UAB
Universitat Autònoma de Barcelona

Quantum Information

Code: 104408
ECTS Credits: 6

2024/2025

Degree	Type	Year
2503740 Computational Mathematics and Data Analytics	OB	3

Contact

Name: Alessio Celi

Email: alessio.celi@uab.cat

Teachers

Anna Sanpera Trigueros

Andreas Johannes Winter

Teaching groups languages

You can view this information at the end of this document.

Prerequisites

It is advisable to have a good command of algebra, especially of vector spaces and, preferably, of complex Euclidean spaces. It is advisable also to be familiar with the basic concepts of classical information, as delivered in the course "Teoria de la informació" of the first semester.

Objectives and Contextualisation

The course is an introduction to the current view of quantum mechanics and its paradigms. With the technology we have today, many of the most paradoxical quantum effects have ceased to be an academic curiosity and have become very powerful resources that will be the basis of many amazing practical applications in the not too distant future. This course introduces some of them: cryptography and quantum computing, in particular. The course is aimed at mathematicians with a strong vocation for data analysis, therefore, it will be necessary to provide essential physical training with an introduction to the fundamentals of quantum mechanics, classical cryptography and computing. The basic concepts of classical information theory are also reviewed. The course has also a computational component: numerical simulations of various phenomena will be done and prototypes of quantum computers will be used to program various protocols. The aim of the subject is not only to give a description of the advances that have taken place in quantum information, but also to provide the student with the basic tools to be able to continue his postgraduate training in this field, if this is their interest.

Learning Outcomes

1. CM30 (Competence) Explain the hypotheses of quantum physics, applying them to information processing problems.
2. KM26 (Knowledge) Identify the impact of quantum technologies on computing, cryptography and other communication protocols in the environment.
3. SM32 (Skill) Apply the concept of quantum measurement to optimisation problems in simple quantum discrimination, estimation and communication problems.

Content

0. Review of linear algebra and complex numbers

- Real vector spaces
- Complex numbers
- Complex vector spaces

1. Elements of quantum theory

- Basic principles
- Mixed states
- Unitary operators
- Qubits
- Entangled states
- von Neumann measurement

2. Quantum cryptography

- Information security
- Quantum communications
- Quantum key Distribution

3. Generalized Measurements and Entanglement

- POVM vs. von Neumann
- Bell states and non-locality

4. Quantum information processing

- Digital electronics
- Quantum gates
- Quantum circuits

5. Quantum computation

- Elements of computer science
- Principles of quantum computation
- Deutsch-Jozsa algorithm and other examples

Some of these arguments will be dealt with in the form of seminars

Activities and Methodology

Title	Hours	ECTS	Learning Outcomes
Type: Directed			
Seminars of specific topics	10	0.4	
Theoretical lessons	28	1.12	
Type: Supervised			
Projects with online quantum computers	12	0.48	
Type: Autonomous			
Homework exercises	36	1.44	
Numerical resolutions of excercises	36	1.44	
Study of the theoretical background	20	0.8	

The course is structured into theory lectures, exercises lectures, and continuous assessment activities.

The theory lectures are on the blackboard. There will be some classes/seminars on some course topics that will generally be in English and will be delivered on the blackboard or as powerpoint presentations.

The exercises lectures are usually made on the blackboard and consist of solving the most significant problems, the statements of which are made available to students through the Virtual Campus.

There will be 4 deliveries. The objective is to deepen, consolidate and extend the students' knowledge about aspects and results explained throughout the course. Thus, the deliveries may contain problems and issues of greater complexity and extension. These should be delivered periodically throughout the course and on previously agreed dates. The aim of these activities is to encourage autonomous work.

All the material: lists of problems, additional teaching material, detailed resolution of some exercises, as well as news related to the course, are made available to the students through the Virtual Campus.

Annotation: Within the schedule set by the centre or degree programme, 15 minutes of one class will be reserved for students to evaluate their lecturers and their courses or modules through questionnaires.

Assessment

Continous Assessment Activities

Title	Weighting	Hours	ECTS	Learning Outcomes
Assessment of computational aspects	20	1.5	0.06	CM30, KM26, SM32
Attendance and participation in specialized seminars	5	0	0	CM30, KM26, SM32
Delivery of exercises (autonomous work)	30	0	0	CM30, KM26, SM32
Evaluation exam of theoretical concepts	45	2.5	0.1	CM30, KM26, SM32

Retaken exam of theoretical and computational aspects	65	4	0.16	CM30, KM26, SM32

The assessment is structured to favor students who follow regularly and deliver assignments without penalizing s
Of the 4 deliveries, two, LL1 and LL2, correspond to the arguments deve
The punctuation of the deliveries will be: LL= 0.4*(LL1+LL2) + 0.1*(Sem1
There will be a final exam (and if necessary a re-examination) solely on t
0.4 * LL + Ex (10 - 0.4* LL)/10
This formula does not penalize those who take the final exam alone but f

Only the students who participed to the exam can participates to the repechage.

Bibliography

The students wil have access to the lessons in pdf format and copies of the Keynote / Powerpoint of the course. For further information, the following bibliography is advisable:

Theory

- S.M. Barnett, Quatum Information, Oxford University Press, 2009.
- J. Preskill. Lectures notes on Quantum Computation. Es pot obtenir gratuïtament a la direcció: http://www.theory.caltech.edu/people/preskill/ph229.
- M.A. Nielsen; S.L. Chuang. Quantum Computation and Quantum Information. Cambridge Univ. Press, Cambridge 2000.

• A. Peres. Quantum Theory: Concepts and Methods. Kluwer, Dordrecht 1995.
• D. Applebaum. Probability and Information. Cambridge Univ. Press, Cambridge 1996.
• D. Boumeester; A. Eckert; A. Zeilinger. The Physiscs of Quantum Information. Springer 2000.
• D. Heiss. Fundamentals of Quantum Information. Springer 2002.

Problems

- Steeb, Willi-Hans, and Yorick Hardy. *Problems and solutions in quantum computing and quantum information*. World Scientific Publishing Company, 2018.
- C. P. Williams; S. Clearwater. Exploration in Quantum Computing. Springer 1998

Software

IBM quantum composer

Language list

Name	Group	Language	Semester	Turn

(PLAB) Practical laboratories	1	Catalan	second semester	morning-mixed
(SEM) Seminars	1	Catalan	second semester	morning-mixed
(TE) Theory	1	Catalan	second semester	morning-mixed