ANX-PR/CL/001-01
LEARNING GUIDE

SUBJECT

595040537 - Introduction To Quantum Computing

DEGREE PROGRAMME

59ID - Grado En Ingenieria Y Sistemas De Datos

ACADEMIC YEAR & SEMESTER

2023/24 - Semester 2

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	595040537 - Introduction To Quantum Computing
No of credits	4.5 ECTS
Type	Optional
Academic year ot the programme	Fourth year
Semester of tuition	Semester 8
Tuition period	February-June
Tuition languages	English
Degree programme	59ID - Grado en Ingenieria y Sistemas de Datos
Centre	59 - Escuela Tecnica Superior De Ingenieria Y Sistemas De Telecomunicacion
Academic year	2023-24

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
Rafael Delgado Lopez (Subject coordinator)		rafael.delgado@upm.es	- -
Rafael Jose Hernandez Heredero		rafael.hernandez.heredero@upm.es	Sin horario.

* The tutoring schedule is indicative and subject to possible changes. Please check tutoring times with the faculty member in charge.

3. Prior knowledge recommended to take the subject

3.1. Recommended (passed) subjects

- Modelos MatemÁticos Y MatemÁtica Discreta

- Probabilidad Y SeÑales Aleatorias

- CÁlculo

- Álgebra

3.2. Other recommended learning outcomes

- This course cannot be followed and passed without a previous knowledge of Linear Algebra, Calculus I, Calculus II and some probability theory. They are not marked in this guide as compulsory prerequisites only because of administrative constraints.

4. Skills and learning outcomes *

4.1. Skills to be learned

CB05 - Que los estudiantes hayan desarrollado aquellas habilidades de aprendizaje necesarias para emprender estudios posteriores con un alto grado de autonomía

CE01 - Que los estudiantes sean capaces de aplicar los conceptos y las herramientas fundamentales de la matemática a la formalización y resolución de los problemas en el ámbito de la titulación.

CG01 - Tener capacidad de trabajar en entornos internacionales y multidisciplinares, haciendo uso de la lengua inglesa en forma oral y escrita.

CG04 - Saber identificar y utilizar las herramientas de las Tecnologías de la Información y de las Comunicaciones más adecuadas para plantear y construir soluciones a problemas

CG09 - Desarrollar la capacidad de aprendizaje a lo largo de la vida (lifelong learning) para adaptarse a un sector tecnológico en continua evolución.

4.2. Learning outcomes

RA159 - To understand quantum annealing techniques.

RA153 - To know the difference between a classical bit and a qbit.

RA154 - To express multi-qbit states using tensor products, and distinguish between entangled and unentangled states.

RA156 - To be acquainted with the basic types of quantum gates.

RA158 - To know about some important quantum algorithms (quantum teleportation, Shor?s algorithm, Grover?s search).

RA160 - To be familiar with applications of quantum computation to problems like the Satisfiability Problem.

RA157 - To analyse and implement simple quantum circuits using simulation packages like Quirk and Qiskit.

RA155 - To compute the evolution of multi-qbit states, understanding its measurement and statistical interpretation.

* The Learning Guides should reflect the Skills and Learning Outcomes in the same way as indicated in the Degree Verification Memory. For this reason, they have not been translated into English and appear in Spanish.

5. Brief description of the subject and syllabus

5.1. Brief description of the subject

This course is an introduction to quantum computing. We will explain the mathematical framework of quantum computation, beginning with quantum bits (qbits) and multi-qbits. The physical model of a qbit as a spin ¿ particle will be discussed, followed by an explanation of the unitary evolution and measurement procedure on a multi-qbit. Quantum gates and quantum circuits will be discussed, using simulators like qiskit and Quirk for designing and analysing simple cases. We will discuss several important quantum algorithms like quantum teleportation, Shor?s factoring algorithm and Grover?s search algorithm. We will end with an introduction to the already commercially available technology of quantum annealing, discussing its application to the problem of Satisfiability.

5.2. Syllabus

1. Introduction to quantum physics and quantum computing
    1.1. From the bit to the qbit
    1.2. Kroneker (or tensor) product
    1.3. The computational basis
2. Quantum states
    2.1. Quantum states, entanglement
    2.2. The spin 1/2 system. The Bloch sphere
    2.3. Hermitian operators and observables.
    2.4. Measurement
3. Quantum gates
    3.1. Introduction to Quantum Gates. Unitary operation over qubit states
    3.2. 1-qubit quantum gate: Pauli gate
    3.3. 2-qubits quantum gates: Hadamard and CNOT
    3.4. 3-qubits quantum gate: Toffoli gate
4. Quantum circuits
    4.1. Introduction to quantum gate notation and basic quantum circuits
    4.2. Usage of Quirk (Quantum Circuit Simulator)
    4.3. Construction of a Toffoli gate by means of CNOT gates
    4.4. Simple quantum circuits for increasing and decreasing
    4.5. A very basic introduction to the ?de-facto? standard (Python) qiskit framework
    4.6. Some quantum gate based algorithms: Quantum teleportation, Schorr?s algorithm and Grover?s search algorithm
5. Quantum annealing
    5.1. Introduction to the concept of quantum annealing
    5.2. Introduction to the Satisfiability Problem
    5.3. Choice of Hamiltonians and interpolation functions to solve a SAT problem via quantum annealing
    5.4. Simulation of simple quantum annealing in qiskit

