



UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Quantum Information and Algorithms

2526-2-F9102Q026

Aims

(DdD 1) Knowledge and understanding

By the end of the course, the student will be able to:

- Understand the peculiarities of quantum information and their theoretical and practical relevance.
- Demonstrate knowledge of the main cryptographic protocols used in quantum communication.
- Acquire an in-depth understanding of the operating principles of quantum computational models.

(DdD 2) Applying knowledge and understanding

By the end of the course, the student will be able to:

- Analyze and classify the main classes of quantum algorithms.
- Implement quantum algorithms using appropriate formalisms and quantum-specific programming languages.

(DdD 3) Making judgements

Throughout the course, the student will develop the ability to:

- Critically assess the potential and limitations of quantum algorithms with respect to specific computational problems.
- Judge the appropriateness of various quantum models and technologies for solving concrete problems.

(DdD 4) Communication skills

Through course activities, the student will be able to:

- Communicate theoretical and practical results in quantum computing with clarity, precision, and appropriate technical language, including in interdisciplinary contexts.
- Present reports on quantum algorithms or protocols to a technical or academic audience.

(DdD 5) Learning skills

By the end of the course, the student will have developed the ability to:

- Pursue further study in quantum computing independently, including through engagement with advanced scientific literature and emerging technological platforms.
- Continuously update their knowledge in a rapidly evolving field, autonomously integrating both theoretical and practical competencies.

Contents

The course provides an introduction to representative topics in the following thematic areas:

1. Quantum Information Theory (basic elements)
2. Quantum Cryptography (quantum key distribution)
3. Quantum Communication (non-ideal channels and error-correcting codes)
4. Quantum Computation (selected advanced algorithms, Machine Learning algorithms)
5. Elements of Distributed Quantum Computing

Detailed program

1. Quantum Information Theory (basic elements reviewed)
 - From Classical to Probabilistic to Quantum Computations
 - Classical vs. Quantum Correlations
 - Information Quantities in Classical and Quantum Systems
2. Quantum Cryptography (quantum key distribution)
 - Entanglement as a Resource for Cryptography: Teleportation and Dense coding
 - Quantum Key Distribution Protocols: Bennet & Brassard 84, Bennet 92, Ekert 91
3. Quantum Communication (non-ideal channels and error-correcting codes)
 - Density matrix theory
 - Decoherence and Non-Ideal Channels
 - Quantum Error Correcting Codes
4. Quantum Computation (selected advanced algorithms)
 - Recall of the fundamental concepts
 - Quantum “Subroutines” (e.g. phase kick-back)
 - Review of “the Canon”, the most well-known algorithms and some variants (ex. Fixed-Point Grover)
 - Further notable algorithms: the Shor factorization algorithm
 - Introduction to Quantum Machine Learning

5. Elements of Distributed Quantum Computing (DQC)

- The non-local CNOT
- The DQC primitives
- The Quantum Internet Paradigm

Prerequisites

Linear algebra, and mathematical topics covered in undergraduate courses held in STEM bachelor degrees. Understanding of basic concepts in statistics and machine learning.

Attendance of the course Foundations of Quantum Computing (1st year M.Sc., called, until AA 23/24, Quantum Simulations), or an equivalent course.

Teaching form

The course consists of

- classroom lectures (DE 32 hours)
- interactive laboratory programming activity (DI 24 hours)

All activities will be held in presence.

The course will be delivered in English.

Textbook and teaching resource

Lecture notes and scientific papers provided by the lecturers.

To further explore the topics in greater detail, the following texts are useful:

- Vathsan - Introduction to Quantum Physics and Information Processing - CRC Press 2016
- Hayashi - Introduction to Quantum Information Science - Springer-Verlag Berlin Heidelberg 2015
- Wolfgang Polak, Eleanor Rieffel: Quantum Computing : A Gentle Introduction. MIT Press, 2011
- Schuld & Petruccione: Machine Learning with Quantum Computers. Springer 2021
- Schuld & Petruccione: Supervised Learning with Quantum Computers. Springer 2018

Semester

Second Year, First Semester

Assessment method

The learning assessment is based on an oral interview, on the subjects exposed in class during the course.

Evaluation criteria:

- Understanding of Concepts (in-depth and comprehensive understanding of course topics)
- Problem-Solving Skills (application of theoretical knowledge and creativity)
- Ability to Explain and Discuss (clarity, synthesis and critical thinking)

Office hours

Upon appointment.

Sustainable Development Goals

QUALITY EDUCATION | INDUSTRY, INNOVATION AND INFRASTRUCTURE
