OPTI 646

Introduction to Quantum Information and Computation

This course covers the Foundations of Quantum Information Science and selected topics in Quantum Communication and Quantum Computation, including physical implementations.

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Text: Quantum Information and Computation", lecture notes by John Preskill, Caltech 1998.

Send me an email after the first lecture to ensure I get you in my mailing list, and I will respond by sending you a PDF copy.

Course Website: https://wp.optics.arizona.edu/opti646/

Lectures: Meinel 305, Tuesdays and Thursdays 2-3:30pm

Office Hours: Meinel 604, Wednesdays 2-3:30pm
If you give me a heads-up beforehand, I can usually find time for a chat outside office hours.

Note: OPTI 646 is taught in a live, in-person format. Video and slides from the lectures will be posted on the course website, but these recordings are not meant to substitute for live attendance.

Grading: Homework (30%), Student Presentation or Term Paper (30%), and class participation (40%).

In place of exams, each student is required to give a Lecture or submit a Term Paper on a topic related to Quantum Information Science.

Prerequisites: A solid knowledge and understanding of graduate level quantum mechanics is essential, as developed in, for example, OPTI/PHYS 570A "Quantum Mechanics", or equivalent. The course uses the notation and conceptual language of the "Cohen-Tannoudji school of quantum mechanics", adapted in the OPTI 570/544/646 series of graduate level courses.

Topics

Introduction and overview

Physics of Information, Quantum Computation
Quantum parallelism, Deutsch's problem
Quantum Error Correction
Quantum Hardware: Ions, atoms, Superconductors, Photons and more

Review of quantum mechanics I - basics

State vectors, Linear operators, Observables, Unitary Operators
Postulates of Quantum Mechanics

Review of quantum mechanics II – bipartite systems

Tensor Product of State Spaces and Operators
Measurements on one Part of a System
Density operator, Separate Description of part of a System, Partial trace
Bayes Rule and the Updating of Probabilities, Collapse of the Wavefunction

Qubits, Spin-1/2 and other 2-Level Systems

Spin State Space, Entangled States, Observables, Pauli Matrices
Pure states, Density operator, Bloch picture.

Entanglement

2 Spins, EPR States, Local Measurements and Correlations
Sending Non-Orthogonal States, Significance of Ensemble Decomposition, Local Hidden Variable Theories, Bell Inequalities, Clauser-Horne-Shimony-Holt Inequality

Quantum Communication

Information in entangled pairs, Dense Coding
Quantum key distribution, Security against eavesdroppers, No cloning theorem, Quantum teleportation

General Theory of Measurement

Von Neumanns Theory of Orthogonal Measurement, System-Meter Model,
Non-orthogonal Measurements, POVM's
Implementation as Orthogonal Measurement in Extended State Space

Open Quantum Systems

Evolution and Decoherence, Operator-sum representation, Kraus operators, Super-Operators, Decohering Quantum Channels, Depolarizing, Phase & Amplitude Damping

Classical & Quantum Information Theory

Shannon for Dummies. Shannon Entropy, Data Compression. Channel Capacity,
Joint and Conditional Entropy, Mutual Information. Quantum Data Compression.

Quantum Computation

Classical Circuits, Universal Gates, Circuit Complexity.
Quantum Circuits, Universal Quantum Gates. Quantum Circuit Complexity,
Complexity Hierarchy.

Student Lectures and Term Papers 2002 - 2023

Student Lecture/Term Paper Topics 2002 (7)
EPR and GHZ, loopholes
Quantum teleportation
Quantum communication and quantum cryptography Neutral atom quantum computation – optical lattices Slow light and quantum data storage
Quantum games
Quantum measurement – QND and POVM

Student Lecture/Term Paper Topics 2005 (6)
Quantum Computing with Ion Traps Quantum Data Storage in Ensembles Quantum Algorithms
Quantum Key Distribution
Solid State Implementations of Quantum Computation Classical Wave Simulations of QM

Student Lecture/Term Paper Topics 2008 (14)
EPR experiments
Quantum Non-Demolition Measurements
Quantum State Reconstruction
Public Key Cryptography and the RSA cryptosystem
Slow light and quantum data storage
Quantum teleportation
Ion trap quantum computation
Linear optics quantum computation
Solid state implementations of quantum computation
Robust quantum control of qubits
Quantum simulation of model Hamiltonians
Shor's algorithm for factoring
Topological quantum computing
Quantum Information Theory - Holevo Information, Accessibe Information

Student Lecture/Term Paper Topics 2010 (9)
EPR experiments
Quantum Non-Demolition measurements
Quantum State Reconstruction
Quantum Metrology
Public Key Cryptography and the RSA cryptosystem
Slow Light and Quantum Data Storage
Ion Trap Quantum Computation
Grovers Agorithm for Data Base Search
Quantum Trajectories and Quantum Monte Carlo Simulation

Student Lecture/Term Paper Topics 2012 (7)
Quantum Non-Demolition measurements Spin Squeezing
Weak Values in Quantum Measurement Quantum Cryptography
Grovers Algorithm
Adiabatic Quantum Computing Quantum Simulation in Chemistry

Student Lecture/Term Paper Topics 2015 (4)
Quantum non-demolition measurements, Superoperators and decoherence
Dynamical decoupling and composite pulses Measurement based one-way quantum computation

Student Lecture/Term Paper Topics 2018 (5)
Quantum Repeaters
Surface Code Quantum Computing Grovers Algorithm
Quantum Tomography
Squeezed States

Student Lecture/Term Paper Topics 2020 (13)
Frequency Combs and Quantum Computation
Overview of Quantum Gates for Ion Trap Quantum Computers
Quantum Non-Demolition Measurements in Quantum Optomechanics
GHZ States and Tests of LVH Theories
Quantum Neural Networks
Continuous Measurement and Quantum Control
Analog vs Digital Simulation and the Effects of Trotterization
Variational Quantum Eigensolver (VQE)
Quantum Metrology: Quantum Fisher Information and Estimation Strategies Quantum Memory: A Review
Shor's Algorithm
A Review of Quantum Error Correction of a Qubit Encoded in Grid States Quantum Error Correction Codes

Student Lecture/Term Paper Topics 2022 (15) Quantum Annealing
Blind Quantum Computation
Measurement Based and Delegated QC Topological QC
Optical Computing with CV Cluster States Semiconductor Spin Qubits
Qubits in Harmonic Oscillators
Quantum Fisher Information and Cramer Rao Bounds Quantum Neural Networks
Optical Coherent State Discrimination
Quantum Causality
Gaussian Boson Sampling
Survey of Optical Quantum Computing
Quantum Acoustics and Quantum Control
Quantum Key Distribution

Student Lecture/Term Paper Topics 2024 (15)
Quantum Annealing Error Correction
Quantum Communication Networks
Superconducting Implementations of QC
Semiconductor Spin Qubits
QKD with 3-Outcome POVM
Nanomechanical Systems in QIS
Quantum Decoherence
Quantum Gates in Ion Traps