Womanium Global Quantum Computing
&
Entrepreneurship Program

Challenge: End-to-end quantum simulation of space telescopes (feat. teleportation)

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Task 1: The fast algorithm

- You are predicting the position of the James Webb space telescope, which we assume to follow a circular orbit around the poles of Earth with a period of months. Pretending we don't know the analytical solution to this problem, we figure out that its positio(x, y) time t is given by the system of differential equations.

$$\begin{pmatrix} \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} 0 & -2\pi/T \\ 2\pi/T & 0 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}.$$

- Using the backward Euler method4 of integration, we can convert this to a linear system of equations

$$\begin{pmatrix} 1 & 2\pi\Delta t/T \\ -2\pi\Delta t/T & 1 \end{pmatrix} \begin{pmatrix} x(t+\Delta t) \\ y(t+\Delta t) \end{pmatrix} = \begin{pmatrix} x(t) \\ y(t) \end{pmatrix}$$

which can then be solved repeatedly to advance the system by the time step each time.

1. How can you encode the position of the telescope on a qubit? [Output: Presentation slide, 3% score]
2. Using the resources in https://qiskit.org/textbook/ch-applications/hhl_tutorial.html, demonstrate how a quantum circuit can simulate the orbit of the James Webb telescope using the implicit Euler method of integration. [Output: Jupyter notebook, 20% score]

Task 2: Input encoding

Now that we have an exponentially fast quantum algorithm, we will focus on how it scales. Imagine that we do not only want to track one satellite, but of them.

1. How can you encode the state of satellites on qubits, i.e.? How many qubits do you need? [Output: Presentation slide, 3% score]

- Now that we have an encoding scheme for the input state, we focus on the complexity of the algorithm.

2. Make a quantum circuit that prepares the input state. [Output: Jupyter Notebook, 20% score]

- With the computational complexity of state preparation determined, we consider the

complexity of the linear systems algorithm. In fact, the computation complexity of solving

linear systems is on classical computers and on quantum computers.

3. If a classical computer and a quantum computer both spent 1 seconds on solving an linear system, how long would it approximately take them each to solve a linear system? [Output: Presentation slide, 3% score]

4. Consider your state preparation circuit and how many steps it requires. Can you give a lower bound on its computational complexity in terms of ? What does this mean for the future prospects of quantum di erential equation solvers? [Output: Presentation slide, 3% score]

Task 3: Teleportation

- In order to avoid the input preparation problem, you have created a quantum-powered satellite equipped with a quantum sensor. Every 24 hours, the satellite scans every satellite orbiting earth and prepares a quantum state that e ciently encodes their positions. However, your quantum computer is located at MIT, so somehow the satellite must be able to transmit its quantum measurements to a quantum computer on good old Earth.

1. Based on the algorithm described in https://qiskit.org/textbook/ch-algorithms/teleportation.html, describe a practical step-by-step guide for how to teleport the measurement quantum state down to Earth. [Output: Presentation slide, 3% score]

- 2. Combine the quantum teleportation circuit with the linear di erential equation

solver you created in Task 1. [Output: Jupyter notebook, 20% score]

Task 4: Practical application to new problems

- Congratulations, you have now created an (almost) end-to-end quantum algorithm!

Notably we have not considered the problem of reading the output, i.e. how to actually get the answer we want from the quantum computer. After tall, the result of the quantum algorithms we consider are quantum states, and those are notoriously hard to read out completely. Due to time constraints we won’t dig deeper into that, and we will instead focus on practical applications. Choose one application to focus on in which you would want to apply a quantum differential equation solver, and present/discuss the following questions. [Output: Presentation slides, 25% score]

1. If you had a perfect quantum computer, which simulation problem would you want it to solve?
2. Which algorithms have promise for solving such problems within the next 20 years?
3. Which data and in what format would that algorithm need fed as input to perform the simulation?

4. How could you collect that data as quantum states or qubits instead of classical bits?

5. Which quantum sensors or collection method would you need to gather the quantum data?

6. How would you transfer the quantum data from the quantum sensor to the quantum computer?

7. What would the impact of your described end-to-end application be, and how could it solve real-life problems?

Thank you