INFO 6205 Spring 2023 Final Project

Travelling Salesman

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Introduction:

Finding the shortest path between a number of points and places that must be visited is the goal of the algorithmic problem known as the "travelling salesman problem" (TSP). The cities a salesperson might visit are the points in the problem statement expressed in terms of latitudes and longitudes.

Aim:

The goal of the project is to determine the shortest path using which each listed city is visited exactly once and finally return back to the starting location.

The problem is named after the analogy of a salesman who must visit several towns and wants to travel the fewest amount of distance possible while doing so. The issue has significant applications in network routing, logistics, and other fields.

The TSP is an NP-hard problem, which means that it is computationally impractical to find an accurate solution for large instances of the problem in linear time. However, there are a variety of approximations, optimization algorithms and heuristics that can be applied to quickly find effective answers.

Approach:

The travelling salesman problem (TSP) can be solved in a number of ways, including accurate and heuristic methods.

Accurate techniques include dynamic programming, cutting-plane algorithms and branch-and-bound algorithms. These techniques are computationally expensive and might not be practical for widespread use cases of the issue.

Even though the solution is not always optimal, heuristic approaches try to find a good one in a fair period of time, maintaining a balance between space, time and efficiency. These techniques consist of Nearest neighbour, Insertion, Simulated annealing, Ant Colony Optimization and Genetic Algorithms.

Program:

Data Structures & Classes: Data structures and classes used in our project are mentioned below:

1. Data structures: Graph, ArrayList, Stack, 2-D Array
2. Optimization classes: ThreeOptSwapOptimization, TwoOptSwapOptimization, AntColonyOptimization, SimulatedAnnealing.
3. Entity class: Point
4. Preprocess class: CsvReader
5. Algorithm classes: Christofides, GreedyAlgorithm and MinimumSpanningTree

Algorithms: The below optimization algorithms are used in the project.

Greedy Algorithm:
The Greedy Algorithm is a simple and fast algorithm for solving the Travelling Salesman Problem (TSP). It starts at a random city and at each step, visits the nearest unvisited city until all cities have been visited. However, it does not guarantee an optimal solution and can give suboptimal results for large problem sizes.

MinimumSpanningTree:
The Minimum Spanning Tree (MST) algorithm is an approach for solving the Travelling Salesman Problem (TSP). It builds a complete graph on the cities, computes the MST using Prim's or Kruskal's algorithm, and traverses the MST to obtain a sequence of cities. Finally, it converts the sequence to a Hamiltonian circuit by adding the starting city at the end. While the MST algorithm is not guaranteed to produce an optimal solution, it can provide a good approximation in practice.

Christofide's Algorithm:
The Christofides Algorithm is an approximation algorithm for solving the Travelling Salesman Problem (TSP). It guarantees a solution within a factor of 3/2 of the optimal solution. It works by finding the minimum spanning tree (MST), finding a minimum-weight perfect matching among the vertices with odd degree in the MST, and then combining the MST and the matching to form a multigraph. Finally, it finds an Eulerian circuit in the multigraph and converts it to a Hamiltonian circuit, which is a solution to the TSP.

TwoOptSwap Optimization:
The Two-Opt Swap Optimization algorithm is a heuristic algorithm for the TSP that combines the Two-Opt and Swap algorithms to explore the solution space more efficiently and converge towards a good solution faster than using either algorithm alone. It has been shown to be effective, but may not be as effective as other heuristic algorithms and requires careful parameter tuning.

ThreeOptSwap Optimization:
The Three-Opt Swap Optimization algorithm is a heuristic algorithm for the Travelling Salesman Problem (TSP) that combines the Three-Opt and Swap algorithms to explore the solution space more efficiently and converge towards a good solution faster than using either algorithm alone. It has been shown to be effective for the TSP, particularly for large problem instances, but requires careful parameter tuning.

Ant Colony Optimization:
The Ant Colony Optimization (ACO) algorithm is a metaheuristic inspired by the behaviour of ants searching for food, used to solve the Travelling Salesman Problem (TSP) and other optimization problems. A colony of artificial ants searches for good solutions by repeatedly choosing the next city to visit based on pheromone trail strength and a heuristic function. The algorithm deposits pheromone on the edges used by the ants, guiding future ants towards good solutions. However, parameter settings need to be fine-tuned for each problem instance.

Simulated annealing:
Simulated annealing (SA) is a metaheuristic algorithm for solving the Travelling Salesman Problem (TSP) that is inspired by the physical process of annealing. SA iteratively explores the solution space by randomly perturbing the current solution and accepting the perturbation based on a probability function. The temperature parameter is gradually decreased over time, allowing the algorithm to converge towards a good solution. SA is effective for large problem instances, but requires careful parameter tuning.

