Seminar 3

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Materials	

Quantum Mechanics I

Week 2 | October 2nd, 2022

Quantum Computing is Interdisciplinary:
Q-computing requires knowledge of math, physics, and coding.

Today’s Topics:

- Classical vs Quantum World
- Discrete vs Probabilistic States
- 4 Essential Q-properties

A quantum computer uses properties of Q-mechanics ton solve problems that classical computers cannot. Q-mechanics is the study of the behavior and interaction of really mall objects, such as atoms and molecules. Active area of research: transition from the classical world to q-world (read more if interested)

“Really Small”

- Size of molecules, atoms, bacteria, wavelength of visible light is where the Q-mechanical behavior begins
- 100,000,000 atoms would fit across your fingernail if lined up in a row
- Q-particles can be: Atoms, molecules, light (made out of q-particles called photons)
    - Light can be both wave and a particle at the same time

Q-mechanics is already powering many of our device:

- Computer Chips
- Laser
- MRI Machine

****This Week's Focus: The What's of Quantum****

The First Quantum Revolution:

By the late 1800s, physicists seemed explained how things we see in the world around us work. However, there was still some things that did not have an explanation. Lights and small particles did not behave in line with the classical laws of physics.

Founding fathers:

- Niels Bohr - proposed the picture of atom with discrete energy level
- Max Planck - quantized behavior
- Albert Einstein - proposed the experiment to show light is both a wave and a particle

Quantum Tunneling is where there is a probability that a small particle can pass through a rigid surface. Quantum Measurement: In the Q-world objects can be moved to other places without external influence. This is due to the fact that all the properties of an object cannot be known at once (example: position/velocity variables). Quantum Zeno Effect - In the Q-world, objects will move only when you're not looking at it. By looking or measuring the particle, you pin the particle in one place.

Quantum Mechanics:

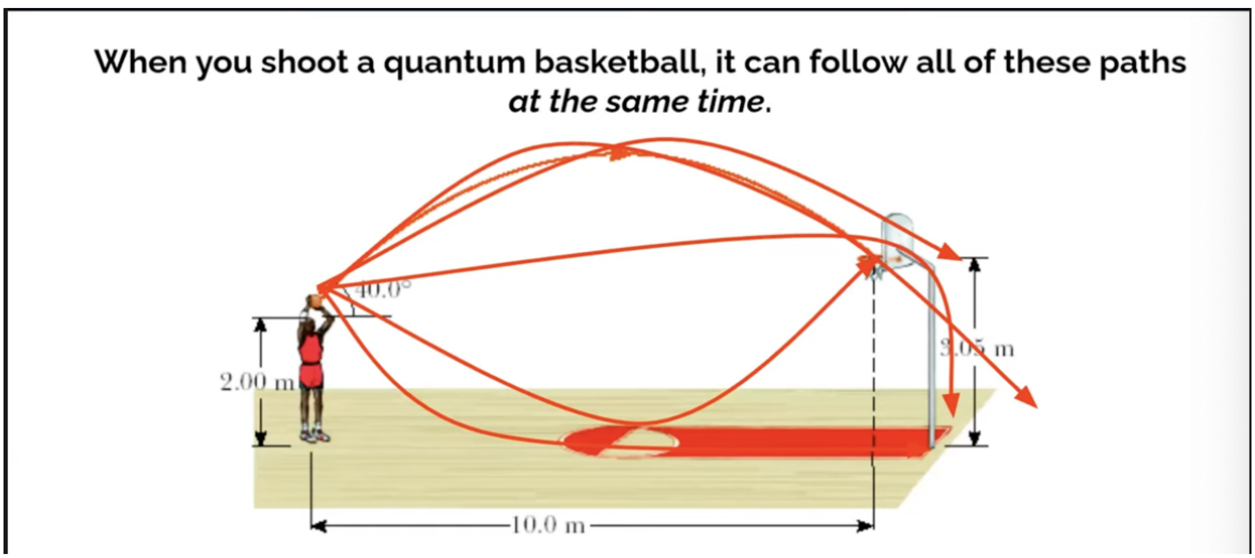
Classical state: Describes where an object is and what it is doing at a certain time. We can use classical laws to know exactly where the ball will be and how fast it is moving at every single movement. (Position/Velocity)

