Quantum Delivery Logistics: Navigating Efficient Routes with QAOA

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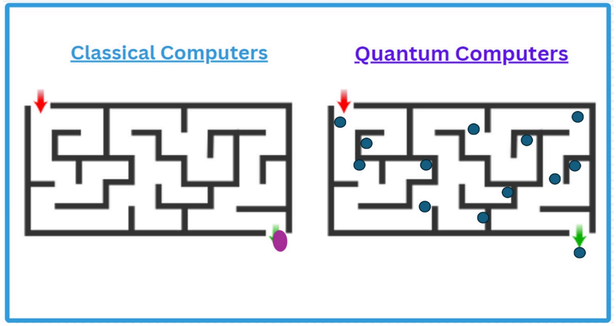
QAOA is a recipe for tackling ultra-complex problems. It combines a regular computer, the coach, with a special quantum computer to explore many solutions at once.

What is QAOA

Quantum Approximate Optimization Algorithm (QAOA) is a quantum algorithm used for solving combinatorial optimization problems. It operates by preparing a quantum state that encodes potential solutions and uses quantum operations to approximate the optimal solution. QAOA leverages quantum parallelism to explore solution spaces more efficiently than classical algorithms.



Real World Scenario – Delivery Route Optimization

E-commerce giants like Amazon and FedEx face a constant challenge: ensuring efficient deliveries of millions of packages daily. Delivery route planning needs to efficiently assign deliveries to drivers while considering:

- Minimizing distance (fuel & time)
- Avoiding traffic congestion
- Matching driver availability and location
- Accommodating special package requirements

This becomes computationally difficult with a large number of deliveries and locations. We need to find an improved approach for optimal route planning.

QAOA to the Rescue

QAOA can handle the complex interplay of various factors affecting delivery routes. Here's a breakdown of how it might work:

Data Representation:

- Delivery locations are mapped to qubits (quantum bits) in a quantum computer.
- The state of each qubit (0 or 1) represents a package being delivered at that location or not.

Encoding the Problem:

- A cost function is created to penalize undesirable aspects of a route, such as distance, traffic delays, or driver unavailability.
- QAOA uses this function to mathematically encode the optimization problem into the quantum system.

Optimizing with QAOA:

- The quantum computer applies a series of controlled rotations (the QAOA part) to the qubits.
- These rotations manipulate the superposition of states, allowing QAOA to explore many possible routes simultaneously.

Finding the Best Route:

- After applying the QAOA rotations, the qubits are measured, collapsing the superposition into a specific delivery route.
- QAOA repeats this process (applying rotations and measuring) multiple times to find the route with the minimum cost (shortest distance, least traffic, etc.).

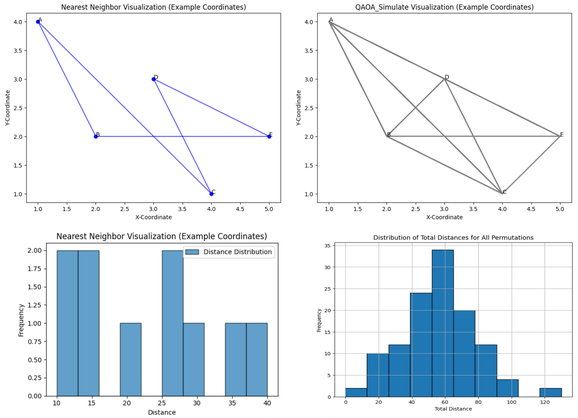
Example : **Encoding the TSP as a Cost Function:**

- The cost function in QAOA is specifically designed to penalize long distances between visited locations in the delivery route. This forces the QAOA algorithm to favour routes with shorter total distances

Advantages of QAOA

- Parallel Exploration: Unlike classical algorithms that explore routes one by one, QAOA can explore many possibilities simultaneously due to the quantum superposition principle. This allows it to find optimal solutions much faster for large-scale delivery problems.
- Flexibility: QAOA's cost function can be easily modified to incorporate additional factors like driver breaks, specific delivery time windows, or even real-time traffic updates. This makes it highly adaptable to different delivery scenarios.

Distance Matrix for 5 cities - TSP



Github Code:
https://github.com/MadhuriKonnur/QAOA_TSP/tree/main

In order to see a specific quantum advantage over a classical algorithmic approach it may require a much larger and complex dataset

Challenges and the Future

- **Quantum Hardware:** Current quantum computers are limited in qubit count and prone to errors. Significant advancements are needed to handle large-scale delivery route optimization problems.
- **Cost Function Engineering:** Developing an accurate cost function that captures all relevant factors is crucial for QAOA's effectiveness.

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