Physics 14N

Quantum Information: Visions and Emerging Technologies

In a classical computer, information is encoded in bits. Quantum mechanics opens new possibilities for information processing with *qubits*. Qubits offer the potential for exponentially enhancing the speed of computations, and for encrypting information so securely that would-be eavesdroppers are thwarted by the laws of physics. In this seminar, we will develop both an intuition and a rigorous mathematical framework for understanding the remarkable behavior of qubits, through a combination of simple optics experiments, pencil-and-paper algebra, and computer simulations. We will discover how the state of a quantum system is altered by the process of measuring it and derive a fundamental consequence: the Heisenberg uncertainty principle, which limits our ability to precisely measure forces, distances, and time.

What most strikingly sets quantum information apart from its classical counterpart is that it can be encoded non-locally, woven into correlations among multiple qubits in a phenomenon known as *entanglement*. We will discuss paradigms for harnessing entanglement to solve hitherto intractable computational problems or to push the precision of sensors to their fundamental quantum mechanical limits. We will also examine challenges that physicists and engineers are tackling in the laboratory today to enable the quantum technologies of the future.

Course Contents

I. Quantum Bits
   a. Mathematical description
   b. Physical incarnations: polarized photons; spins
   c. Entanglement

II. Quantum communication
   a. Quantum key distribution
   b. Quantum teleportation

III. Quantum computation
   a. Algorithms (search, factorization)
   b. Error correction
   c. Experimental platforms & challenges
   d. Alternative approaches, e.g., simulation

IV. Quantum measurement
   a. Heisenberg uncertainty relations
   b. Applications of quantum sensing

Contact Information

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Class Meetings: MW 1:30-2:50 pm, Lathrop 290 (Mon) / Lathrop 282 (Wed).

Textbook: Rieffel & Polak, *Quantum Computing: A Gentle Introduction*

Website: All course materials will be posted on Canvas.

Homework: Homework will be posted on Canvas each Tuesday and due the following Tuesday at 5 PM.

Field Trip: We will take a field trip to Rigetti Computing (Berkeley, CA) on Friday, May 18. Your attendance is required (and it will be fun!).

Grading

Your grade will be based on in-class activities, homework, and a final project. The final project includes an in-class presentation and a paper or other deliverable (e.g., computer simulation) on the same topic.

- In-class activities: 20%
- Homework: 35%
- Final project: 30%
- Final presentation: 15%

Honor Code

The Stanford University Honor Code and Fundamental Standard are a part of this course. Their full text can be found online.