Quantum Hardware for the Theorist

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Course Objective

This course introduces the hardware used for quantum information technologies and the associated practical challenges involved in realizing quantum information processing systems which theorists should take into account. The aim is to bridge the gap between theoretical quantum algorithms and protocols and their real-world implementation on hardware.

Problem Setting

We can illustrate these aspects with a quantum algorithm that we want to run on a real quantum computer. Assume a quantum algorithm on n qubits, corresponding to qubit initialization, unitary transformation U and qubit measurements. U can be approximated using a universal gate set (e.g., CNOT and arbitrary single-qubit gates) and in theory, we should simply run this quantum circuit on physical qubits to obtain the desired result.

However, when interacting with experimentalists, you will face hardware-specific limitations that may prevent direct implementation. This course provides the practical knowledge to anticipate such constraints, estimate runtime and feasibility, and define a hardware-specific theoretical model for executing quantum algorithms.

Course Breakdown (6 Lectures + Labs)

This lecture series consists of 6 sessions of 3 hours each, mixing lectures and tutorials/labs.

1–2: Quantum Systems, Gates implementation, and orders of magnitude.

- The "physics" of hardware components:
  - Discrete energy levels in atoms and ions
  - Solid-state physics (semiconductor / metal)
  - Photons and quantized modes of the electromagnetic field
- Mechanisms for defining a qubit in these systems (e.g. DV / CV encoding)
- Gate operations: physical mechanisms of interaction and dynamics under the Schrödinger equation

3–6: Quantum computing hardware model and popular hardware platforms

This section is divided into three parts:

Introduction to hardware Using cold atoms platforms as an illustration, we will introduce all the important concepts of QC on real hardware (gate implementation techniques, operational timescales, noise sources...). We will extend these general concepts to superconducting circuits quantum computing and photonic quantum computing as well.

Quantum Computing hardware model Introducing general concepts to consider hardware from a theorist perspective. The goal is to understand the key constraints (e.g. connectivity constraints, noise...) imposed by different hardware platforms and to abstract them out with a more theoretical perspective, and understanding the interest and limitations of such hardware models.

Projects / Labs The objective is to apply these concepts in a lab projects. To experience them on real experimental platforms (such as the ones accessible on the cloud).

Exam

1. Labs report
2. Written Exam:
    - Exercices
    - Paper analysis