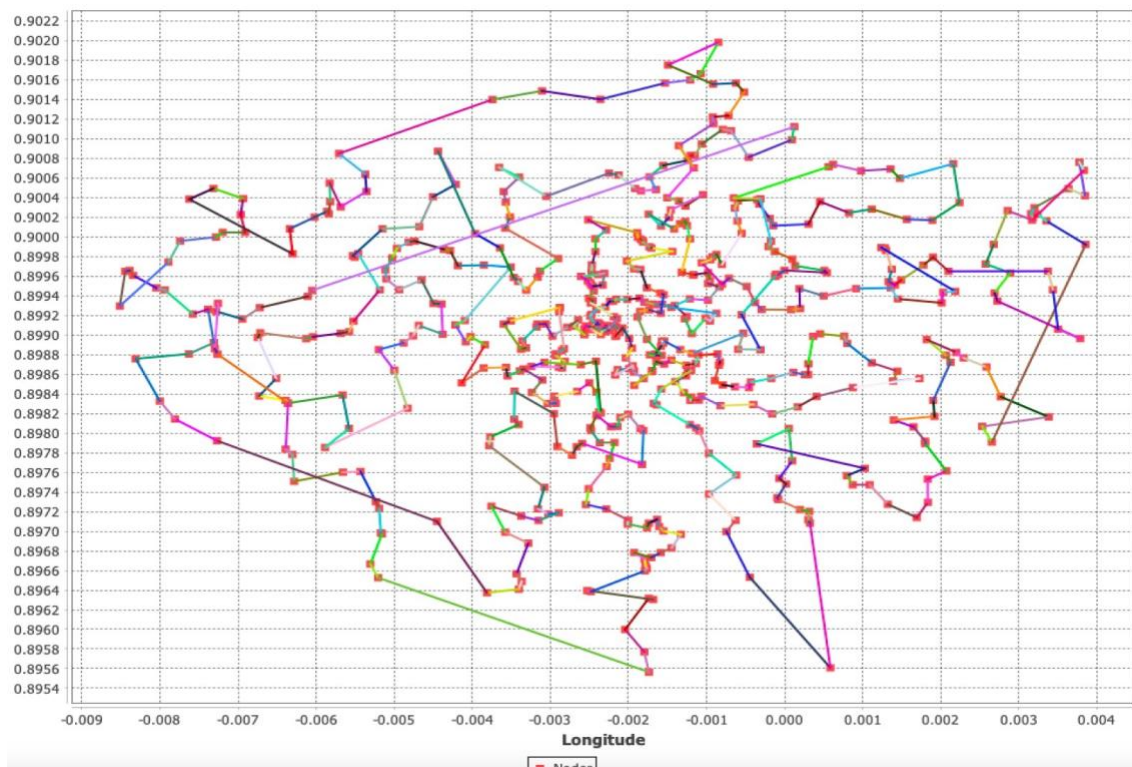
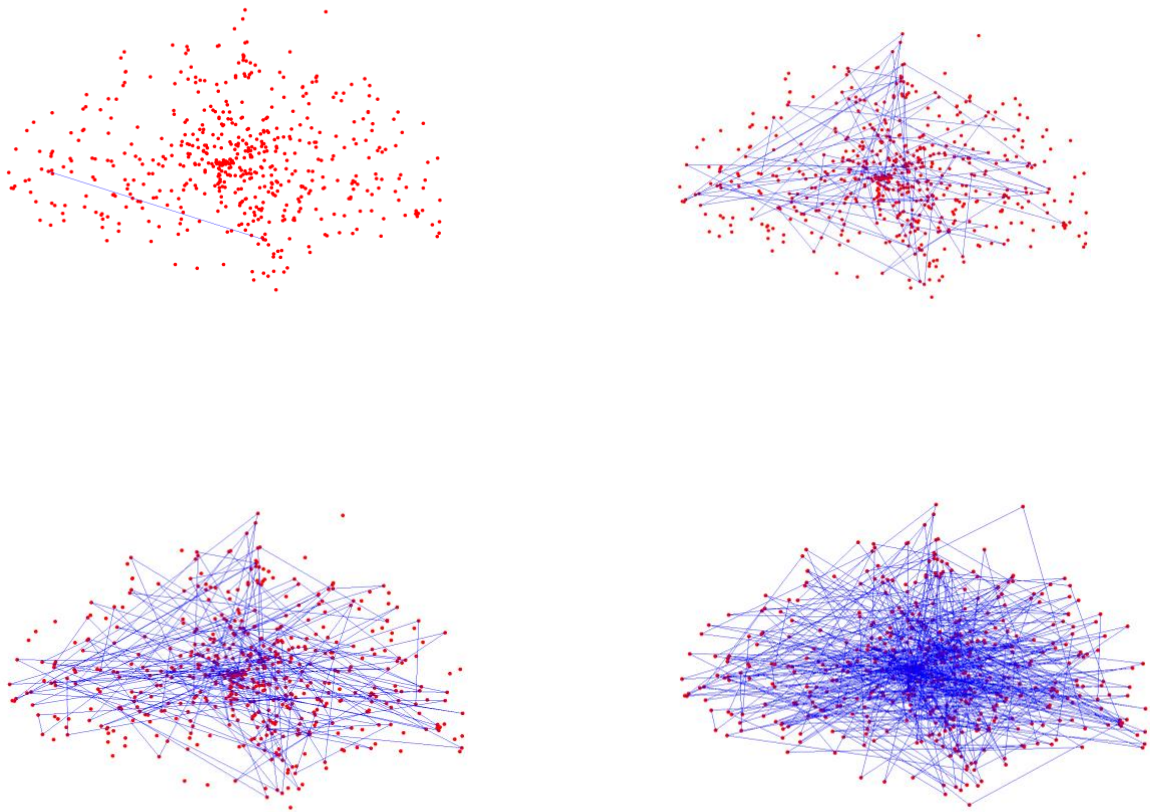


