Introduction to Quantum Computing – KEN3241 (4.0 ECTS)

Data Science and Artificial Intelligence

2025-2026

Period 1

Contact Information

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Course Description and Intended Learning Outcomes

This course offers an introduction to the interdisciplinary field of quantum computation. The focus will lie on an accessible introduction to the elementary concepts of quantum mechanics, followed by introducing the mathematical formalism and a comparison between computer science and information science in the quantum domain. The theoretical capability of quantum computers will be illustrated by analysing fundamental algorithms of quantum computation and its potential applications.

Quantum technology has become one of the most prominent interdisciplinary fields of recent research, bringing together ideas from quantum mechanics, (theoretical) computer science and information theory. This course will focus on introducing the mathematical concepts underpinning quantum computation, and on explaining how this new computational paradigm might potentially offer possibilities beyond the scope of conventional computers. Topics that will be introduced and discussed include:

- An exposition of the machinery borrowed from quantum mechanics, such as superposition of states, quantum entanglement, (de)coherence etc., which gives rise to the potential speed-up of quantum algorithms over their classical counterparts.
- Most common models of quantum computation (e.g., quantum circuits and measurement-based quantum computing).
- Some of the most common quantum algorithms and protocols (quantum teleportation, EPR paradox, an exposition of Bell's theorem) etc.
- The course will finish with an exposition of potential applications of quantum computation and algorithms in other fields (such as security/cryptography, optimization etc.)

Important: no prior knowledge in quantum mechanics is assumed or required, and all necessary concepts will be introduced and motivated from a mathematical and theoretical computer science point of view. Possible quantum architectures and/or related hardware issues will not be discussed. It is expected that you have a very good understanding of Linear Algebra. Good understanding of Algorithms & Data Structures as well as core concepts of Theoretical Computer Science, although not strictly necessary, will help you in the course.

Intended learning outcomes (ILOs):

- Knowledge and understanding: to understand the differences between classical and quantum computation. Where the computational power of quantum machines is coming from and what are the limits of this new computational paradigm.
- Applying knowledge and understanding: what does the term "quantum supremacy" refer to and why it is important? How likely it is to be achieved and what would it mean for our current understanding of the computational landscape?
- Making judgement: learn to judge and identify the settings where the potential quantum power might be beneficial and how they can leverage this and learn to analyse simple quantum algorithms for different computational problems.
- Communication: learn to discuss quantum computation critically and judge not only its benefits but, equally important, its shortcomings.
- Learning skills: be able to understand and use the mathematical framework of quantum computing to solve computational problems. To critically read and understand scientific papers on quantum computing. To explain and analyse quantum algorithms described in quantum circuit or measurement-based quantum computing models.

Course Materials

- Quantum Computer Science: An Introduction. David Mermin. Cambridge University Press 2007. (Freely available from author's webpage: http://www.lassp.cornell.edu/mermin/qcomp/CS483.html).
- Quantum Computation and Quantum Information (10th Anniversary Edition). Nielsen & Chuang. Cambridge University Press, 2011. The most comprehensive textbook on QC. A bit old but very relevant. A bit advanced.
- John Preskill's legendary lecture notes (more advanced): http://theory.caltech.edu/~preskill/ph229/
- Xanadu Quantum Codebook (https://codebook.xanadu.ai/T.1)
- An Introduction to Quantum Computing. Kaye, Laflamme & Mosca. Oxford University Press, 2007. A good Intro textbook.
- Quantum Mechanics: The Theoretical Minimum. Susskind& Friedman. Penguin Books 2014. Although this is about Quantum Mechanics (and not QC) some of the chapters give a very nice intro the all relevant concepts (quantum states etc.)
- There are tons of other books and sources around. Before you start reading one, let me know!

Study Load

- This course is worth 4 ECTS, 1 ECTS = 28 hrs study, 4 * 28 = 112 hrs in total.
- 30 contact hours (1hr individual work for each tutorial spread over the course weeks, 1hr Q&A session).
- 112 – 30 = 82hrs self-study
- We will have around 12 lectures/topics, If you study* each lecture 5 hrs (12 * 5 = 60), this leaves 22 hrs for general revision (past exams etc).

*Study includes, reading the textbook, looking through the lecture slides and lecture notes, doing practice problems, discussing the topic with fellow students, etc.

Assignments & Homework

- I will upload 3 sets of exercises for your practice and we can discuss in class. I will also try to upload solutions/answers to most of the questions.

