A Primer in Quantum Computing
Cascade 2024

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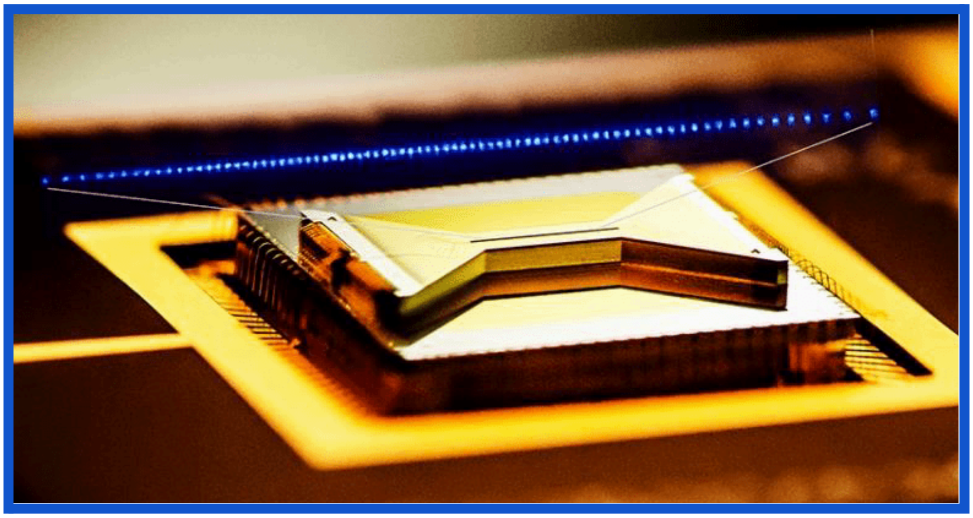

Quantum computer using trapped-ions as qubits. Image from IonQ.

Motivation

Quantum is weird… so much so that people have wondered whether we can use this 'weirdness' to our advantage. What happens when you start playing by a different set of rules? Can we do better than the status quo? These are the questions behind quantum computing.

Thinking about bits, 0's and 1's, has gotten us very far already! It's how you're reading this syllabus right now. This is the world of classical physics: the one you and I are so familiar with. But by using *quantum-bits* (*qubits* for short), like in atoms and light, we unlock a new set of rules that *might* make for even better computers.

Course Description and Outcomes

In this course, we'll learn that this quantum "weirdness" is actually very precise, and **very understandable**, with the right tools. We'll see how these tools: linear algebra and probability, explain the behavior of qubits and quantum measurement, and how these can be applied to real-world applications:

- How does quantum measurement make private communication safe? (Quantum cryptography)

- Are there certain things we can do on a classical computer (like yours or mine) that can be done *better* on a quantum computer?
- What's this about entanglement, and "spooky action at a distance" Einstein was talking about?

Along the way, we'll also be learning to use Python and the QuTiP library to write programs that mimic quantum systems (see Workshops below)!

As you can see, quantum computing exists at the intersection of many many fields; so far we've talked about physics, math, cryptography/communications, and computer science. I believe there's a place for everyone in this field, and hopefully you'll find that something in this class speaks to you, and pursue it further!

<u>Schedule</u>*

Session	Topics	Workshop
10/12	What's a qubit? - Experimental motivation and interpretation - Quantum states - Normalization condition - Linear algebra and Dirac notation	Set-up QuTiP and build your first qubits.
10/19	Quantum Measurement 1: How does it work? - Copenhagen interpretation of quantum mechanics - Probability amplitudes, "collapse of the wavefunction" - Quantum uncertainty: measuring in different bases	Take quantum measurements of superpositions in QuTiP.
10/26	Quantum Measurement 2: How can it keep our data safe? - Applications to quantum cryptography: BB84	Alice, Bob, and the Eve-sdropper
11/2	Quantum Algorithms 1: What can we do to our qubit? - Single-qubit gates - Qubit states and the Bloch "plane" - Quantum circuits	Build quantum circuits in QuTiP and measure the outcomes.
11/9	Quantum Algorithms 2: Are these any better than classical ones? - Deutsch's algorithm and quantum advantage - Survey of other historical algorithms: Shor, Grover	Build Deutch's algorithm in QuTiP… does it work?
11/16	[*If time permits…*] What happens when we have more than one qubit? - Tensor product of qubits - Entanglement and entangling circuits [*otherwise*] - Quantum Algorithms 3: Finish up discussion on	[*If time permits…*] Generating entanglement in QuTiP, "spooky action at a distance."

	Deutch's algorithm - Outlook: what to look into next? - Open discussion: Q&A, feedback	[*otherwise*] Finish Deutch's algorithm

*We'll go as fast or as slow as we need to… or even go off on tangents if that's where the class's interest is!

Workshops

Each class will be divided into a lecture/seminar style portion, followed by an open workshop where you'll get a chance to apply what you've learned. These are meant to be collaborative (please work together!) and informal.z

We'll be using ***QuTiP*** (Quantum Toolbox in Python) and ***Google CoLab*** to transfer the math and physics we learn into code. These tools are ubiquitous in quantum computing research/development, so hopefully you'll find gaining experience in these to be valuable!

Prerequisites

TLDR: Algebra and Geometry

The language of quantum mechanics, and thereby quantum computing, is *linear algebra*: the study of vectors, matrices, and the spaces they live in. Though you may not be familiar with it formally, you've probably been exposed to it more than you realize! Regardless, **we'll learn this math as we go** and do so in the context of quantum computing.

That said, the topics below are some you'll want to be familiar with coming in:

- From Algebra, you'll want to know how to
  - Solve for variables
- From geometry:
  - Graphing: circles and points
  - Pythagorean Theorem: a^2 + b^2 = c^2
- From probability:
  - Probability of outcomes should add up to 1 (100%) (coin-flip: 50% heads + 50% tails)

No knowledge of quantum physics or Python programming is expected; we'll learn (quite a bit) about these topics together!