Dissertation Planning

Quantum Algorithms for Optimizing Urban Transportation

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Agenda

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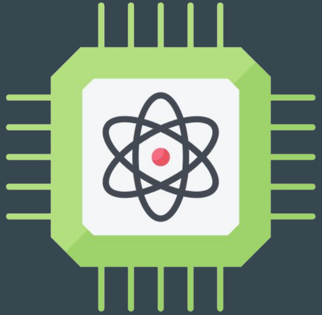
Context

Transportation is fundamental for urban life, playing a critical role in **daily routines, energy consumption and environmental sustainability**. Exploration of innovative solutions is imperative as cities grow.

With the rise of **quantum computing**, its integration with transport optimization becomes compelling for **minimizing commuting times, energy consumption, and carbon emissions**.

The **Capacitated Vehicle Routing Problem** (CVRP) has been extensively examined in the transportation field. Its **recent** application to the quantum domain holds the potential for future efficiency improvements.



Motivation

Utilizing **quantum algorithms**, a quantum (or hybrid) implementation of the CVRP has the potential to achieve **speedup** not possible for classical computers.

Given the recent and rapidly advancing nature of quantum technology, **studies** in this field are **limited** and tend to become **outdated quickly**.

New implementation based on **current** and **anticipated near-future technology**: potential for improvements in cost, time, energy consumption, and carbon emissions.

CVRP is applicable to various logistic fields (e.g. shipment services, emergency evacuations).

Goals

The primary goals of this dissertation include:

- Implementation of quantum (or hybrid) algorithms capable of solving the Capacitated Vehicle Routing Problem (CVRP).
- Comparing the algorithms' performance on current quantum hardware (e.g. superconducting, annealer, photonic, etc.) with its classical counterparts.
- Studying how the implementations scale on current and anticipated upcoming technology, compared to classical computing.

Problem

The **Capacitated Vehicle Routing Problem (CVRP)** involves efficiently **allocating resources**, in this case, public vehicles with **different capacities**, to pick up goods or passengers from diverse locations within a given area.

The challenge lies in identifying the most **optimal set of routes** for these vehicles to achieve an objective function, such as travel time.

CVRP is **NP-Hard**, so finding the optimal solution with classical algorithms is **inefficient**. The alternative is high-quality **approximate** solutions!

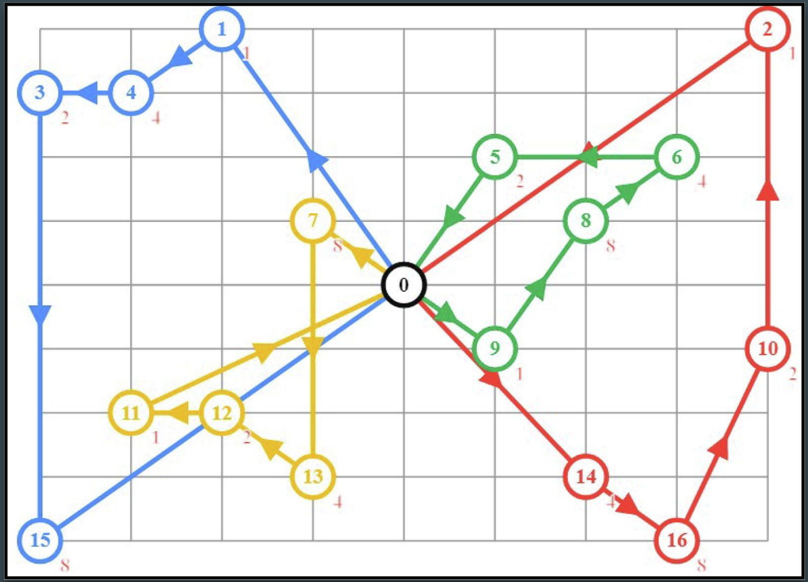


Fig. 1: Example of an output of the CVRP

Problem

As a natural extension of the CVRP, it's possible to add **constraints** such as **time windows or pickup and delivery**. This creates multiple **variations** of CVRP, essentially involving the introduction of constraints to the original problem.

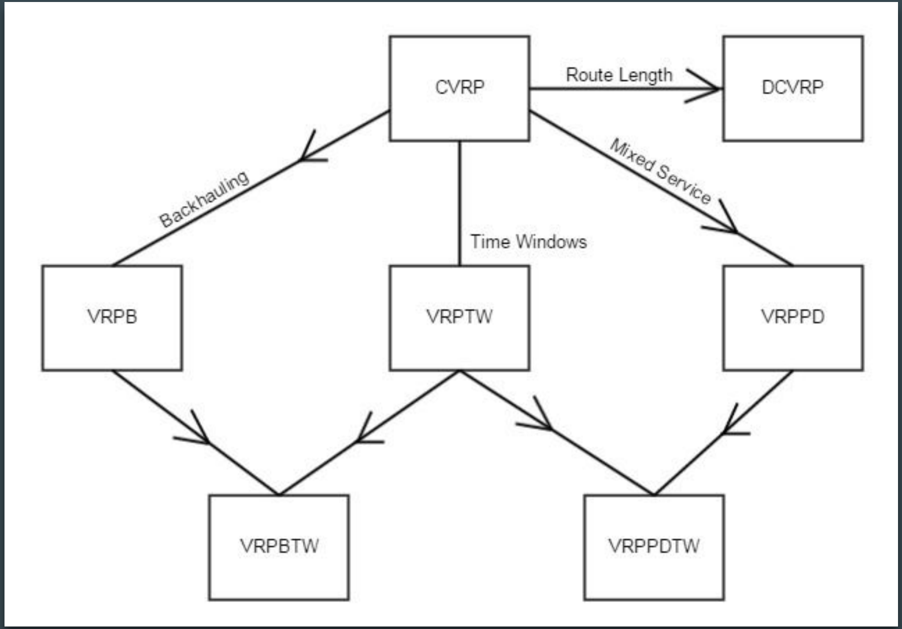


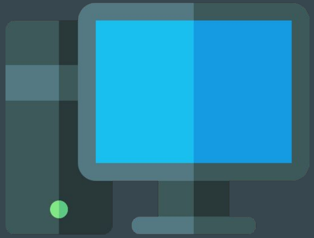
Fig. 2: Variations of the CVRP

State of the Art: Classical Approaches

CVRP has undergone extensive study over the years, leading to well-refined classical approaches. **Exact solutions** are attainable for up to approximately **150 passenger** locations. Beyond this point, **heuristic** solutions consistently produce results within a **1% margin**.

