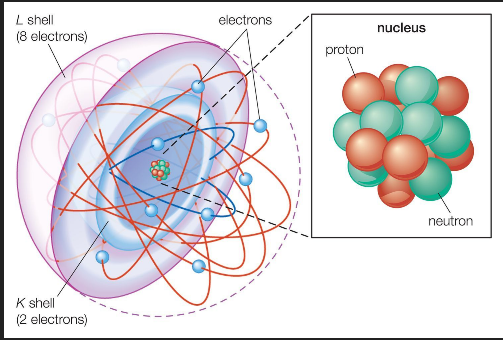
Quantum Computing

What is Quantum Computing?

- Technology that uses the laws of quantum mechanics to solve problems
- Encodes information using qubits
  - Qubits act as an artificial atom and can have a value of 0, 1, or anything in between

Why do we need Quantum Computing?

- Quantum computing can solve problems with a high degree of complexity that classical computers struggle with
  - Difficult for binary coded computers to model problems with lots of variables interacting in complex ways
  - Examples
    - Modeling behavior of individual atoms in a molecule
      - Different electrons interacting with one another
    - Detecting subtle patterns of fraud in financial transactions
    - Physics in a super collider

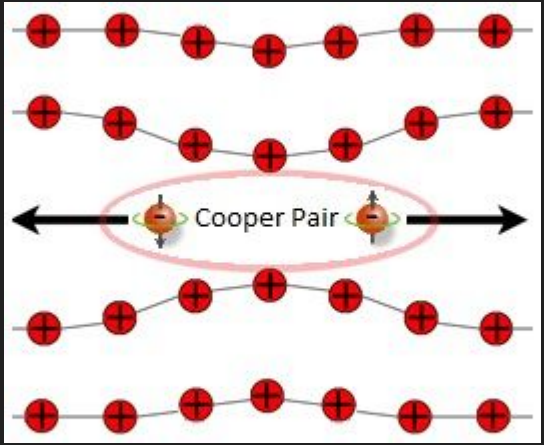


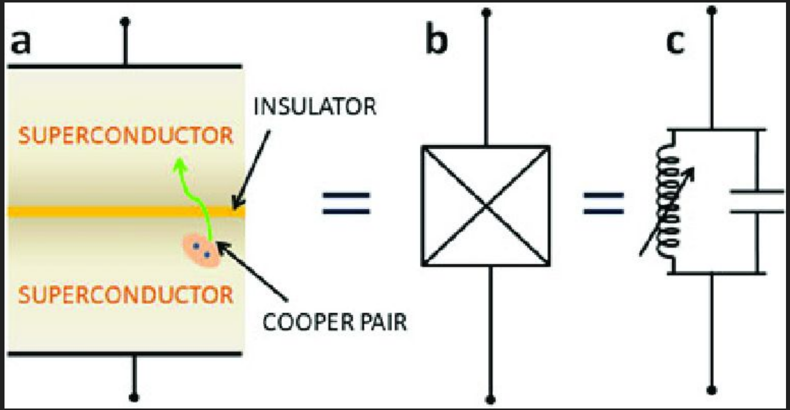
How does quantum computing work? (IBM)

- Quantum Hardware systems the size of a car
- Requires many cooling systems to keep superconducting processor at ultra cold temperatures
  - Close to absolute zero (-273 C), 1/100 degree above absolute zero
  - To avoid decoherence
    - Retain quantum states

Cooper Pairs

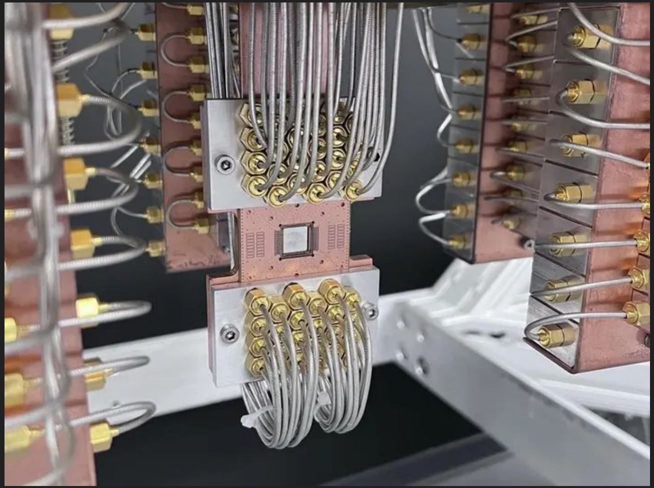
- At ultra low temperatures, electrons move without resistance, makes them superconductors
- Electrons pass through superconductors, match up and form Cooper Pairs
  - Cooper Pairs can carry a charge across barriers or insulators in a process called quantum tunneling
  - 2 superconductors placed on either side of an insulator form a Josephson Junction
    - (a) Josephson junction with Cooper pair

