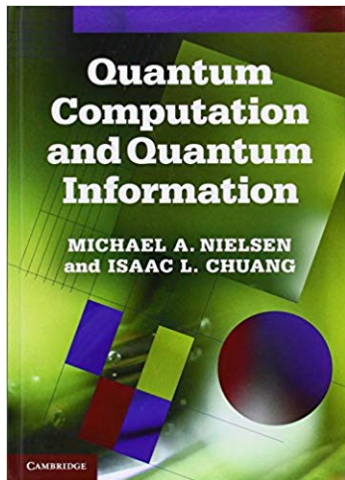# Quantum Computing

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Outline

- **Reading** (October)
  - You read the provided material at home
  - We meet weekly to answer your questions
- **Assigning Topics** (Beginning of November)
  - Everyone gets a topic to present (1-2 persons per topic)
- **Preparation** (November, December)
  - You prepare the talk on your topic
- **Block Presentation** (Beginning of January)
  - Everyone presents their topic
  - 35 minutes talk + 15 minutes discussion
  - Short discussions in between
- **Preparing Essay** (January, February)
  - Summarize the main ideas
  - At most 8 pages
- **Essay Deadline** (End of February)
  - Hand in via email

The Book

Can be found online and in the CS library.

Reading

Read the following chapters from 'Quantum Computation and Quantum Information':

- **2.1.1 - 2.1.7: Linear Algebra**
  - should be familiar from 'Diskrete Strukturen' and 'LA'
  - some new concepts (i.e., complex linear algebra, tensors)

- **3: Introduction to Computer Science**
  - should be familiar from 'Berechenbarkeit und Komplexität'

- **1.1 - 1.4: Introduction and Overview**
  - introduce core ideas of quantum computation

- **2.2.1 - 2.2.3: Postulates of Quantum Mechanics**
  - explains the theoretical fundamentals

- **4.1 - 4.4: Quantum Computation**
  - more details on quantum computation

Meetings

- Three weekly meetings will be held Fridays at 12:30. The room will be announced.

Resigning

Two weeks after assigning the topics you can resign without any consequences. Just write us an email.

Essay

- Feel free to use the same structure as for the presentation
- LaTeX is mandatory (tutorial: https://www.latex-tutorial.com/tutorials/)
- at most 8 pages
- template is available on our website

But:

- Do not simply retell the chapter!

The Topics

Fundamentals

1. **Measurements** (2.2.3 - 2.2.5, Box 2.5, 4.4) (1 P)

2. **Universal Quantum Gates** (4.5) (1 P)

3. **Quantum Error Correction** (10.1, 10.2) (2 P)

4. **Density operator** (2.4) (1 P)

5. **ZX-Calculus** (Book: Picturing Quantum Processes) (1 P)
   ▶ https://en.wikipedia.org/wiki/ZX-calculus

6. **Quantum Information Theory** (1.6, 8, 2.3) (1-3 P)
   ▶ Multiple people can split the topic based on the examples
     in Chapter 1.6.1

Quantum Search

Searching within n Elements in $O(\sqrt{n})$.

Complexity Theory

How Quantum Computation relates to P, NP ...

Relavant book for these topics: *Quantum Computing since Democritus* by Scott Aaronson
https://www.scottaaronson.com/democritus/

10. Quantum Computational Complexity (4.5.5 and references therein) (1 P)

11. Quantum Merlin Arthur (QMA) (1-2 P)
- https://arxiv.org/abs/0804.3401
- https://arxiv.org/abs/quant-ph/0210077v1

12. Quantum Interactive Proofs (QIP) (1-2 P)
- https://arxiv.org/abs/0804.3401

Custom Topics

13. Classical Verification of Quantum Computations
(Jérôme)

14. Random Oracles (Sebastian)

Fourier Transformation

15. Quantum Fourier Transform (5.1) (2 P) (hard)
- definition, properties, compare to fourier transform

16. Phase Estimation (5.2) (hard)
- important subroutine for factoring

17. Factoring & Order Finding (5.3, possibly 5.4) (3 P)
(very hard)
- Shor's Algorithm
- lets us break RSA

Real Quantum Computers

18. Physical Fundamentals (1.5, 7) (1-2 P)
- ▶ how can you implement a quantum bit?
- ▶ how can you apply transformations?

19. How to use Real Quantum Computers (not in book)
(1 P)
- ▶ www.research.ibm.com/ibm-q/
- ▶ en.wikipedia.org/wiki/IBM_Q_Experience
- ▶ en.wikipedia.org/wiki/Qiskit

Bonus

20. Google Quantum Surpremacy (not in book) (1 P)

- ▶ which algorithm yields an estimate of 10000 years?
- ▶ which algorithm yields an estimate of 2.5 days?
- ▶ www.scottaaronson.com/blog
- ▶ what is and is not possible today?