Introduction to Quantum Computing

CMSC / PHYS 457

Lecture 1

Runzhou Tao

Jan. 28, 2025

Today's Plan

- Introduction to the course
- Brief history of quantum computing

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Staff

- Instructor: Runzhou Tao, Assistant Prof. at CS Department
- Research Interest: Quantum Software
- Email: rztao@umd.edu

- TAs:
  - Rushil Dandamudi (rushilcd@umd.edu)
  - Sajjad Nezhadi (sajjad@umd.edu)

Why Quantum Computing? or Why are you here?

- One sentence about who you are (e.g., name, major, graduate/undergraduate).
- One sentence about why you are here.

- Finish Assignment 0

Topics

- Foundations of Quantum Computing
  - Qubits, Quantum Circuits, Entanglements, …
- Quantum Algorithms
  - Shor’s Algorithm, Grover’s algorithm, …
- Quantum Programming
  - How to write codes
- Selective Advanced Topic (tentative)
  - Formal Verification of Quantum Programs, Variational Quantum Algorithms …

In this course, you will…

- Understand and comprehend the theoretical foundation of quantum information and computation.
- Cover a selective collection of fundamental topics in quantum algorithms, quantum complexity, and quantum programming.
- Learn about the research frontier of one specific topic via the course project.
- Get ready for research in the field of quantum information.

Grading

- Assignments: 3 regular + 2 coding; 40% grade
- Exams: 2, 20% grade each
- Projects: 20%

Projects

- In group of 3-5 people
  - Submit list of your team members in Assignment 0
  - Due

- Project proposal (late Feb)
- Mid-term report (early Apr)
- Presentation & Final report (May)
- Each 5% grade

Project Idea Examples

- High-level quantum programming languages
- Quantum machine learning algorithms
- Quantum Nash equilibrium
- Efficient circuit implementation of some quantum algorithm
- …

- Feel free to schedule a meeting with the instructor about project ideas!

Course Website

- https://www.cs.umd.edu/class/spring2025/cmsc457/
  - **Check frequently!**

- Piazza: Discussions, Ask for help
- ELMS: Submitting assignments, solutions
- GradeScope: Grading assignments & exams

Textbook

- No required textbook, mainly refer to:

- An Introduction to Quantum Computing by Phillip Kaye, Raymond Laflamme & Michele Mosca Oxford University Press (2007).
  - “KLM”
- Other lecture notes specified on the course website

- **Treat Reading Assignment Seriously!** Important to fill in the details of lectures.

Office Hours

- Tao: By appointments / after class
- Dandamudi: 12pm-2pm Monday, AVW 4160
- Nezhadi: 1:30pm-3:30pm Thursday, AVW 4160

- In general, please send your questions/requests to Piazza or set up appointments via emails with the instructor and the TA. We will act as soon as possible to reply to your requests.

Please let us know ASAP if

- You cannot submit assignments electronically.
- Time conflicts of exams.
- Concerns about the difficulty of the course.

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History of quantum computing: Early Days

- Early 20th century: quantum mechanics formulated to explain the behavior of subatomic particles.

