Introduction to Quantum Computing: Revision Notes

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Exam Format

- Date & Time: Wednesday 20 December 2023. Time 13:00-15:00
- Two questions with equal weight.
- Each question divided into two parts with each one multiple sub questions.
- *NOTES AND CALCULATORS PERMITTED examination: candidates may consult up to THREE A4 pages (6 sides) of notes. CALCULATORS MAY BE USED IN THIS EXAMINATION*

General Advice

- **Read all questions before choosing and be "strategic"**
- **Questions** are divided into two parts:
  - Each part of a question is divided into small subquestions (weight is clearly stated).
  - In general subquestions hardness increase gradually, but not always.
  - Balance distribution of easy, medium and hard subquestions.
- **Do good time management!**
- **Exam with notes (6 sides) and calculator**
- **Past papers**: Only 2020-2023 IQC exams were open book(-ish). 2015-2019 had more theory questions and some material not longer cover by IQC.
- **Study Tutorials & train with past years exams** (check assignments)!
- We encourage you to use Piazza as a mutual help support tool, but we will not monitor Piazza ourselves next weeks.

The Basics of QC and QM (Raul' part)

Disclaimer: These are general indicative guidelines (all material unless explicitly mentioned is examinable)

- Lecture 2,3,4,5 (Postulates): Material essential for next chapters. Need to know (for example): basic linear algebra and complex numbers, quantum states, operations and measurements (projective measurement, global and partial), tensor products, inner-products.
- Lecture 6 (Circuit model): crucial to recognize most important gates and be able to compute the quantum state along the different layers of a quantum circuit and a final measurement outcome probability.

Quantum Algorithms I (Raul' part)

- Lecture 7 (Phase Kickback and Deutsch-Jozsa): Deutsch-Jozsa, parallelization, phase kickback, Walsch-Hadamard transform, outcome probability resulting from quantum interference. Quantum/classical oracle of a Boolean function and phase kickback.
- Lecture 8 (Bernstein-Vazirani): Classical reversible circuit and its quantum analogue. Existence of quantum oracle from classical one. Building a phase kickback unitary from the quantum oracle. Bernstein-Vazirani algorithm.
- Lecture 9 (Grover): representation on 2dim space, Grover iterations, phase kickback reflection and reflection over initial state. Estimation of number of iteration needed to reach solution.
- Lecture 10 (Simon's Algorithm): Projective measurement. Measurement of a subsystem. Understand the classical post-processing. Understand why the outcome of lower register is not necessary for solving the problem (just a trick to simplify the proof).

Quantum Algorithms II (Raul’ part)

- Lecture 11 (Hadamard Test): Non-demolition measurement of a qubit. Parity check of two qubits (crucial concept in quantum error-correction). General Hadamard Test. Use of projectors to separate subspaces and define measurements.

- Lecture 12 (Quantum Error Correction): classical repetition code, quantum bit flip repetition code, quantum repetition for phase errors. Shor’s 9 qubit QECC. Use of parity check to detect and correct errors in other QECC (see tutorial 5).

Quantum Algorithms III (Raul' part)

- Lecture 13 (Quantum Fourier Transform): Binary representation of integers. Fourier transform over Z_{2N}. Iterative construction of QFT circuit. Counting of gates.

- Lecture 14 (Quantum Phase Estimation): Action of an exponentiation of U on an eigenvalue of U. Parallelization of the measurement register and control of different exponentiations of U. Connect the output with QFT to understand that the outcome of measurement is the eigenvalue of U. Order finding and factoring (Shor's algorithm).

Near-term QC (Petros' part)

- Lecture 15 (VQA I)

(i) Understand what VQA/VQE is. Motivation, mathematical prob., relevance and the four steps.

(ii) Understand Max-Cut to Ising Spin mapping. Mapping solution (cut) to spin configurations and think how this generalises.

- Lecture 16 (VQA II)

(i) Energy estimation. Including decomposing Hamiltonian to Pauli.

(ii) Ansatz states. Understand the concept of parametrised circuits/states. Be able to produce output state in simple examples. Compute expectation values of observables on output states.

(iii) Classical optimisation. Concept and gradient decent (see example in tutorial 7)

(See Tutorial 7)

MBQC (Petros' part)

- Lectures 17-19: Need to know

(i) basic MBQC patterns for single-qubit, two-qubit gates and how they are combined.

(ii) how to read an MBQC pattern to obtain the corresponding unitary implemented

(iii) How to find the MBQC pattern of a simple circuit

(iv) how corrections work on angles (when measurement outcomes are not 0)

(v) how to correct the output state (when measurement outcomes are not 0)

(vi) how UBQC works (protocol and intuition). No details of the proof are required.

(See Tutorial 8)

Tutorials & Coursework Specifics

- Tutorials: all.

- Assignment/CW: Note that assignments are generally harder than tutorials (and exams) since you had longer time. Still a good exercise to go through the solutions to understand the concepts and tools used. Obviously, there will be no coding question in the exam.