Quantum state: These objects also have a state but unlike a classical state, we cannot predict with certainty what state the object will be in. Instead the Q-state describes the probability that we find the object in one classical state versus another

- Options or paths available to q objects are discrete
- Classical states include continuous paths which is not the case in q-states
- Particles jumps/"leap" to different positions, rather than "travel" like in classical states (no "in between" state is present for q-states)

Superposition:

Quantum objects can be in multiple states at once - this is superposition. We may be more likely to find the object in one state or another, but all states are possible at the same time. All states are possible at the same time - some may be more likely than others (higher probability)



Famous Example: Schrodinger's Cat

Let’s try an experiment:

1. Place a sealed vial of poison and a cat inside a box
2. Close the box
3. Come back some time later to see which of these possibilities occurred:
   a. The cat avoided the vial of poison and is alive (but probably a bit annoyed)
   b. The cat knocked over the vial of poison and is dead

Classical World - the cat is either dead or alive

Quantum World - the cat is both dead and alive until the lid is opened; the cat can be both dead and alive at the same until measured. Before observed, it will be in a superposition

Quantum State of an Electron:

The real picture of an atom is dictated by q-mechanics. We actually can’t pinpoint where an electron is located around an atom. Instead there are probability clouds of finding the electron in certain spaces of atoms. You cannot pinpoint the location of an electron specifically. the electron is in a superposition of many different possible locations until it is measured at which the electron assumes a position.

Interference:

- In the q-world, the states of an object can add up or cancel out.
- The classical version of this occurs in waves when they collide
- Two waves can cancel each other out in some places and also make each other stronger in other places
- Constructive Interference:
  - When two q-particles add up (wave properties add up) to create something with more amplitude or energy
- Destructive Interference

    - When two q-particles with opposite velocities collide and vanish and cancel each other out

Entanglement:

The state of q-objects can be so deeply tied together that there is no way to fully describe one object without describing the other object. one object's state depends on the other's.

When you spin your ball one way, you're friend's entangled ball could spin the other way. This can be configured to many different cases where the balls spin in the same direction, etc…

- Entanglement works over **ANY** distance - Einstein called it "spooky action at a distance"

The Power of Entanglement:

- Can be used as a wya to store and find out information more powerfully than is possible with classical objects. For this reason, it is vital ingredient in many, if not all, q-algorithms
- We don't actually know **WHY** entanglement works - it is still being studied

Measurement:

When we want to find out what state a q-object is in, it is forced to randomly choose one classical state to be in. We say that measurement collapses superpositions for this reason. When a measurement is made a state must be chosen in the classical world.

Measurements are a way to ask a object about its state, classical or quantum.

Classical World:

- Height, when being measured, always stays the same regardless of whether or not you are measured or whether who is measuring your height

Quantum World:

- There is no way to predict your exact height before measurement
- You can calculate a probability distribution, but no exact value will exist
- You may get different measurements every time you measure (the value will be random, but can be predicted using p-distributions)

When we observe or measure a q-object, we change its state!

- When a Qubit is measured it must choose to be 0 or 1, and this will change its superposition state it was originally in

