المملكة العربية السعودية
وزارة التعليم
كلية الحاسب
قسم علوم الحاسب

بسم الله الرحمن الرحيم

Kingdom of Saudi Arabia
Ministry of Education College of Computer
Department of Computer Science

CS348 – Optimization Techniques
Semester:462

Traveling Salesman Problem Optimization Using Genetic Algorithm and Simulated Annealing

Instructor: Dr. Ali Mostafa

Mohaya Almutairi 431107802
Fares Alsuhaibani 431107834
Abdullah Alfayez 431108148

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1. Introduction

The Traveling Salesman Problem (TSP) is a classic combinatorial optimization problem that aims to determine the shortest possible route that visits a given set of cities once and returns to the starting city. The TSP is widely applicable in logistics, manufacturing, and network routing. Due to its computational complexity (NP-hard), exact solutions are impractical for large instances. Therefore, this project explores two powerful metaheuristic techniques to solve the TSP:

- Genetic Algorithm (GA)
- Simulated Annealing (SA)

2. Mathematical Formulation

- Given: A set of n cities with pairwise distances d(i,j).
- Objective: Find the shortest possible tour visiting each city exactly once and returning to the start.

Objective Function

$$\min \sum_{i=1}^{n-1} d(c_i, c_{i+1}) + d(c_n, c_1)$$

Constraints

- Each city must be visited exactly once.
- The tour must return to the starting city.

Decision Variables

- A permutation of city indices representing the route.

3. Optimization Techniques

3.1 Genetic Algorithm (GA)

Genetic Algorithm is a population-based search technique inspired by biological evolution. Key components include:

- Chromosome: A city sequence representing a complete tour.
- Fitness: Total route distance (lower is better).
- Selection: Chooses top individuals to reproduce.
- Crossover: Combines two parents into one child by merging partial routes.
- Mutation: Randomly swaps two cities to maintain diversity.

GA works by evolving the population over many generations to improve solution quality.

3.2 Simulated Annealing (SA)

Simulated Annealing is a single-solution-based optimization method inspired by the annealing process in physics. It involves:

- Initial State: Random city sequence.
- Neighbor Generation: Swapping two cities.
- Acceptance Criterion: Always accept better solutions; worse ones are accepted with a probability $\exp(-\Delta/T)$, where T is temperature.
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- Cooling Schedule: Temperature decreases gradually, reducing the chance of accepting worse solutions over time.

SA balances exploration and exploitation, making it robust for escaping local optima.

4. Experimental Setup

- Number of Cities: 10 (randomly placed in 2D space).
- Distance: Euclidean distance between cities.
- GA Parameters:
  - Population size: 100
  - Generations: 200
  - Mutation rate: 1%
- SA Parameters:
  - Initial temperature: 1000
  - Cooling rate: 0.995
  - Stopping temperature: 0.001

5. Results

Best GA Route: [4, 6, 9, 7, 8, 1, 3, 0, 2, 5] (Distance: ≈ 269.59)
Best SA Route: [1, 7, 9, 8, 6, 4, 5, 2, 0, 3] (Distance: ≈ 269.38)

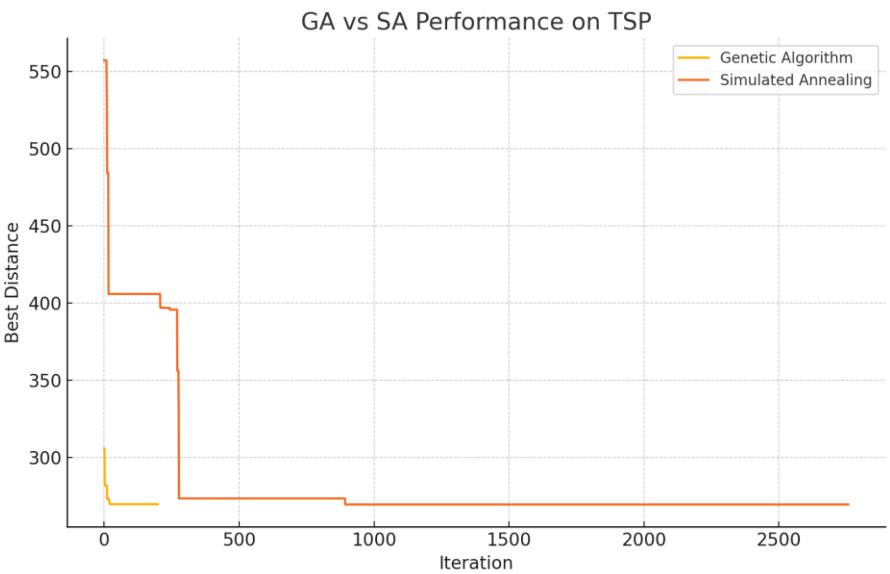
Simulated Annealing slightly outperformed GA in terms of best distance. However, GA offers broader search through population diversity and is more stable across multiple runs. Both methods performed well given the problem size.

6. Visualization

A plot comparing distance improvements:

- **X-axis**: Iterations
- **Y-axis**: Best distance found so far

Both curves show decreasing distance, with SA converging faster and GA improving steadily.



7. Conclusion

This project successfully applied **Genetic Algorithm** and **Simulated Annealing** to solve the TSP. Simulated Annealing provided a marginally better solution in this run. However, both techniques are effective, and their relative performance can vary with parameter tuning and problem size. This study demonstrates the strength of metaheuristic methods for solving complex optimization problems.