Invariants: The below invariants are maintained throughout the project.

1. Distance between cities: The distances between the cities remain constant during the entire optimization process.
2. Symmetric distance matrix: The distances between any two cities are the same regardless of the direction of travel (Distance between city A and city B is the same as the distance between city B and city A).
3. Triangle inequality: The sum of the distances between any three cities is always greater than or equal to the distance between any two of those cities.
4. Subtour elimination: Every solution visits all the points at least once. There is no solution where subtours are present.

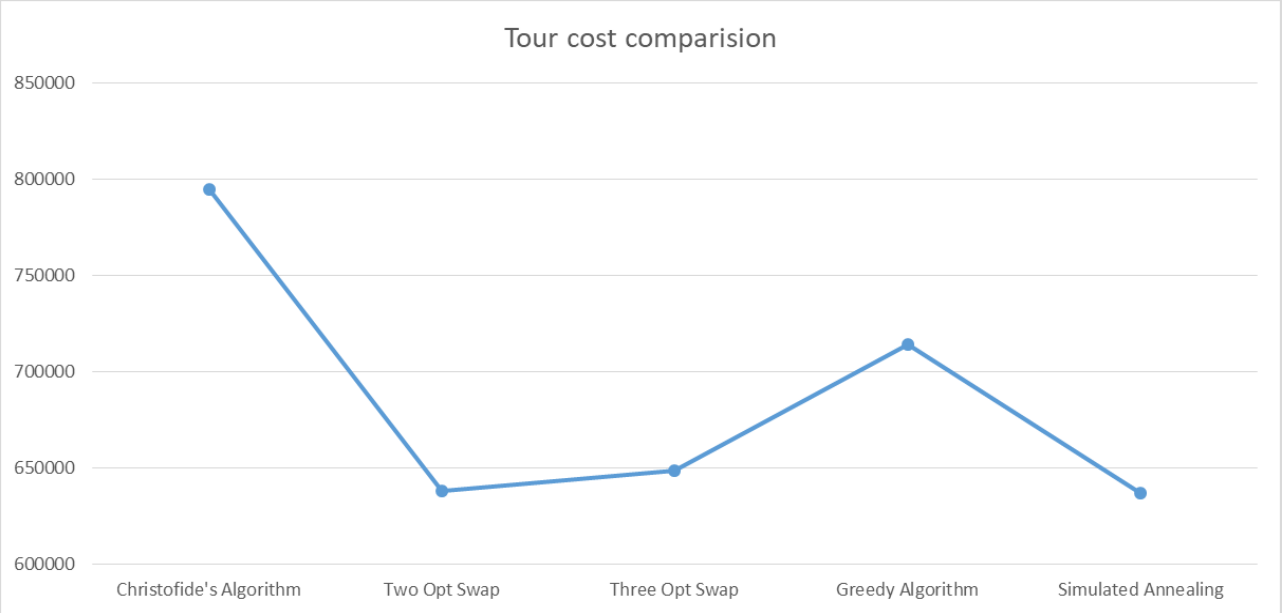
Flow Chart:

Observations and Graphical Analysis:

After applying the Christofide's Algorithm and the optimization techniques on a set of given points, we can visualise the following observations.

1. The minimum spanning tree acts as a lower bound for the travelling salesman problem. This means that any number of optimizations applied on top of the minimum spanning tree will not reduce the cost further.
2. Christofide's algorithm is calculated from the minimum spanning tree and the other optimizations are applied on top of it.

3. The Two Opt optimization is more time effective than the Three Opt method as the time complexity is lower in Two Opt.
4. The trade off on the time does not tend to improve the cost of the tour as the Three Opt tour cost is still higher than the Two Opt method.
5. The Simulated Annealing method tends to provide the most optimised solution for the given set of points as we have passed the Two Opt tour on which random swaps happen. Even though the cost decrease is very minimal the simulated annealing algorithm achieves the solution in a time effective manner.
6. The Ant Colony Optimization method did not provide an exactly optimised solution for the given set of points and the execution time exceeds the other optimization methods used.

