Introduction to quantum computing and quantum annealing

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Logistics

Lectures will take place from 12:00 - 1:30pm in the TRIUMF auditorium on May 9, 10, 13, and 14.

Prerequisites

Basic quantum mechanics and linear algebra (superposition of states, measurement, spin 1/2 systems, Hamiltonians, eigenvalues/eigenvectors). Experience with Python is helpful for following the demonstrations and playing with the software on your own. No quantum computing experience is necessary.

May 9th/10th: gate model quantum computing

Day 1: Theory

- Motivation behind quantum computing
- Mathematical representation of qubits
- Unitary operations; common quantum gates and universal gate sets; quantum circuits
- Measurements; measurement bases; projectors
- Visualizing qubits on the Bloch sphere
- Multi-qubit systems; tensor products and entanglement
- *Applications*: superdense coding, quantum teleportation, Deutsch's algorithm

Day 2: Hardware and applications

- A visual walk-through of Grover's search algorithm
- The quantum Fourier transform and eigenvalue estimation
- Computational speedups and quantum advantage
- Overview of current quantum hardware status (NISQ devices): major players, qubit hardware graphs, error rates, technical challenges
- Overview of Hamiltonian simulation
- *HEP application*: Calculating neutrino oscillation probabilities on a quantum processor
- *HEP application*: Finding ground states of molecules with the variational quantum eigensolver

May 13th/14th: quantum annealing

Day 1: Theory

- The adiabatic theorem
- Equivalence of adiabatic and gate-model quantum computing
- Simulated annealing and the Ising model; transverse-field Ising model
- Brief overview of superconducting qubit hardware
- D-Wave quantum annealers: what are they? How do they work?
- Quadratic unconstrained binary optimization problems (QUBOs)
- Equivalence of QUBOs and Ising Hamiltonians
- Examples of formulating problems as QUBOs

Day 2: Hardware and applications (tentative)

- How to solve bigger problems: minor embeddings and qbsolv
- *Application* Solving a simple graph theory problem (hopefully using the actual quantum processor!)
- Graph embedding; how do I couple two qubits that aren't directly connected?
- *HEP application*: classifying Higgs decay signals
- *HEP application*: particle tracking with LHC data
- Brief survey of ideas in quantum machine learning

Software demonstrations

I will be doing demonstrations live, but will also distribute the code and Jupyter notebooks so you can follow along or play with it afterwards. You will need to install:

- Python 3 (I recommend the Anaconda distribution since it comes pre-installed with Jupyter and the scientific packages you will need),
- Qiskit, IBM's software platform, installable from their Github page or via pip,
- D-Wave's Ocean SDK, installable via pip with instructions here

I recommend doing the installation before the lectures start. If at any point you're stuck, feel free to message me (odimatteo@triumf.ca) or even better, drop by my office (MOB 284) with your laptop and I will help.