PHYS223 - Introductory Quantum Computing

Spring 2022

Professor: Rogério de Sousa

This course, targeted at 2nd year undergraduate students in science and engineering (including computer science and software engineering) teaches the basics of quantum computation and information.
The student will get to submit jobs to cloud-based quantum computers provided by IBM-Q and D-Wave Leap, using a Python-based interface.

Prerequisites

MATH211 or MATH110 (Matrix algebra).
No background in quantum physics or Python is needed.

Lectures

Tue, Fri: 2:30pm - 3:50pm.

From January 11 to 21, synchronous on Zoom.

After January 25, face-to-face at Clearihue A325 (pending UVic's approval).

All lecture materials and assignments are available in the course's Brightspace:

https://bright.uvic.ca/d2l/home/155644

The synchronous online lectures will be recorded on Zoom and the videos will be posted on BrightSpace for students to watch again. The face-to-face lectures will not be recorded but the equivalent Zoom lecture from last year will be made available. In all cases, it is strongly recommended to watch the lectures live - We will engage on group activities that make problem solving productive and fun.

Therefore, attendance is not required, but is strongly recommended. All lecture boards are available online; you will find them under "Live lecture boards" in the content link.

Office hour

Time TBD, in my private Zoom room.

How to ask questions about content, assignments, etc

Use our P223 Discussion Forum - Questions about the course, assignments, etc.

NEW: I will be giving up to 10% bonus to the final grade for students who actively participate in class and in the forum.

Each of the 6 assignments carries 1% bonus associated to forum participation (6% total). For each assignment, you can get:

- 0.25 % for each question you ask;

- 0.50 % for each question you answer correctly;
- 1.00 % for an answer that I judge to be exceptional for the class.

I will also give extra credit for class participation. This will amount to 4% on the final grade depending on whether I felt that you asked questions and interacted with me and the class during the lectures.

Whenever you have questions about the material taught, please send messages or questions using the UVic brightspace forum. That way all students will have access to our conversation.

If you wish to send me a private message, please send it to my UVic email: rdesousa@uvic.ca .

Textbook

A First Introduction to Quantum Computing and Information, Bernard Zygelman (Springer Nature AG Switzerland, 2018).
This is an eBook: You can **download a free .pdf copy** from the University of Victoria library.

Other suggested books, videos, websites:

- "Quantum Computation and Quantum Information", Michael A. Nielsen and Isaac L. Chuang (Cambridge University Press, U.K. 2000). This book is often referred to as the "Bible" of the field. While it is self contained, it is aimed at graduate students.
- "Quantum Computing: A beginner's introduction", Parag K. Lala (McGraw-Hill Education, New York, 2019).
- "Canadian Summer School on Quantum Information" (video), https://www.youtube.com/watch?v=Q4xBlSi_fOs
- "Quantum Information for Developers", ETH-Zurich (Lecture notes and videos), https://qid.ethz.ch/

Topics to be covered

Part I: Fundamentals
Survey of quantum physics: Stern-Gerlach experiment and the spin of the electron, analogy with polarization states of light. Linear algebra with complex numbers and Dirac's notation. Inner products, tensor products, adjoint operation. Operators as square matrices, basis change. Hermitian and normal (diagonalizable) operators. Unitary operators. Quantum theory: State space, observables, projections, and quantum measurement. Pauli matrices and their eigenstates. Expectation value of observables. Representing single qubit states in the Bloch sphere. Entangled states.

Part II: Quantum Computation Quantum circuits: One-qubit operations (Pauli, Hadamard), controlled two-qubit operations, measurement. How to draw quantum circuits and relate to matrix representation. Circuit that generates Bell states. Irreversibility and universality for classical gates. Universality for quantum gates. How to program a quantum oracle that evaluates 1-bit Boolean functions. Elementary quantum algorithms and quantum speed-up: Deutsch and Deutch-Josza, quantum parallelism. Bernstein-Vazirani, Simon's algorithms. Quantum cryptography with BB84. Elementary quantum tomography. No-cloning theorem, quantum teleportation. Elementary 3-qubit error correction.
Part III: Hands-on with IBM-Q and D-Wave Leap Overview and installation of Anaconda, Jupyter notebook and Python. IBM's Qiskit, installation, tutorials, and simple examples. Composing quantum circuits and running them in simulators and real devices. Comparisons between simulations and experiments, quantum depth, noise. Elementary phase estimation (without quantum Fourier transform). Hamiltonians, ground and excited states, time evolution. Quantum adiabatic theorem. Introduce the idea of using adiabatic evolution to implement quantum computation. Other models for quantum computing, overview of adiabatic quantum computing and equivalence to gate model. Adiabatic version of Deutch-Josza algorithm. Equivalence of adiabatic quantum computing (AQC) to gate model (within polynomial overhead). NP-complete problems: Combinatorial problems and their reduction to 3-Satisfiability (3-SAT) problems. AQC algorithm for 3-SAT and quantum annealing. Overview of D-Wave's Leap, installation, tutorials, and how to use. Example code: Constructing QUBOs for 2 qubits, 3-bit 3-SAT. Chaining and minor embedding to the device's architecture. Minor-embedding tools. Solving graph optimization problems with quantum annealing; application to vertex cover and map coloring problems.

Grading scheme

Assignments	20%
Midterm	30%
Final	50%

Assignments

There will be 6 assignments. All assignments are already posted on this website, with noted due dates on Friday at 6pm, e.g. P223 - Assignment 1 (A1) is due Jan. 21.

Assignment solutions will be available online a few days after the due date.

The assignments will be graded by the TA, TBD. Any questions on grading should be addressed directly to him by email, at <TAemail>.

Midterm exam

Feb. 18th (Friday), 2:30 pm - 3:50pm.

Notes on the exams

- On all examinations the only acceptable calculator is the sharp EL-510R. This calculator can be bought in the bookstore
  for about $10.

- You are allowed one 8.5X11'' handwritten formula/note sheet. **You can only write on ONE side of the sheet: I am doing this because some people were copying assignment solutions to the formula sheet, a habit that should be discouraged.**
  You will be responsible for the "usual" definitions and equations that we have dealt with in class on a regular basis.

Final letter grade: UVic's percentage grading system

A+	90-100	Exceptional performance.
A	85-89	Outstanding performance.
A-	80-84	Excellent performance.
B+	77-79	Very good.
B	73-76	Good.
B-	70-72	Solid.
C+	65-69	Satisfactory.
C	60-64	Minimally satisfactory.
D	50-59	Marginal performance.
F	0-49	Unsatisfactory performance.

How to succeed

- Attend classes live;

- Most important: **Attempt the assignments by yourself, without looking at solutions first**. If you can't solve a problem, talk to your classmates, or attend the office hour. However, it is extremely important that you attempt to solve the problem by yourself first. Experience shows that students who copy solutions from others usually perform very poorly in the exams and fail the course.

- Common mistake: Some students do not study/review the board/notes/book before attempting the assignments. Instead,
  they "pick" their notes trying to find the material needed to solve a particular

problem. Such method does not work
because it leads to fragmented knowledge; the student does not understand the connection between the topics. Moreover, studying that way does not prepare for the exam, because there will be no book or notes to "pick" during the exam.

- Suggestion on how to study: Do a subject review before attempting the assignment, by reading the board/book/notes.
  Start by reading the assignment fully, and then attempt the problem that appears to be easier (it is okay to briefly go
  back to the book or notes during the assignment).
- Solve extra problems to practice for the exams.