DEPARTMENT OF PHYSICS

FCC155 Quantum computing, 7.5 credits

Kvantdatorer och kvantberäkningar, 7,5 högskolepoäng

Second Cycle

Confirmation

This course syllabus was confirmed by Department of Physics on 2020-11-06 and was last revised on 2023-05-08 to be valid from 2024-01-15, spring semester of 2024.

Field of education: Science 100%
Department: Department of Physics

Position in the educational system

The course can be part of the following programmes: 1) Complex Adaptive Systems, Master's Programme (N2CAS) and 2) Physics, Master's Programme (N2PHY)

Main field of studies	*Specialization*
Physics	A1N, Second cycle, has only first-cycle course/s as entry requirements

Entry requirements

A Bachelor's degree in Physics, or equivalent, including course in quantum mechanics.

Applicants must prove their knowledge of English: English 6/English B from Swedish Upper Secondary School or the equivalent level of an internationally recognized test, for example TOEFL, IELTS.

Learning outcomes

The aim of the course is to familiarise the students with both important quantum algorithms (such as Quantum Fourier transform, Phase estimation, and Shor's algorithm), variational quantum algorithms that utilise an interplay between classical and quantum computers (such as the Variational Quantum Eigensolver (VQE), and the Quantum Approximate Optimisation algorithms (QAOA), among others), and the intersection of quantum computing and machine learning. The course will also give the

students practical experince of programming a quantum computer.
Quantum computers are rapidly improving, and recently ”quantum computational supremacy” was achieved, i.e., a quantum computer was able to perform a computational task much faster than a classical computer. Quantum computing is expected to have applications in many areas of society. The course prepares the students for applying quantum computation to a variety of important problems.

On successful completion of the course the student will be able to:

List modern relevant quantum algorithms and their purposes.
Explain the key principles of the various models of quantum computation (circuit, measurement-based, adiabatic model).
Explain the basic structure of the quantum algorithms addressed in the course that are based on the circuit model, and to compute the outcome of basic quantum circuits.
Compare, in terms of time complexity, what quantum advantage is expected from the quantum algorithms addressed in the course with respect to their classical counterparts.
Program simple quantum algorithms on a cloud quantum computer or a cloud simulator.
Understand the basic principles of the continuous variable encoding for quantum information processing.
Give examples of the motivation for applying quantum computing to machine learning and of what the obstacles are to achieving an advantage from doing so.

Course content

Elementary quantum gates and basic quantum computing formalism
Introduction to complexity classes and relevant conjectures
Circuit model for quantum computation
Foundational theorems for quantum computation: Solovey Kitaev theorem; Gottesman-Knill theorem.
Other models for universal quantum computation beyond the circuit model: Measurement Based Quantum Computation and Adiabatic quantum computation
Quantum Fourier Transform and Phase estimation algorithms
Shor’s algorithm
Quantum Machine Learning
Quantum Cloud Computing exercise
Quantum algorithms for solving combinatorial optimization problems: quantum annealing and QAOA
Variational quantum eigensolver
Quantum superiority models: Boson sampling and the instantaneous quantum polynomial (IQP) protocol
Continuous-Variable (CV) quantum computation: MBQC and GKP encoding
CV Quantum superiority models: CV IQP

CV annealing

Form of teaching

The course comprises lectures, tutorial exercise sessions, and a programming laboratory exercise.

Language of instruction: English

Assessment

The assessment comprises two hand-ins and a a final written exam.

A student who has taken two exams in a course or part of a course without obtaining a pass grade is entitled to the nomination of another examiner. The student needs to contact the department for a new examiner, preferably in writing, and this should be approved by the department unless there are special reasons to the contrary (Chapter 6 Section 22 of the Higher Education Ordinance).

If a student has received a recommendation from the University of Gothenburg for special educational support, where it is compatible with the learning outcomes of the course and provided that no unreasonable resources are required, the examiner may decide to allow the student to sit an adjusted exam or alternative form of assessment.

In the event that a course has ceased or undergone major changes, students are to be guaranteed at least three examination sessions (including the ordinary examination session) over a period of at least one year, but no more than two years, after the course has ceased/been changed. The same applies to placements and professional placements (VFU), although this is restricted to just one additional examination session.

Grades

The grading scale comprises: Pass with Distinction (VG), Pass (G) and Fail (U).

Course evaluation

The results of and possible changes to the course will be shared with students who participated in the evaluation and students who are starting the course.