612 Syllabus - Physics of Information

Spring 2025

Instructor

Prof. Fabio Anza
Physics, Room 413
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Time and Place

Monday & Wednesday
3:00 pm → 4:15 pm
Fine Arts 014

Dates

First Day of Class: 27th of January 2025
Last Day of Class: 12th of May 2025
Finals Week: 15th → 21st of May 2025

No class on:

- 17th and 19th of March (Spring Break)

Take-home exams:

- Classical Part - 5th → 12th of March. Due on the 12th of March
- Quantum Part - 5th → 12th of May. Due on the 12th of May

Course Project

- The project's first draft will be part of the homework from the 23rd to the 27th of April.
- Project presentations will be on Finals Week.

Office Hours

Tuesday
9:00 am → 11:00 am

Textbooks (required)

Cover and Thomas - Elements of Information Theory (2nd edition)
(Wiley Series in Telecommunications and Signal Processing)

Nielsen and Chuang - Quantum Computation and Quantum Information
(10th Anniversary Edition) Cambridge University Press

Literature (highly recommended)

Kurt Jacobs - Stochastic Processes for Physicists
Cambridge University Press

Mark Wilde - Quantum Information Theory
Cambridge University Press

Steven Strogatz - Nonlinear Dynamics and Chaos: with applications to physics, biology, chemistry, and engineering
CRC Press

Scope

The course has two broad goals:

1. To provide the students with a core set of tools to study the physics of classical and quantum information processing. Both in natural and artificial systems.
2. To expose students to modern research themes in the growing area of science and technology of information processing

Course Structure

The course will be structured in three parts:

1. Classical Information Processing
   - Basics of probability theory and stochastic processes;
   - Elements of classical information and computation theory
   - Dynamical Systems and physical models of classical information processing
2. Quantum Information Processing
   - Basics of many-body quantum systems: density matrices, POVMs, and CPTP maps
   - Elements of Quantum Information and Computation
   - Physical models of quantum information processing
3. Class-chosen topics
   - The class will choose a set of topics from a list that will be handed over in the first or second lecture. Examples include fundamental limits to computation dictated by physical laws, Maxwell's demon, Landauer's bound and the thermodynamics of information processing, molecular motors and information engines, Bekenstein's bound, Black Hole's entropy, and many others.

Learning Goals

At the end of the course, you should expect to

- Be familiar with the basics of
  1. Many-body probability theory and stochastic processes
  2. Dynamical Systems
  3. Many-body quantum mechanics
  4. Classical and quantum information theory
- Know the core aspects of information processing at the classical and quantum levels.
- Be capable of assessing the core information-theoretic features embedded in a classical or quantum system and their dynamics.
- Have carried out at least one project within the physics of information processing

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Homework

When and Where
Homework assignments will be posted on Blackboard every Wednesday after class.
Submissions are due a week after, before the following Wednesday's class.

What
The assignments will have two parts:

- Complex technical problems to be worked out in detail. There will generally be three, but their number may experience fluctuations depending on the topic.
- A reading assignment complementary to the material to be discussed in class. Homework assignments will also contain questions about the reading material.

How to submit
I'll accept submissions in the following formats:

- Handwritten
  - These have to be clear, legible, and organized. Think of them as sections you would read in an example of a solved problem you might want to find in a textbook. Figures should be printed and attached to the homework sheets when plots are needed.
- A zipped folder with all or some of the following
  - A Jupyter notebook with Python code and explanatory Markdown cells
  - Data files
  - A working Latex file and additional files like images, code, and data.

Students are encouraged to work together to solve problems and discuss readings. However, the submitted homework solutions must be personal work. So, it must be written in your own words, using your logic, and showing a person-specific understanding of the problem, its solution, and the topic.

Late homework will not be accepted.

Exams

There will be three exams:

- One on the *classical part*. Standard take-home written exam (during spring break)
- One on the *quantum part*. This will also be a take-home written exam (after we are done with the quantum part)
- Project report and presentation (finals week)

Grades

A numerical score will determine your final grade. This score is computed as the weighted sum of the partial scores in three categories: H (Homework), E (Exams), and P (Project). Each category is assigned an equal weight of 1/3, with a maximum total score of 1. The scale is set as follows

Grade	Score
A	$[0.9, 1]$
A-	$[0.85, 0.9[$
B+	$[0.8, 0.85[$
B	$[0.75, 0.8[$
B-	$[0.7, 0.75[$
C+	$[0.65, 0.7[$
C	$[0.6, 0.65[$
C-	$[0.55, 0.6[$
D	$[0.4, 0.55[$

For example, if you get $H = 0.85, E = 0.7, P = 0.95$ your score will be $B+$:

$$\text{Final Score} = \frac{0.86}{3} + \frac{0.7}{3} + \frac{0.93}{3} = 0.83 \qquad \longrightarrow \qquad \text{Final Grade} = B+$$

You will be graded in each category in the following way:

Homeworks
The Homework Score (H) will be determined as follows

- Each homework assignment with 100% score leads to 1 point
- Sub-problems in each assignment will be given a weight proportional to their difficulty
- The final homework score will be the average number of points you have over all homeworks.

Exams
The Exam Score (E) will be the average of the individual scores in each of the two exams, with equal weight given to the classical and quantum parts.

Project
The Project Score (P) will be the average of two elements:

- The written report, with weight 0.6
- The oral presentation, with weight 0.4