- You can work in pairs but submit your own solution (indicating who was your pair).
- Grade of homework: Pass/fail.
- Generative AI is not allowed to solve exercises.
- For each topic you can play with PennyLane Codebook modules which are indicated in the course schedule table, they are not graded but it is an additional material you are free to use to consolidate your knowledge.

Final Exam

- The final exam will be a closed book exam.
- Final exam = 100% grade.
- The duration of the exam is 120 minutes, without breaks.

Resit

- Same format of final exam

Grading

- Final exam = 100% grade.
- I will assess all final exams.
- Grades will be provided by the official deadline.
- Written feedback will be given on each exam question if needed to help students understand their performance and improve.

Course Schedule

- Schedule ***tentative*** *– we might change or skip few classes to solve exercises etc*

Lecture no.	***Date***	***Time***	***Subject***
1	Monday, 1 September	8:30-10:30	- Intro to Quantum Theory and Quantum Computation. Double slit experiment. Spins and measurements. - The concept of Qbit
2	Thursday, 4 September	13:30-15:30	Mathematics of Qbits Part I (Linear Algebra recap, bra-ket notation, state of Qbit) Practice: Codebook module I.1: Qubits, bra-ket notation, superposition, and measurements. Codebook module I.2: Quantum circuits Codebook module I.3: Unitary matrices
3	Thursday, 4 September	16:00-18:00	Mathematics of Qbits Part II (Mathematics of Quantum Spins, Equivalent states, Rotation, Amplitudes and Interference, A model for Quantum Polarization)

			Practice: Codebook module I.5: Global and relative phases Codebook module I.6: Rotation gates and Bloch sphere
4	Monday, 8 September	08:30-10:30	Mathematics of Qbits Part III (Unitary Transformations, Measurements, Projection Operations) Practice: Codebook module I.4: Quantum operations and 1-qubit gates Codebook module I.9: Projective measurements, basis, and basis rotations Codebook module I.10: Observables and expectation values
5	Thursday, 11 September	13:30-15:30	Quantum Entanglement Part I (Entangled and Unentangled Qbits)
6	Thursday, 11 September	16:00-18:00	Quantum Entanglement Part II (Standard Basis for Tensor Products, Process of Entangling Qbits) Practice: Codebook module I.11: Tensor product and multi-qubit systems Codebook module I.12: Entanglement and controlled operations
7	Monday, 15 September	08:30-10:30	Exercises set 1 Entangled Qbits in different Basis and Intro to Bell's Inequality. Practice: Codebook module I.14: Bell state and bell basis
8	Thursday, 18 September	13:30-15:30	Bell's Inequality: Hidden variables and explanation of entanglement.
9	Thursday, 18 September	16:00-18:00	Exercises set 1
10	Monday, 22 September	08:30-10:30	Quantum Gates and Circuits Part I, No Cloning Theorem.
11	Thursday, 25 September	13:30-15:30	Alg Quantum Gates and Circuits Part II (Bell's circuit, Superdense coding, Quantum Teleportation) Practice:

			Codebook module I.15: Quantum teleportation
12	Thursday, 25 September	16:00- 18:00	Alg Exercises set 2
13	Monday, 29 September	08:30- 10:30	Alg Introduction to Quantum Algorithms, Deutsch's Algorithm Practice: Codebook module A.1: Exponential speedups Codebook module A.2: Oracles Codebook module A.3: Pair programming Codebook module A.4: Global information and promises
14	Thursday, 2 October	13:30- 15:30	Alg Deutsch-Jozsa Algorithm Practice: Codebook module A.6: The Deutsch Jozsa algorithm
15	Monday, 6 October	08:30- 10:30	Grover's Algorithm Codebook module G.4: A Grover step and scaling Codebook module G.5: Geometry and scaling of Grover search for multiple solutions Tutorial video on Grover's algorithm Demo on Grover's algorithm
16	Thursday, 9 October	13:30- 15:30	Exercises set 3
17	Thursday, 9 October	16:00- 18:00	A tour on Quantum Cryptography (Alice, Bob, Eve and the BB84 Protocol, Quantum Key distribution) and beyond: a gentle introduction to Shor's algorithm for factoring, Grover's algorithm for searching and The HHL algorithm. Practice: BB84 notebook attached Codebook module S.5: The RSA encryption system Codebook module S.4: The sequential structure of Shor's algorithm Codebook module G.1: Amplitude amplification and the diffusion operator Codebook module G.2: The geometry of Grover search Codebook module G.3: Phase kickback and implementing diffusion and oracle

			operators using multi-controlled X gates. Q&A