Middle East Technical University | Department of Computer Engineering

CENG 487

Introduction to Quantum Computing

Fall 2023-2024

Assignment IV

Due date: January 7, 23:59

Introduction

In this assignment you are supposed to solve two questions related to the Grover's Search Algorithm and Quantum Fourier Transform (QFT). If the question does not ask for an explanation, you can directly provide the answer. The circuits will be implemented on IBM Quantum Computing. **For this assignment, you can use the simulator**. The necessary information regarding IBM Quantum Computing can be found in the first assignment. It will not be repeated here, please check that assignment for the clarification about the environment.

Part 1 - Grover's Search Algorithm (60 pts)

Grover's Algorithm provides a speed-up for the unsorted search problem. The main approach is applying phase inversion on the target element and then inverting all the elements about the average.

a) For an input with 4 elements, what would be the matrix that does the inversion operation? *(10 pts)*

b) Consider the matrix you defined in part **a**. Apply that matrix on the input $[15, 23, 18, 32]$. What do you get? What would you get if you apply it again? Briefly explain the result. *(10 pts)*

c) In the attached file you will find a Jupyter notebook based on the IBM Quantum Learning's Grover algorithm (here). Note that we made slight modifications to make it runnable.

Change the given notebook so that it applies the Grover's search algorithm to find X, where X is the 6-bit binary string that corresponds to the sum of the digits of your student ID. Provide the following;

- Screenshot of the *oracle*
- Screenshot of the circuits
- Final plot of the distributions

Analyze the plot. What can we infer from it and how does this acts as a search algorithm? *(25 pts)*

d) For the notebook in part **c**, change the number of iterations so that the algorithm can not find X anymore. What was the original number of iterations, and what is the updated number of iterations when the algorithm is not working? The plot should not be very clear, so provide a list of outcomes along with it. Try three different iteration numbers and briefly analyze the results. *(15 pts)*

Part 2 - Quantum Fourier Transform (40 pts)

a) For the following either state "True" or "False". If the statement is true, no explanation needed. If false, correct the statement in one sentence. *(15 pts)*

A QFT is a unitary operation.

B QFT circuit contains a mixture of Hadamard gates, Phase gates and controlled-NOT gates.

C Phase gate R_k used in QFT is $R_k = \begin{bmatrix} 1 & 0 \\ 0 & e^{2\pi i} \end{bmatrix}$

D The single qubit QFT gate is the Hadamard gate.

E Quantum phase estimation is irrelevant for Shor's factorization algorithm.

b) As in part **1c**, use X = 6-bit binary representation of the sum of the digits in your student ID. Implement the circuit and apply Quantum Fourier Transform on X. Provide a screenshot of the circuit. Visualize the results as a plot (you can copy and paste in case the plot is not readable) and briefly explain them. *(25 pts)*

Submission

- Submit a single **PDF** file named eXXXXXXX.pdf, where XXXXXXX is your student ID.
- Hand-written solutions will **not be accepted**.
- We have a late policy with penalty. The penalty is $5 * day^2$ where day is the amount of days submitted late. After three days, late submissions will not be accepted.
- The assignments are for individual work. We have zero tolerance policy for cheating. People involved in cheating will be punished according to the university regulations.
- You may ask your questions by sending a mail to "mduymus@ceng.metu.edu.tr".