Universitat Autònoma de Barcelona

Quantum Information

2023/2024

Code: 104408
ECTS Credits: 6

Degree	Type	Year	Semester
2503740 Computational Mathematics and Data Analytics	OB	3	2

Contact

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Teaching groups languages

You can check it through this link. To consult the language you will need to enter the CODE of the subject. Please note that this information is provisional until 30 November 2023.

Teachers

Anna Sanpera Trigueros

Andreas Johannes Winter

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.

Competences

- Demonstrate a high capacity for abstraction and translation of phenomena and behaviors to mathematical formulations.
- Make effective use of bibliographical resources and electronic resources to obtain information.
- Plan and carry out studies of physical system using analytical or numerical methods and interpret the results.
- Students must be capable of applying their knowledge to their work or vocation in a professional way and they should have building arguments and problem resolution skills within their area of study.
- Students must be capable of collecting and interpreting relevant data (usually within their area of study) in order to make statements that reflect social, scientific or ethical relevant issues.
- Students must have and understand knowledge of an area of study built on the basis of general secondary education, and while it relies on some advanced textbooks it also includes some aspects coming from the forefront of its field of study.
- Using criteria of quality, critically evaluate the work carried out.

Learning Outcomes

1. Apply the concept of quantum measurement to problems of optimising simple problems in quantum discrimination, estimation and communication.
2. Explain the postulates of quantum physics and apply these to information-processing problems.
3. Make effective use of bibliographical resources and electronic resources to obtain information.
4. Master the Dirac and matrix principles and formalism of quantum physics.
5. Students must be capable of applying their knowledge to their work or vocation in a professional way and they should have building arguments and problem resolution skills within their area of study.
6. Students must be capable of collecting and interpreting relevant data (usually within their area of study) in order to make statements that reflect social, scientific or ethical relevant issues.
7. Students must have and understand knowledge of an area of study built on the basis of general secondary education, and while it relies on some advanced textbooks it also includes some aspects coming from the forefront of its field of study.
8. Understand the impact of quantum technologies in computing, cryptography and other communication protocols.
9. Using criteria of quality, critically evaluate the work carried out.

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

Methodology

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.

Activities

Title	Hours	ECTS	Learning Outcomes
Type: Directed			
Seminars of specific topics	10	0.4	8
Theoretical lessons	28	1.12	8, 2, 3

Type: Supervised			
Projects with online quantum computers	12	0.48	9, 8, 2
Type: Autonomous			
Homework exercises	36	1.44	1, 9, 8, 4, 3
Numerical resolutions of excercises	36	1.44	1, 9, 8, 6, 3
Study of the theoretical background	20	0.8	1, 8, 2, 6, 3

Assessment

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.

Assessment Activities

Title	Weighting	Hours	ECTS	Learning Outcomes
Assessment of computational aspects	20	1.5	0.06	8, 4, 7, 5, 3
Attendance and participation in specialized seminars	5	0	0	1, 8, 4, 2, 7, 5, 3
Delivery of exercises (autonomous work)	30	0	0	1, 9, 8, 4, 5, 6, 3
Evaluation exam of theoretical concepts	45	2.5	0.1	1, 8, 4, 2
Retaken exam of theoretical and computational aspects	65	4	0.16	1, 8, 4, 2, 3

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