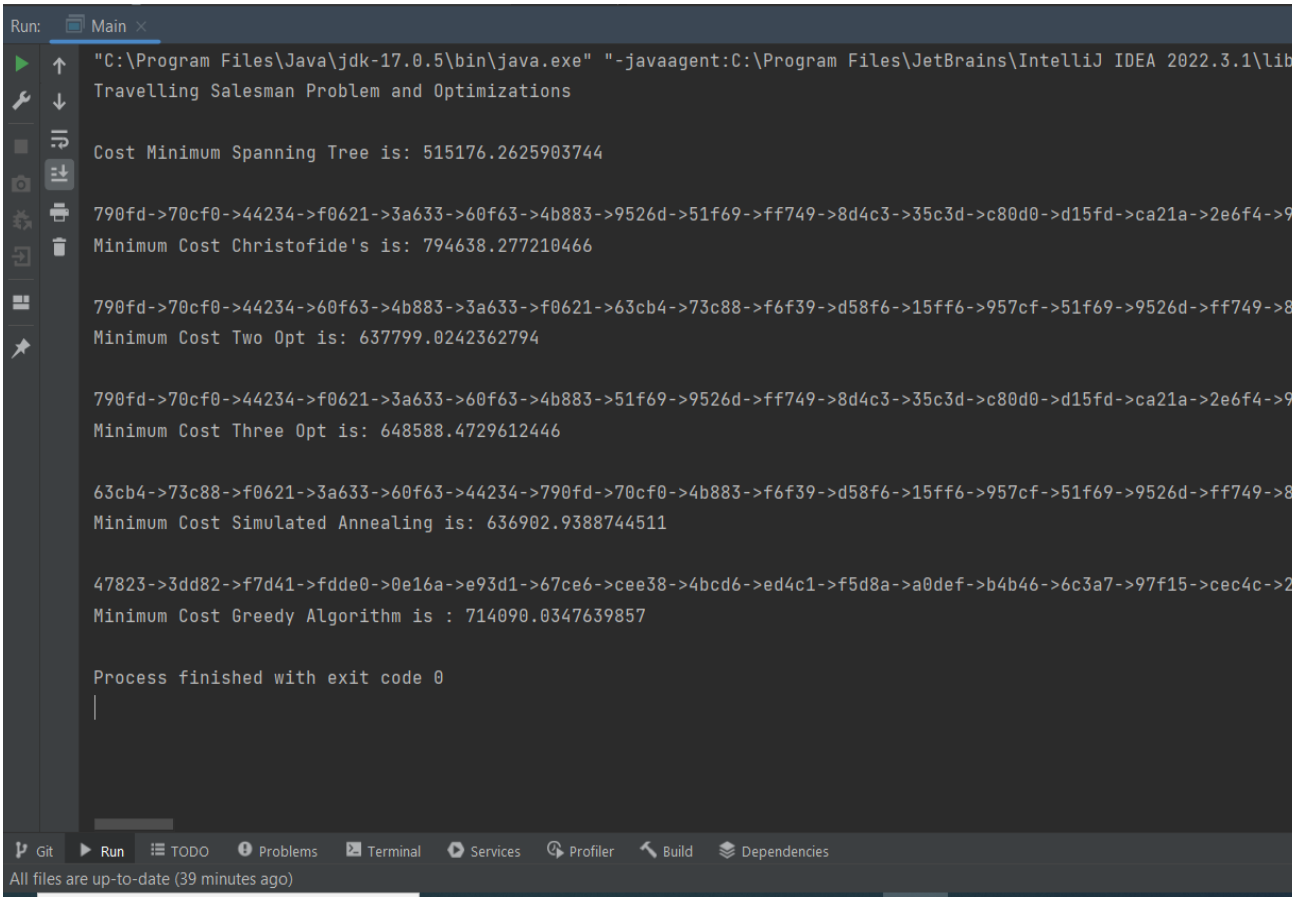


Results and Mathematical Analysis:

From running the above algorithms and optimisations, we can conclude that for the given set of points, the Simulated Annealing Optimization algorithm provides the lowest tour cost. The Two Opt Swap method also provides an optimised solution close to the Simulated Annealing method. The Simulated Annealing method can further be optimised by increasing the temperature value or decreasing the cooldown value.

