QUANTUM INFORMATION SCIENCE

T Technical Teaching

QUANTIS

KOUNTOURIS Marios

ABSTRACT

Interested in learning how to communicate using quantum bits? Curious about how quantum algorithms and quantum computers work? This is an introductory course to quantum communication, computation, and information processing. We will cover various aspects of quantum information science and systems, introducing in a simple manner key principles and concepts, which are often considered "hard" or mysterious.

After a brief overview of quantum technology, the course starts with a concise introduction of key principles of quantum mechanics. Then, we cover fundamental aspects of quantum information, such as qubit, entanglement, Bell inequalities, and EPR (Einstein-Podolsky-Rosen) paradox, as well as of quantum communication (noise, quantum channels, decoherence, von Neumann entropy, Holevo capacity). We also present basic principles of quantum computing and study key quantum algorithms (e.g., Shor's, Grover's, quantum Fourier transform). Finally, we discuss potential applications and emerging topics, such as quantum AI and quantum/ post-quantum security.

Previous exposure to quantum mechanics is not required. All necessary concepts and mathematical formalism are taught during the first lectures.

Teaching and Learning Methods: Lectures supported by illustrative examples and exercises. Each session starts summarizing key concepts from previous lecture. Optional project for in-depth study of theoretical concepts or for understanding practical aspects (e.g. implementing/programming basic quantum algorithms and gates).

Course Policies: Attendance to lectures is not mandatory but highly recommended.

BIBLIOGRAPHY

- M. Nielsen and I. Chuang, "Quantum Computation and Quantum Information", Cambridge University Press, 2nd edition, 2010
- J. Watrous, "The Theory of Quantum Information", Cambridge University Press, 2018
- S. Aaronson, "Quantum Computing Since Democritus", Cambridge University Press, 2013

REQUIREMENTS

Basic knowledge in linear algebra, matrix analysis, calculus, and probability theory.

DESCRIPTION

The course will cover the following topics:

- **Introduction**: history, overview, applications, challenges, and state-of-the-art implementations.
- **Elements of Quantum Mechanics**: state, measurement, spin, density operators, tensor products, unitary transformation, Hilbert spaces, Dirac and braket notation.
- **Foundational aspects**: quantum information, qubits, entanglement, teleportation, Bell inequalities, Einstein–Podolsky–Rosen paradox, superdense coding, quantum Zeno effect.
- **Quantum Communication**: quantum noise and quantum channels, decoherence, no-cloning and no-communication theorems, quantum repeaters.
- **Quantum Information Theory**: information and entropy (classical and quantum), capacity of quantum channels (Holevo-Schumacher-Westmoreland (HSW) and Lloyd-Shor-Devetak (LSD) coding theorems).
- **Quantum algorithms**: Shor's factoring, Grover's search, quantum Fourier transform, Deutsch-Jozsa algorithm.
- **Quantum computation**: circuits and universal gates, complexity, challenges of scalable quantum computing.
- **Special topics:** quantum Internet, quantum AI, quantum security.

Learning outcomes:

- understand the foundational concepts of quantum information science.
- familiarize with the terminology, the principles, and the mathematical formalism of quantum systems
- understand the theoretical and algorithmic aspects of quantum communication and computation.
- be able to follow recent developments in quantum technology and its applications

Hours for

Lecture: 21.00

Problem session: 5.00 (included in the lectures)

Programmed personal work: 10.00 (for the optional project)

Grading Policy: Final Exam (100%. or 75% with optional project) - written exam all documents authorized. Optional project (25%)