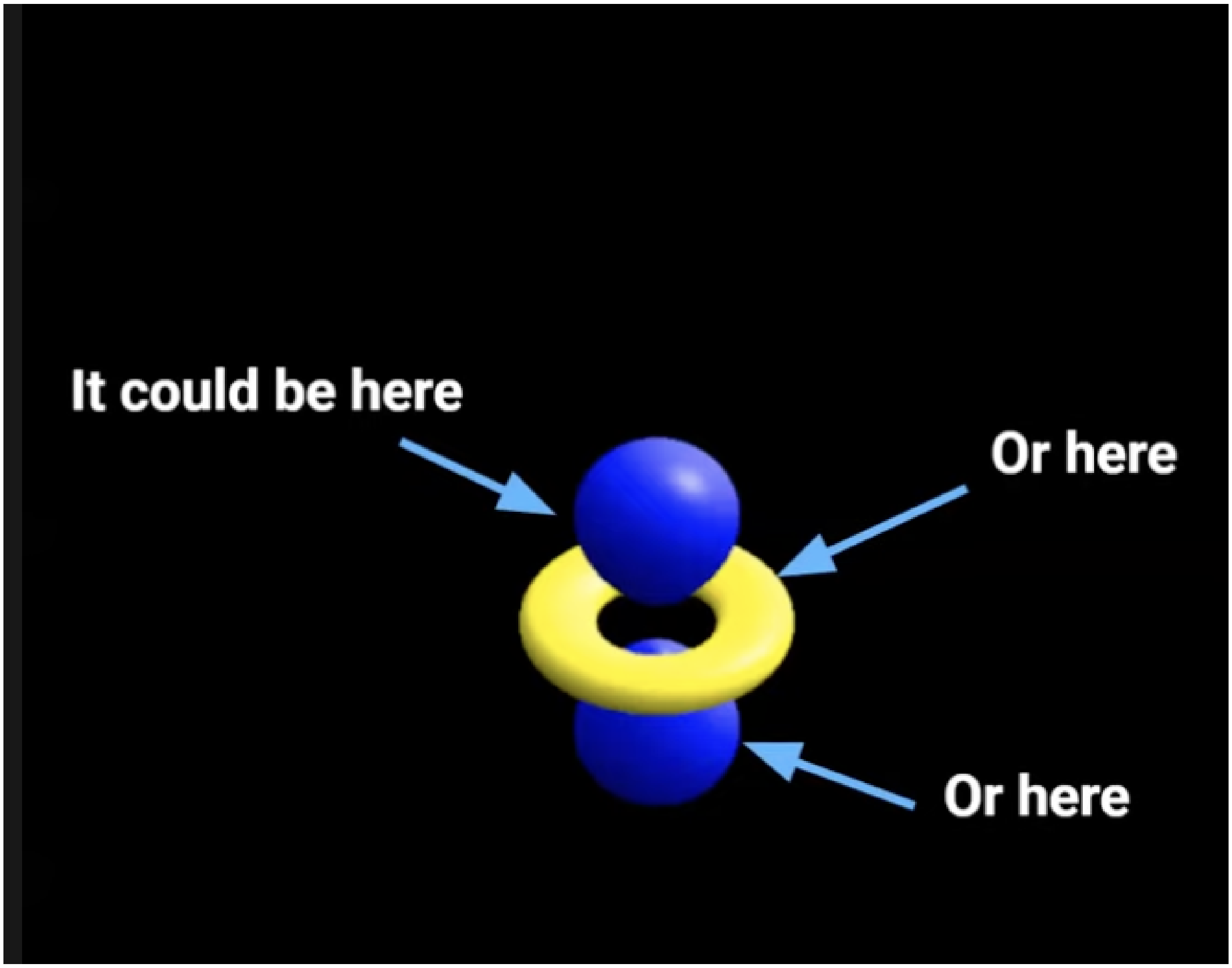
Two Principles of Q-Measurement:

1. Outcome of a q-measurement is often random
2. By observing (measuring) a q-state, we can change it

Part of designing a q-algorithm is to do it so that by the time it comes to measurement, you will get the right answer with very high or 100% probability - the ART of q-algorithms

Quantum Measurements are Probabilistic

Before we measure, we can only predict where an electron is **likely** to be found, not where it is exactly



When we make a measurement, we get one of these possible outcomes shown ABOVE

Solving Problems Using Quantum:

- Solving a Maze:
  - Normally, you would have to try each option and hope you find a good solution soon, given no prior experience
- Solving a Maze now using quantum computing…
  - Let’s create an equal superposition over all possible paths, this means we are in an equal combination of every single path
  - However, when we measure, we get one single path
  - Use interference to cause the bad paths to destructively interfere and the good paths to constructively interfere

    - Now, we are far more likely to get a “good path” rather than a “bad path”

Question/Answer Session:

- Classical laws can be derived from the quantum laws since the latter is a more fundamental basis of understanding
- Quantum Computers are noisy - the cooling system and pumps are what causes this noise
- Electron jumps through a “quantum jump” from one energy level to another energy level (discrete jumps, not continuous)
- Measurements are the only aspect of quantum mechanics that is probabilistic
- What counts as an observation in terms of quantum measurement:
    - Any interaction in which you learn about the state of the quantum particle counts as a measurement
- The art of designing a quantum algorithm is a system that produces the ideal quantum state at the end after interference and super position ends