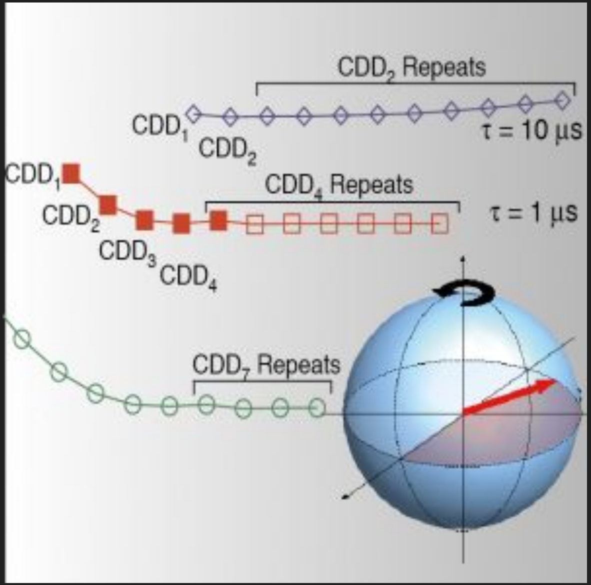




Control

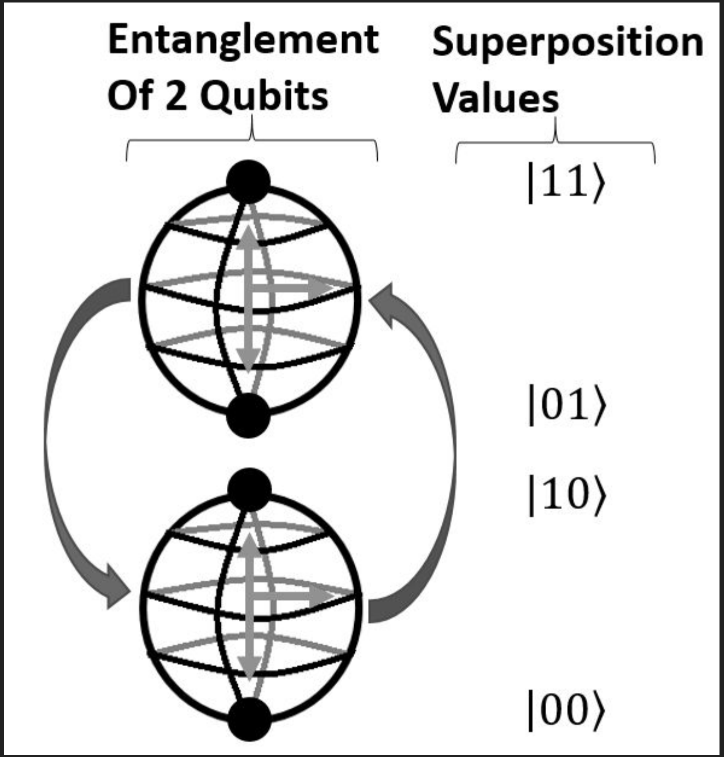
- Josephson junctions act as superconducting qubits
  - Quantum computer fires microwave photons at qubits to control behavior
    - Makes qubits hold, change,and read out individual units of quantum information





