Summary of Key Concepts

The Quantum Stack

Week of October 8, 2023

Resources

- QXQ YLC Week 3 Lab Notebook [STUDENT].ipynb
- QXQ YLC Week 3 Homework [STUDENT].ipynb
- 1. QxQ YLC 23-24 Python Basics Cheat Sheet
- Transistors & The End of Moore's Law [Video]

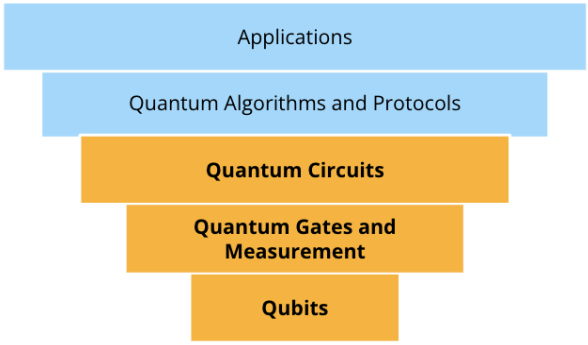
Key Terms

Key Term	Definition
Qubit	A Qubit is a quantum bit. This is the basic unit of information of a quantum computer, operating under the laws of quantum mechanics. Qubits can be a 0, 1 or a combination of these two states.
Ket Notation	Ket notation, also called Dirac notation, is a method of representing the state of finite or infinite complex vectors in their state space.
Bloch Sphere	A three-dimensional representation utilizing the unit sphere of the state of a quantum mechanical system, named after the physicist Felix Bloch.
Vectors	Vectors are a mathematical method to represent general systems (quantum and non-quantum) using a list of numbers representing the contribution to each state (ex: 0 or 1).
Quantum Gate	Quantum gates perform some quantum operation on qubits to change their state in order to perform quantum computations.
Quantum Circuit	Quantum circuits are a sequence of quantum gates acting on a qubit or a group of qubits.

Lecture

Learning Objectives

1. *Recognize* the layers of the quantum stack: qubits, quantum gates, quantum circuits, quantum algorithms/protocols, and applications.
2. *Recognize* the three main representations of qubits: kets, Bloch spheres, and vectors.



Key Ideas

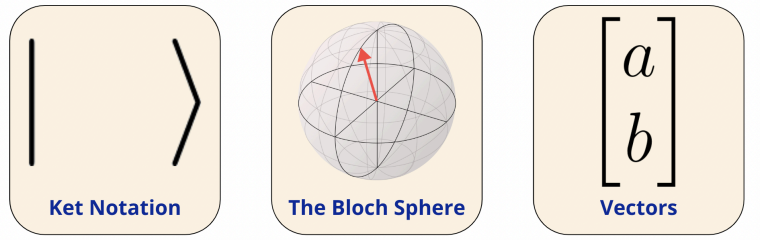
1. The **Stack** organizes all layers of a computer's operation, starting with the most fundamental and hidden from sight on the bottom.
2. **Moore's Law** says that we are able to double the power of computers every year. To squeeze more power into computers, we must make transistors (bits) smaller and closer together.
    a. After a certain size however, quantum effects begin to cause problems for our classical computers. This is bringing about the "end of Moore's Law".

    b. **Quantum tunneling** is a quantum mechanical behavior that has a detrimental effect on classical computers.

3. The layers of the quantum stack: **qubits, quantum gates, quantum circuits, quantum algorithms/protocols,** and **applications**. Focusing on the bottom three layers:
    a. A **Qubit** is a quantum bit. They operate under the laws of **quantum mechanics.** Qubits can be a **0, 1** or a **combination of these two states.**

        i. There are several different types of qubits that are used by different quantum computers, but in this course we will primarily focus on **superconducting qubits**.

ii. Representations of Qubits



- **Kets** are a mathematical method meant to represent purely quantum states. It is useful because **it offers a neat notation to do math for a quantum system**, but it is difficult to visualize.
- **The Bloch Sphere** is a geometric representation of a quantum state. It is useful because **it allows for easy visualization**, but it is difficult to communicate this to a computer.
- **Vectors** are a mathematical method to represent general systems (quantum and non-quantum). They are useful because **states can be easily communicated to a computer**, but calculations with them can be cumbersome.

b. **Quantum gates** perform some quantum operation on qubits to change their state in order to perform quantum computations. In this lecture the X gate and H gate were explored.

c. **Quantum circuits** are a sequence of **quantum gates** acting on a **qubit** or a group of qubits. The three main components of a quantum circuit were discussed.
   i. Initial **qubit** state as the input to the quantum circuit.
   ii. The **quantum gates** as the computation.
   iii. **Measuremen**t as the output of the circuit. This is the *only* way for us to find out any information about qubits, so it is *vital*.

Lab

Learning Objectives

1. *Understand* basic python code.
2. *Understand* what objects, attributes, and methods are.
3. *Recognize* the essential programming skills of: debugging, commenting, and reading documentation.

Key Ideas

1. Python is an Object-Oriented Programming (OOP) language that encapsulates data and behavior into **objects**.
    a. **Attributes** represent the data we work with.
    b. **Methods** are the actions we can perform on this data. Methods in Python are specialized functions that operate on an object's attributes, often encapsulating behavior relevant to those attributes.
2. To be a good programmer, you also need to develop some essential programming skills:
    a. **Debugging** is the process of getting rid of errors in your code. Sometimes the code does not run at all and each part of the code needs to be checked. Other times you code runs, but not in the correct way. In this case you need to test each part for functionality until you find the problem.
    b. **Comments** are a way to add notes in your code. They help with having others understand your code, explaining code that is difficult to understand, and remind you what you did and why if you are returning to code you have written previously.
    c. **Documentation** is a description of any function object, or other part of a programming language. Knowing how to read documentation is a key skill to develop as a programmer.