The visualization graph for the Travelling salesman problem is as below:

Output for First dataset points: 157

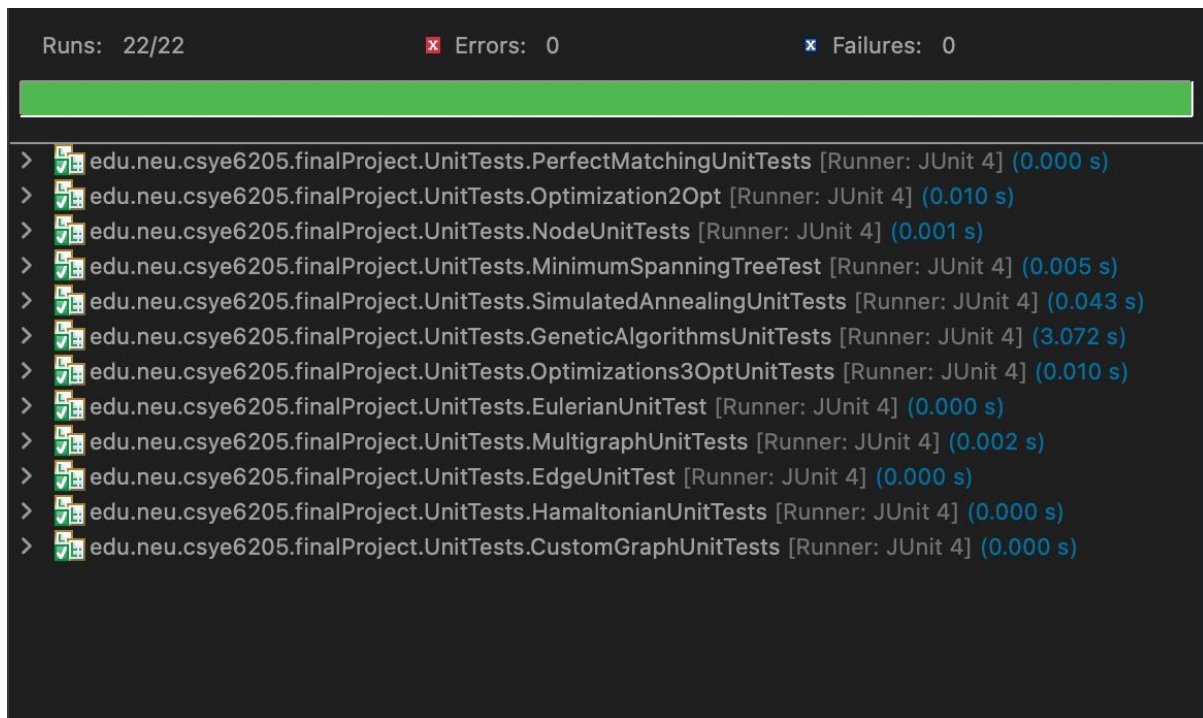


Output for Second dataset points: 585



UNIT TESTS

The code run all 22/22-unit tests cases.



```
Runs: 22/22      x Errors: 0      x Failures: 0

> [✓] edu.neu.csye6205.finalProject.UnitTests.PerfectMatchingUnitTests [Runner: JUnit 4] (0.000 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.Optimization2Opt [Runner: JUnit 4] (0.010 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.NodeUnitTests [Runner: JUnit 4] (0.001 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.MinimumSpanningTreeTest [Runner: JUnit 4] (0.005 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.SimulatedAnnealingUnitTests [Runner: JUnit 4] (0.043 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.GeneticAlgorithmsUnitTests [Runner: JUnit 4] (3.072 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.Optimizations3OptUnitTests [Runner: JUnit 4] (0.010 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.EulerianUnitTest [Runner: JUnit 4] (0.000 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.MultigraphUnitTests [Runner: JUnit 4] (0.002 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.EdgeUnitTest [Runner: JUnit 4] (0.000 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.HamaltonianUnitTests [Runner: JUnit 4] (0.000 s)
> [✓] edu.neu.csye6205.finalProject.UnitTests.CustomGraphUnitTests [Runner: JUnit 4] (0.000 s)
```

CONCLUSION

To sum up, we implemented and assessed several algorithms to tackle the TSP problem, which included Christofides algorithm, 2-opt, 3-opt, genetic algorithm, and Simulated Annealing optimization. Our evaluation was based on their solution quality, time complexity, and space complexity.

Christofides algorithm turned out to be a pragmatic choice for medium-sized TSP problems as it provided a satisfactory balance between solution quality and time complexity. Whereas 2-opt and 3-opt algorithms produced highly accurate solutions, but their time and space complexity make them more suitable for smaller problems. Genetic algorithm and Simulated Annealing optimization demonstrated promising outcomes but required significant computational resources to deliver near-optimal solutions.

Finally, we concluded that simulated annealing optimization provided the best possible route and ratio with the MST and must be preferred for finding the shortest route for the travelling salesman problem.

In conclusion, the algorithm selection for the TSP problem relies on the problem size, the desired solution accuracy, and the available computational resources. This report's findings offer valuable insights into the strengths and limitations of different algorithms and can serve as a guide to select an appropriate algorithm for a specific TSP problem.

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