Some classical solutions include:

- Modified version of Particle Swarm Optimization (M.A. Hannan et al., 2017)
- Integer Programming and Variable Neighborhood Search (Kangzhou Wanga et al., 2017)
- Fuzzy C-means (Mario Marinelli et al., 2018)



State of the Art: Quantum Approaches

QAOA

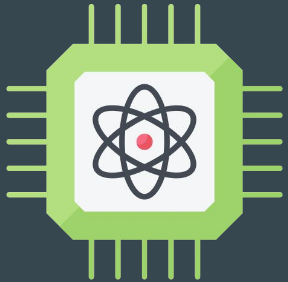
- **Quantum Approximate Optimization Algorithm** solves quadratic problems with binary variables (QUBO).
- Bentley et al. (2022) extended the Travelling Salesman Problem (TSP).
- 7 vehicles with a capacity of 20 passengers requires **1000 qubits**!

Quantum Annealing

- Similar to Simulated Annealing, the quantum optimisation algorithm is **implemented in hardware**.
- Feld et al. (2019) and Harikrishnakumar et al. (2020) created different formulations.
- D-Wave 2000Q was discussed but not implemented.

Quantum Evolution Algorithm

- Probabilistic algorithm, similar to classical genetic optimisation.
- Cui et al. (2013) proposed an Improved QEA for CVRP.
- Experiments showed high precision but low efficiency.



Methodology

This dissertation aims to investigate the implementation of algorithms using various technologies. Each one involves the following steps:

1. Propose an **algorithm** tailored to the specific technology (following on literature).
2. Implement and validate the algorithm using a **simulator** (e.g. Qiskit, Ocean, Strawberry Fields).
3. Implement the algorithm on a **real machine**, if available (e.g. IBM-Q, D-Wave, Amazon Braket).
4. **Analyse results** and compare them with classical approaches in terms of efficiency and solution quality.
5. Evaluate the **scalability** of the algorithm, considering the prospects of future hardware.

Ultimately, compare the suitability of different technologies for addressing the CVRP in both the present day and the near future.

Work Plan

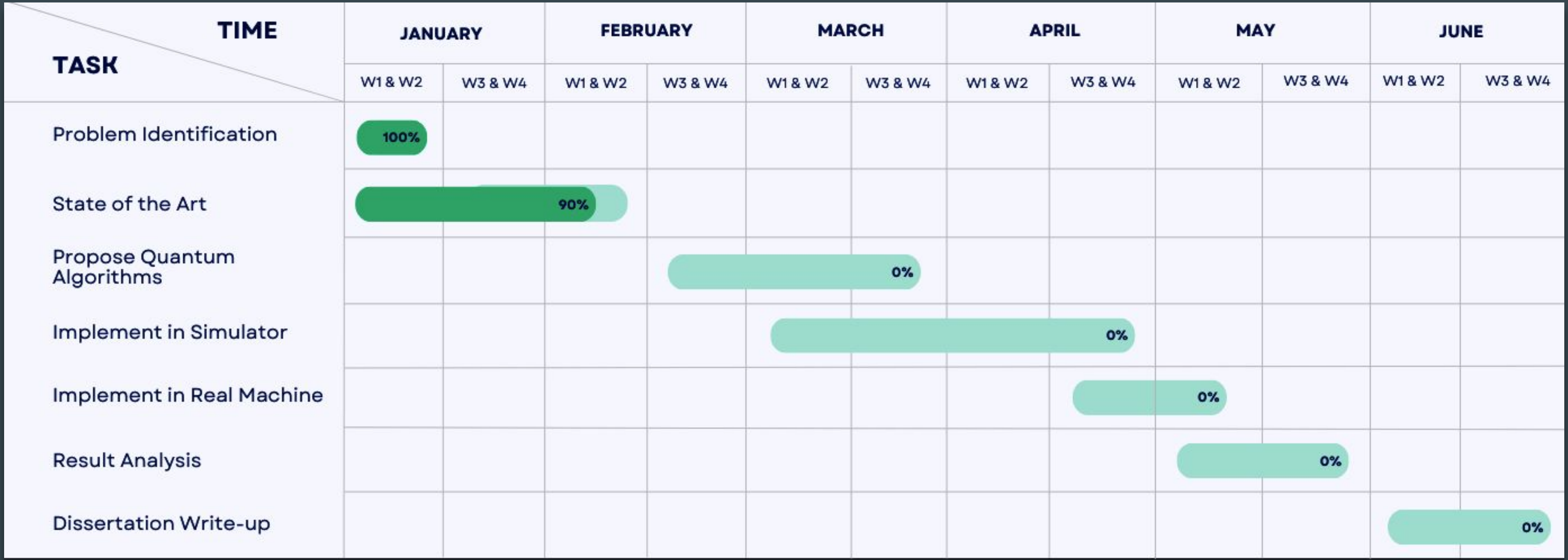


Fig. 3: Gantt chart with the work plan