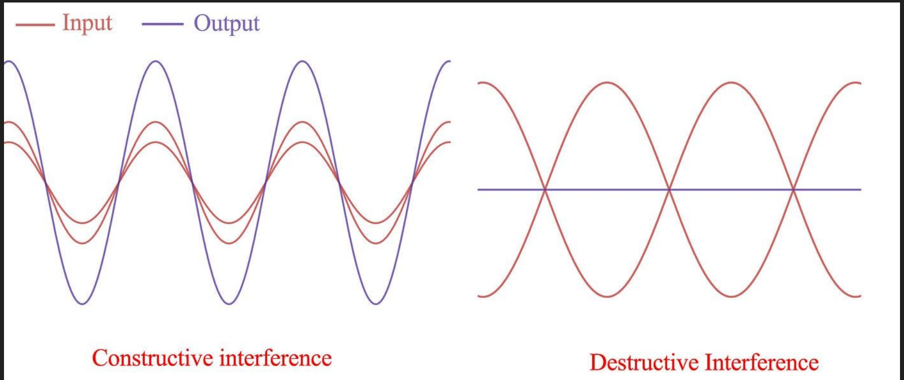
Superposition

- Qubits can place their quantum information in a state of superposition
  - Represents combination of all possible configurations of qubit
  - Groups of qubits in superposition can create complex multidimensional computational spaces
    - Can represent complex problems in new ways
- Quantum entanglement
  - When 2 qubits entangle, changes to one qubit directly impact the other



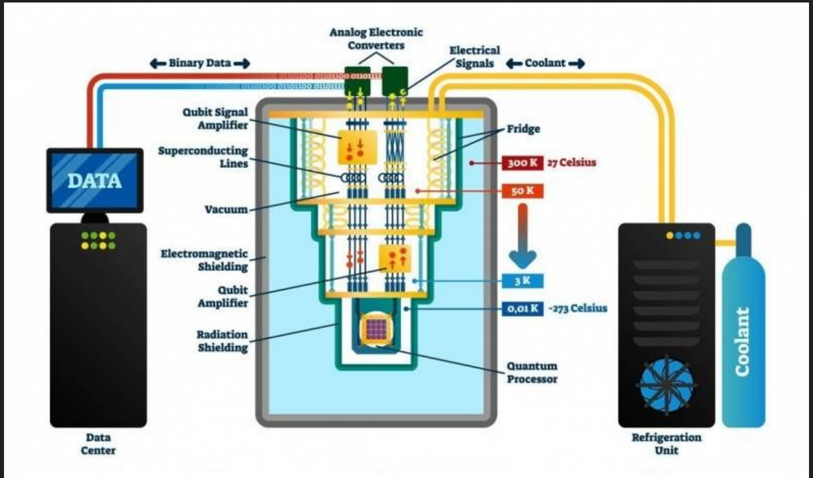
Interference

- In an environment of entangled qubits placed into the state of superposition, there are waves of probability
  - Probabilities of outcomes of a measurement of the system
  - Waves of probability can build on each other when:
    - Qubits peak at a particular outcome
    - Qubits cancel each other out when peaks and troughs interact
      - Forms of interferences



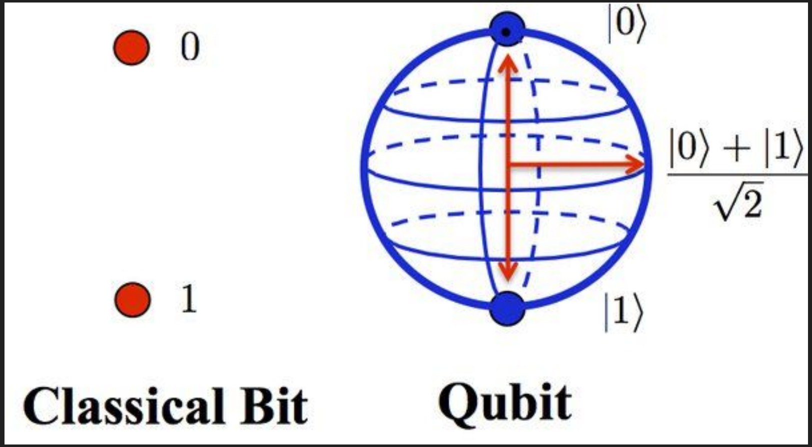
Computation of a Quantum Computer

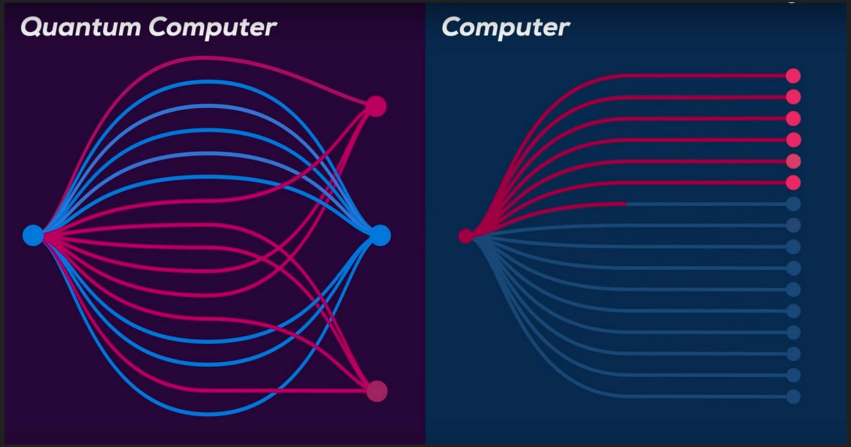
- Prepares superposition of all possible computational states
  - Quantum circuit prepared by a user uses interference selectively on components of the superposition according to an algorithm
  - Many possible outcomes cancelled out through interferences while other amplified
    - Amplified outcomes are solutions to computation