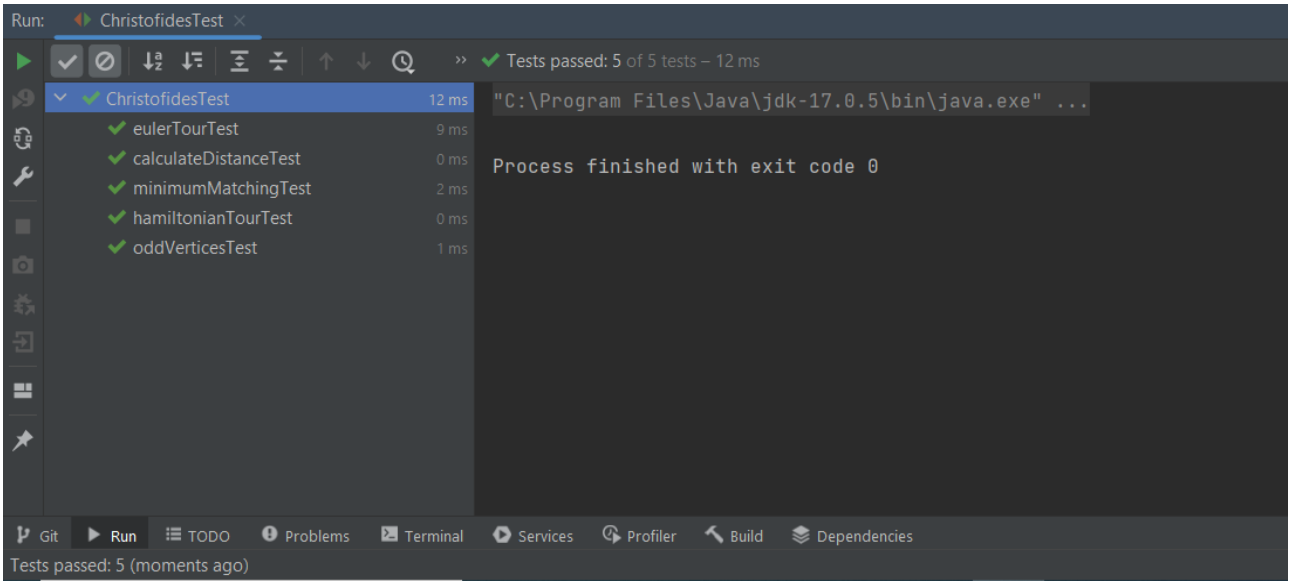
The tour cost in metres for all the algorithms are as following:

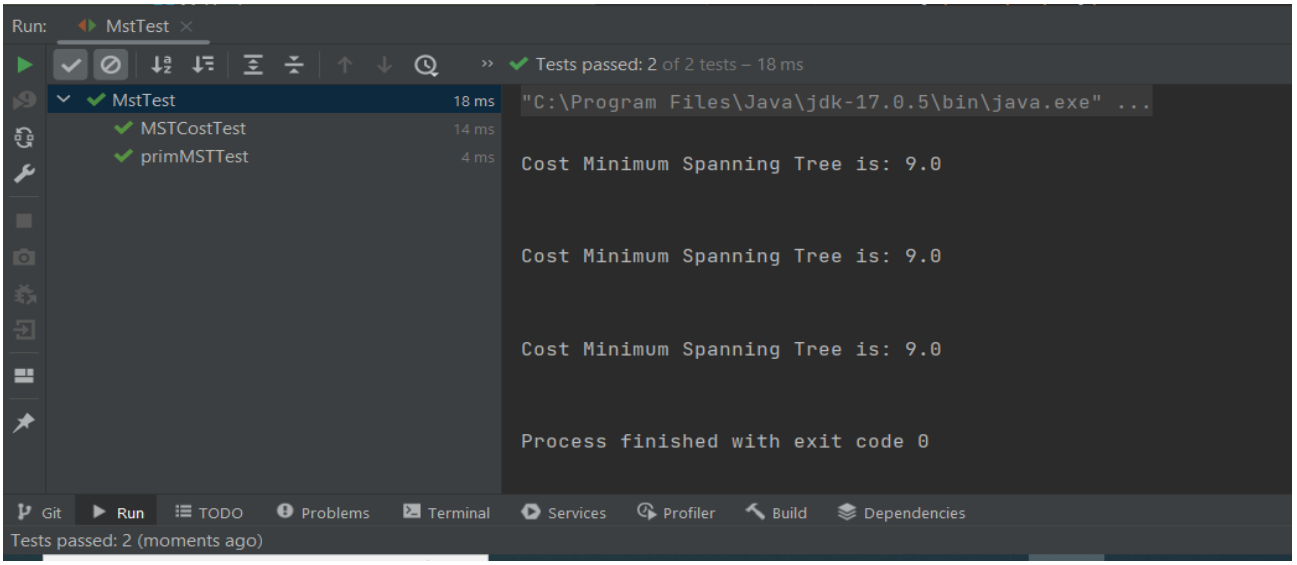
Minimum Cost of Spanning Tree is: 515176.2625903744 m
Minimum Cost of Christofide's is: 794638.277210466 m
Minimum Cost of Two Opt is: 637799.0242362794 m
Minimum Cost of Three Opt is: 648588.4729612446 m
Minimum Cost of Simulated Annealing is: 636902.9388744511 m
Minimum Cost of Greedy Algorithm is : 714090.0347639857 m



Unit Tests:

The Unit Tests were performed on the separate functions as shown below:





Conclusion:

Based on the results obtained from running the algorithms and implementing various optimizations, we can conclude that the Simulated Annealing Optimization algorithm is the most effective in providing the lowest tour cost for the given set of points. The Two Opt Swap method also provides a highly optimised solution, which is very close to the solution provided by the Simulated Annealing method.

References:

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