**AMATH900 (AMATH495, QIC895) Quantum Computer Programming**

*Term:* Winter 2020

*Instructors:* Achim Kempf (akempf@uwaterloo.ca) and Nadine Stritzelberger (nstritze@uwaterloo.ca)

*Time:* Mondays and Wednesdays, 4:00 - 5:30 pm

*Room:* MC 6460

*First lecture:* Monday, January 6th 2020, 4:00 - 5:30 pm in MC 6460. Please bring your laptop along!

*Prerequisites:* A first course in quantum mechanics. Alternatively, knowledge of these parts of the text (**Quantum Computing: An Applied Approach**) by Jack D. Hidary: Chapter 1 + Toolkit.

*Course outline:* Given the accelerating progress in quantum computing hardware and the recent achievement of quantum supremacy, this special topics graduate reading course is an introduction to the programming of quantum computers. We will follow the recent text **"Quantum Computing: An Applied Approach"** by Jack D. Hidary (Springer, Oct. 2019) and we will therefore mostly work with Python-based Cirq. The intended audience are graduate and advanced undergraduate students in related fields such as applied mathematics, physics and computer science. Students are expected to give presentations during the term.

*Contents:*

- Basics of quantum computing
- Complexity theory
- Quantum hardware
- Development libraries for quantum computer programming (esp. Cirq)
- Applications to quantum protocols and algorithms for near-term and for future error-corrected machines, from quantum machine learning and quantum chemistry to Shor's algorithm.

*Schedule*

Lecture 1 (2020-01-06): Introduction (Achim, Nadine, Evan)
Format of reading course, Guidelines for presentations, Presentation schedule
Installation of Python and Cirq: Colab Notebook

Lecture 2 (2020-01-08): Basics and History of Quantum Computing (Nadine)
Ch. 1, 2, 3 (p. 3-36)
Optional: see also video and slides by Stefan Leichenauer and this worksheet.

Lecture 3 (2020-01-13): Basics and History of Quantum Computing (Nadine)
Ch. 1, 2, 3 (p. 3-36)

Lecture 4 (2020-01-15): Complexity Theory (Evan)
Ch. 4 (p. 37-44)

Lecture 5 (2020-01-20): Hardware: Building a Quantum Computer (Evan)
Ch. 5 (p. 47-60)
See also video by Ken Brown and video and slides by Eric Ostby.

Lecture 6 (2020-01-22): Development Libraries for QC Programming (Evan)
Ch. 6 (p. 61-79)

Lecture 7 (2020-01-27): Teleportation and Superdense Coding (Nadine)
Ch. 7.1 - 7.3 (p. 80-88)

Lecture 8 (2020-01-29): Quantum Games, Bell Inequalities and Bell Inequality Test
Ch. 7.4 (p. 88-93)

Lecture 9 (2020-02-03): Deutsch-Jozsa Algorithm
Ch. 8.1 (p. 95-104)
See also this worksheet for this and other textbook algorithms.

Lecture 10 (2020-02-05): Bernstein-Vazirani Algorithm, Simon's Problem
Ch. 8.2 - 8.3 (p. 104-108)

Lecture 11 (2020-02-10): Quantum Fourier Transform
Ch. 8.4 (p. 108-111)
See also the first part of this video by Stefan Leichenauer.

Lecture 12 (2020-02-12): Shor's Algorithm
Ch. 8.5 (p. 111-126)

Lecture 13 (2020-02-24): Shor's Algorithm
Ch. 8.5 (p. 111-126)

Lecture 14 (2020-02-26): Grover's Search Algorithm
Ch. 8.6 (p. 126-130)

Lecture 15 (2020-03-02): Variational Quantum Eigensolver
Ch. 9.1 (p. 131-139)

Lecture 16 (2020-03-04): Quantum Chemistry
Ch. 9.2 (p. 139-144)

Lecture 17 (2020-03-09): Quantum neural networks and gradients (Guillaume)
Assigned reading: Quantum Approximate Optimization Algorithm (QAOA), Ch. 9.3 (p. 144-154)
See also this video by E. Farhi
See also the second part of this video by Stefan Leichenauer along with this worksheet.

Lecture 18 (2020-03-11): Quantum optimization, adiabatic quantum computing, QAOA and other variants (Guillaume)

Lecture 19 (2020-03-16): Quantum-classical hybrid neural networks and hybrid backpropagation (Guillaume)
Assigned reading: Machine Learning on Quantum Processors, Ch. 9.4 (p. 154-160)

Lecture 20 (2020-03-18): Applications of hybrid quantum-classical neural networks for quantum simulation (Guillaume)

Lecture 21 (2020-03-23): Google Quantum Machine Learning Software Tutorial (Guillaume, Evan, Trevor)

Lecture 22 (2020-03-25): Quantum Phase Estimation
Ch. 9.5 (p. 160-166)

Lecture 23 (2020-03-30): Solving Linear Systems
Ch. 9.6 (p. 166-178)

Lecture 24 (2020-04-01): Quantum Random Number Generator, Quantum Walks and Implementation of a Quantum Walk
Ch. 9.7 - 9.8 (p. 178-187)

Lecture 25: Assigned reading: Applications and Quantum Supremacy, Ch. 10 (p. 189-198)