Quantum vs Classical Computing

- Classical
  - Transistors
  - Power proportional to the number of transistors
  - Easier to manufacture
    - More effective with everyday operations
- Quantum
  - Qubits
  - Power increases exponentially with number of qubits
  - Difficult to manufacture
    - No advantages with everyday operations



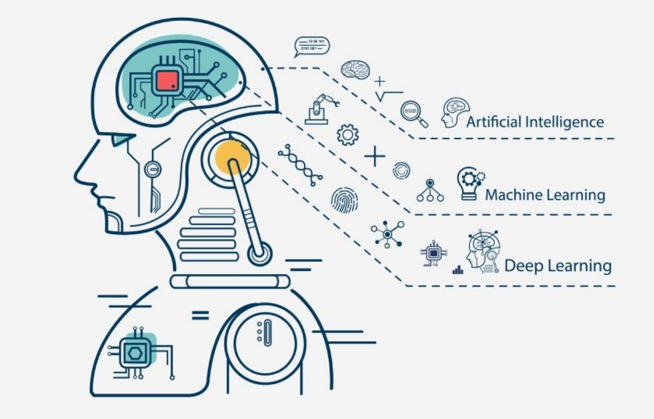


Advantages of Quantum Computing

- Chemical Simulation
    - Allows exploration of larger and more complex molecular structures
    - More accurate and detailed simulations
    - Methods such as Density Functional Theory, Hartree Fock Theory, and Post Hartree Fock Method

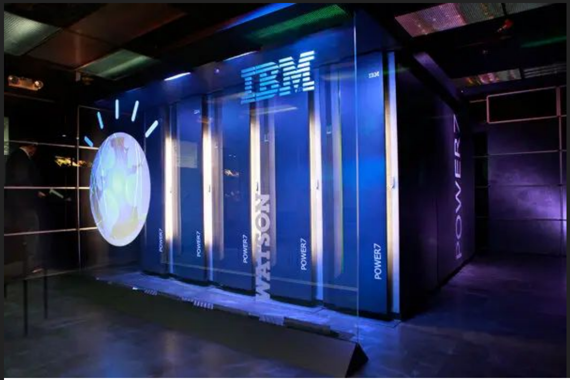
Advantages of Quantum Computing (continued)

- Optimization
  - Optimize routes for freight transportation, to reduce costs and boost customer satisfaction
- Machine Learning
  - Handle complexity and keep possibilities open to increase the scope of learning



Applications of Quantum Computing

- IBM
  - Quantum computing being used with AI
    - Advances deep learning and increases understanding of quantum mechanics
- JPMorgan Chase
  - Quantum computing can help model financial markets and gauge probabilities
  - Speed up the Monte Carlo Method of estimation



Applications of Quantum Computing (Continued)

- Auto Industry
  - Daimler Truck AG
    - Help cellular simulation and aging of batteries
    - AI autonomous vehicles and logistics
  - Volkswagen
    - Traveling Salesman problem
      - Find shortest route for hitting multiple cities
      - Traffic and travel optimization for buses

Applications of Quantum Computing (Continued)

- Post Quantum
  - Cyber security, quantum based encryption
- ColdQuanta
  - Cold atom quantum computing, to act as qubits
  - Support communications, gps, and signal processing apps
- IonQ
  - Simulations for electrolysis, deconstructing water into hydrogen and oxygen for hydrogen fuels

Sources

- https://www.ibm.com/topics/quantum-computing
- https://www.cbsnews.com/news/quantum-computing-advances-60-minutes/#:~:text=Quantum%20computing%20ditches%20transistors%20and,computer%20is%20a%20tough%20climb.
- https://builtin.com/hardware/quantum-computing-applications
- https://thequantuminsider.com/2023/06/19/advantages-of-quantum-computing/