INTRODUCTION AND OVERVIEW OF CLASS.

Quantum Information Procesing.

↑ ↗

* quantum physics
* information procesing.

Discussion and motivation:

1) Quantum physics.

Fundamental laws of nature are quantum in fact.
Classical physics emerges as a behavior of material systems at appropriate energy, distance, time scale, as well as complexity scales.
How this classical behavior emerges is rather unclear.

In any case, quantum laws & description of phys systems depart from classical one in many strange ways and new concepts are needed.

In this class you will acquire some portion of quantum laws. Fortunately for the aspects that will concern us in quantum information and computation, this can be done with

a minimal amount of physics knowledge.

2) Information theory (classical).

As you all know modern classical information th assumes that the basic unit of information is the bit 0/1. Mathematically this is a random variable. Information measures are given by entropic quantities, like Shannon's entropy, based on probability distributions. For example the amount of information of a source described by some probability distribution is given by Shannon's entropy which also tells us by how much we can compress a message (for example).

Now, classical information theory is largely independent of the underlying technology used to store (memonics), communicate, or measure signals and information.

However this is done in physical systems after all!

And at some scales the physical systems obey the quantum laws (which are very different than usual classical laws).

So the question arises: How do quantum laws interfere with information theory?

Do they help in any way or do they impede information processing?

The answer turns out to be not so simple.

But in many ways that we will see in this class quantum behavior offers new resources to process information! Resources that have no classical analog and force us to rethink many paradigms.

3) Quantum information.

In QI Theory the basic unit of information is not the classical bit 0 / 1 (a r.v with $p(0)=q$; $p(1)=1-q$ say).

but a new notion called the

"QUANTUM BIT" or "qubit"

We will learn what a qubit is in many stages as we go along through the class.

For the moment let us just give a glimpse:

a A qubit is a vector that is a "superposition" of a "0" and "1" "states": $\psi = \alpha \begin{pmatrix} 1 \\ 0 \end{pmatrix} + \beta \begin{pmatrix} 0 \\ 1 \end{pmatrix}$

$= \alpha |0\rangle + \beta |1\rangle$

b When observed or measured the "vector" gets "projected". The axis of projections depend on "the way it is measured". The projection is random. The outcome depends on ψ and on the "way we measure". In any case one classical bit of info is extracted from measurement.

C When the qubit is not isolated (from the environnement) the vector description is not sufficient. The qubit is described by a matrix (2 x 2, called the Density Matrix). This density matrix is an analog of a probability distribution. We will come to this aspect only in the third part of the class.

Overview of Chapters this semester.

Quantum physics primer

1. Interference experiments, Classical versus quantum behavior (purely phenomenological description)
2. Mathematical principles of Quantum Physics
   - recap of linear algebra i.- Dirac notation
   - Axioms of Quantum Phys.
   - Qubits, Bach sphere, physical examples.
3. Examples and applications of the formalism to the interference experiments

Communication protocols

4. Quantum Key distribution, Basic protocol.
5. Entanglement I
6. Entanglement II

(5 & 6: Bell states, Teleportation, Dense coding, Bell inequalities, Swapping & repeaters for networks.)

Manipulating qubits

7. Dynamics of two level systems I
8. " " " II

(7 & 8: • Spin in magnetic field • Rabi oscillations • Gates)

9. " of 2 qubit systems

(9: • Heisenberg interaction • CNOT gate)

Quantum Info Theory

10. Density matrix (qubits in enviroumement)

11. von Neumann entropy I

12. " " " II

13. " " " III

} Analog of Shannon's entropy

} Entanglement entropy, ect...

14. Selected topics / project / ...