- 1970s: Quantum information theory, no-cloning theorem

- 1981: Feynman proposed quantum computing to simulate quantum systems

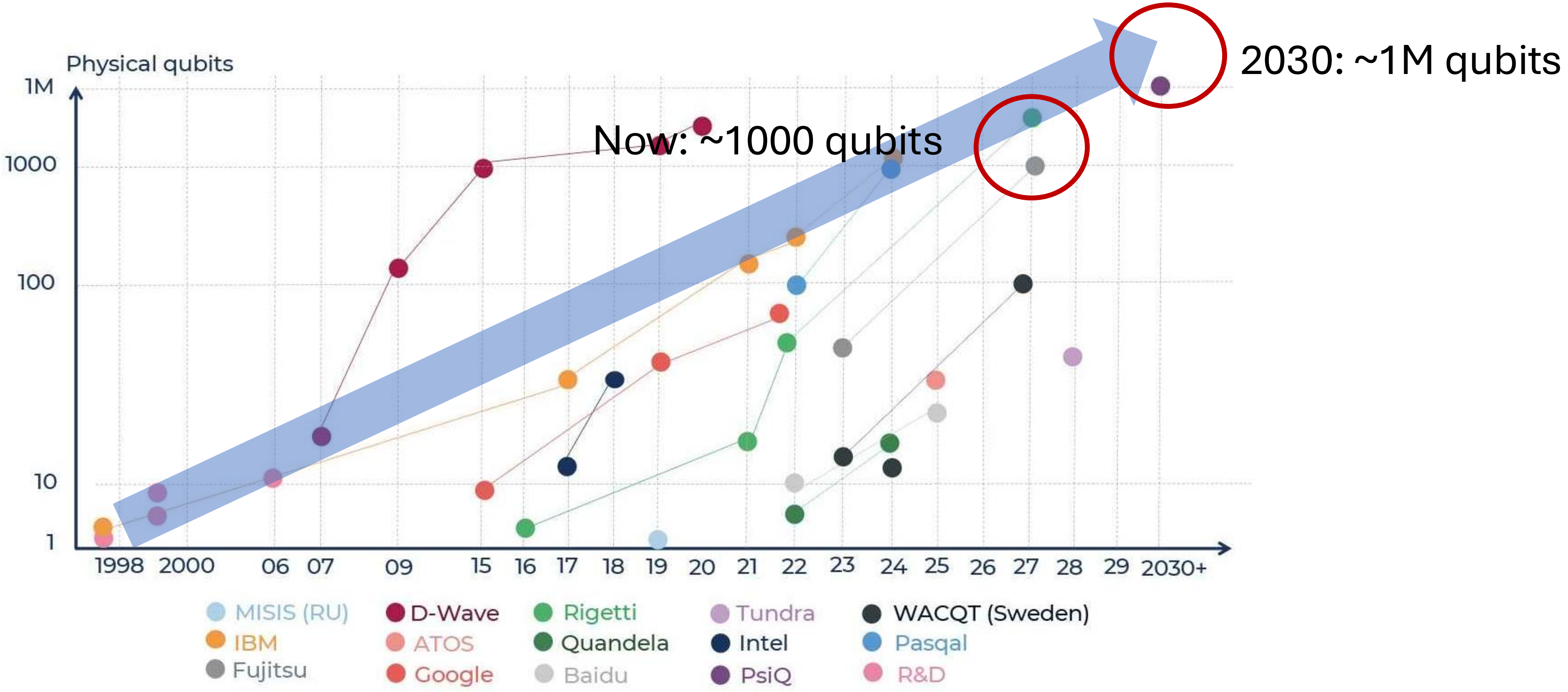
History of quantum computing: Algorithms

- 1992: Deutsch-Jozsa Algorithm, first quantum algorithm that no classical algorithm is possible
- 1993: Simon’s algorithm. Exponential speedup over classical
- 1994: Shor’s algorithm (Factorization)
- 1996: Grover’s algorithm (Unstructured Search)

History of quantum computing: Experiments

- 1998: First experimental demonstration of a quantum algorithm (2 qubits) @
- 2001: Factorization of 15 by IBM
- 2000s & 10s: More qubits

History of quantum computing: Experiments



- Number of qubits is not everything because of noise & connectivity!

Emerging quantum computers

- Many players racing to build (scalable) quantum computers:

QUANTINUUM Google IBM

XANADU PsiQuantum IONQ QuEra Computing Inc.

- Different labs/companies are betting on different horses
  - Superconducting qubits, ion traps, photonic systems, neutral atoms, ...

Future Directions

- Quantum Advantage / Supremacy
  - Demonstrate a special purpose application which cannot be simulated as fast using existing classical computers (~100 qubits)
- Near-term quantum computing
  - Demonstrate a useful application (chemistry, optimization, …) with a quantum device which does not need full fault tolerance (1K-5K qubits)
- Fault-tolerant quantum computer
  - Run useful quantum algorithms with exponential speed up over their classical counterparts (requires error correction) (>1M qubits)
- Find useful algorithms
- Build software systems to support quantum computing
  - my research interest

Assignments

- Assignment 0 (not for credit)
  - Introduce yourself & find team members
  - Due Feb. 11

- Reading Assignment: KLM Chapter 1 & 2