6. Schedule

6.1. Subject schedule*

Week	Classroom activities	Laboratory activities	Distant / On-line	Assessment activities
1	**Chapter 1** Duration: 03:00 Lecture			
2	**Chapter 2** Duration: 02:00 Lecture **Chapter 2** Duration: 01:00 Problem-solving class			
3	**Chapter 2** Duration: 02:00 Lecture **Chapter 2** Duration: 01:00 Problem-solving class			**Individual Work** Individual presentation Continuous assessment Not Presential Duration: 00:00
4	**Chapter 3** Duration: 03:00 Lecture			
5	**Chapter 3** Duration: 02:00 Lecture **Chapter 3** Duration: 01:00 Problem-solving class			
6	**Chapter 4** Duration: 03:00 Lecture			
7		**Chapter 4** Duration: 03:00 Laboratory assignments		
8	**Chapter 4** Duration: 03:00 Lecture			
9		**Chapter 4** Duration: 03:00 Laboratory assignments		
10		**Chapter 4** Duration: 03:00 Laboratory assignments		**Laboratory Evaluation** Problem-solving test Continuous assessment Presential Duration: 03:00

11	**Chapter 5** Duration: 03:00 Lecture			
12	**Chapter 5** Duration: 03:00 Lecture			**Group Work** Group work Continuous assessment Not Presential Duration: 00:00
13		**Chapter 5** Duration: 03:00 Laboratory assignments		
14		**Chapter 5** Duration: 03:00 Laboratory assignments		
15				
16				
17				**Global Exam** Written test Continuous assessment Presential Duration: 03:00 **Global Exam** Written test Final examination Presential Duration: 03:00

Depending on the programme study plan, total values will be calculated according to the ECTS credit unit as 26/27 hours of student face-to-face contact and independent study time.

* The schedule is based on an a priori planning of the subject; it might be modified during the academic year, especially considering the COVID19 evolution.

7. Activities and assessment criteria

7.1. Assessment activities

7.1.1. Assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
3	Individual Work	Individual presentation	No Presential	00:00	10%	/ 10	CE01 CG01
10	Laboratory Evaluation	Problem-solving test	Face-to-face	03:00	25%	/ 10	CE01 CB05 CG04
12	Group Work	Group work	No Presential	00:00	15%	/ 10	CE01 CB05 CG09
17	Global Exam	Written test	Face-to-face	03:00	50%	3 / 10	CE01 CB05

7.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
17	Global Exam	Written test	Face-to-face	03:00	100%	5 / 10	CE01 CB05 CG01 CG04 CG09

7.1.3. Referred (re-sit) examination

Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
Extraordinary Exam	Written test	Face-to-face	03:00	100%	5 / 10	CE01 CB05 CG01 CG04 CG09

7.2. Assessment criteria

Assessment criteria

There are two categories of graded items:

- Problem solving, group projects and lab activities: 50% of the total grade, as indicated above.

- Global Exam: the remaining 50%.

If the grading of the Global Exam results in a higher mark than the average between activities and exam, the final grade will be that of the exam. That is, the grade will be the result of applying the following formula:

Total grade=Max((activities+exam)/2, exam)

where both "activities" and "exam" are marked from 0 to 10 points. To pass the course, a total grade of 5 or more, and a minimum mark of 3 points in the final exam are required.

The extraordinary exam (in June/July) will allow to pass the course if a grade of 5 over 10 or more is obtained. The total grade will be that of the extraordinary exam.

8. Teaching resources

8.1. Teaching resources for the subject

Name	Type	Notes
N. D. Mermin. Quantum Computer Science, Cambrigde University Press	Bibliography	Good reference for Chapters 1 to 4
M.A. Nielsen and I.L. Chuang. Quantum Computation and Quantum Information	Bibliography	Complete general reference (except for Chapter 5)
McMahon. Quantum Computing Explained	Bibliography	Simple introduction, accessible through UPM Ingenio
https://qiskit.org/learn/	Web resource	Nice textbook and tutorials by qiskit
https://qiskit.org/ecosystem/optimization/tutorials/index.html	Web resource	Introduction to quantum annealing

9. Other information

9.1. Other information about the subject

Sustainable Development Goals contribution.

The main SDG that the course can contribute to are, perhaps, the following.

SDG 4: Quality Education, by providing high level technical and theoretical knowledge promoting equality and sustainable development.

SDG 9: Industries, Innovation and Infrastructure by enhancing scientific research, and upgrading the technological capabilities of industrial sectors.