Quantum Computing: Basic Definitions

1. Superposition: A probability
2. Entanglement: Distributed probability
3. Interference: Constructive or Destructive

Applications

1. Quantum Simulation
2. Optimization Problems
3. Cybersecurity

Models of Quantum Computing

- Gate Model: There is a collection of qubits which are entangled with each other and a bunch of gates which can perform operations on small numbers of these qubits. These gates, change the states of the qubits without measuring them.
- Measurement Based: Set a collection of qubits with an initial entangled state and then measuring qubits one by one during the computation.
- Adiabatic QC: Takes advantage of the fact that every system in physics always moves towards the minimum energy state. It poses the problems that want to be solved in such a way so that the minimum energy state of the quantum system is the answer to the problem. Mathematically, is equivalent to gate model.
- Quantum annealing: Also uses energy minimisation but it's not universal.
- Topological QC: This is the most theoretical. It builds its qubits from an entity in physics called a *Majorana zero-mode quasi-particle* which is a type of *non-abelian anyon*. Quasi-particles are created from the collected behaviour of many particles together, having particle-like properties despite not being actually real or fundamental ones. (e.g. an electron "hole"). In this model, the quasi-particles are predicted to be a lot more stable than other qubits because they are made from parts which are physically separated from each other, avoiding *noise* by being protected by an energy gap. Any perturbations of noise which have a lower energy than the energy gap is not felt by the quasi-particle.

Obstacles

- Decoherence: It's wanted that the qubits be entangled with each other and anything else. It is ever possible to make a working quantum computer with a large number of qubits, or will decoherence and noise ruin everything?
- Quantum Error Correction: This is an error correction scheme to make fault-tolerant quantum computers by using many entangled qubits together to represent one noise free qubit. Estimation: 100 to 1000 qubits for 1 logical qubit.

- Scalability

Physical implementations

- Superconducting QC: Currenty the most popular method. Their qubits are made from superconducting wires with a break in the supercounductor called a *Josephson junction*. The level system is encoded in pairs of the electric charge moving across the junction, specifically the frequency at which charges oscillate back and forth across the junctions. Other designs use the magnetic flux in a loop of wire or the phase across a wire as a two level system known as flux qubits or *phase qubits*.
- Quantum DOT QC: Also known as *Silicon spin QC*. Here the qubits are made from electrons or even groups of electrons and the two level system is encoded into the spin or charge of the electrons. On the chip, there's a small area where the electron is restricted called a *quantum dot*. Operations on the qubits are performed through voltages, microwaves or magnetic fields on the chip. The materials used as the semiconductor are: silicon, gallium arsenide, silicon carbide or even diamond.
- Linear Optical QC: They use photons of light as the qubits and they operate on these qubits using optical elements like mirrors, waveplates or interferometers. The two level system could have different designs, either a superposition of different paths a single photon takes through the chip or a superposition of different numbers of photons present in a path. They could be mannipulated applying a voltage to a path.
- Trapped ion QC: They use charged atoms as qubits. The atoms are ionised (have a missing electron) meaning they can be levitated and moved about with electromagnetic fields. Here the two level state is encoded in two specific energy levels of the atom which can be manipulated or measured with microwaves or laser beams.
- Colour centre QC: Also *Nitrogen vacancy QC*, are similar to Trapped ion QC in that the qubits are made from atoms. But insted of being trapped in an electromagnetic field, they are embedded in a gap of the material like nitrogen embedded in diamond or silicon carbide. Typically the two level system is the nuclear spins of the embedded atoms and they are entangled together with electrons.
- Neutral atoms in Optical Lattices: The qubits are atoms, and the design uses cold atom physics capturing neutral atoms like caesium into an optical lattice which is a crisscrossed arrangement of laser beams, which form energy wells shaped kind of like an egg box. These atoms are cooled down with lasers to a few millionths of a kelvin. There are number ways to encode the two level system: either the hyperfine energy level of the atom, the excited states or even Rydberg atoms. The atoms can be controlled and entangled with each other with lasers.
- Other approaches:
  - Electron on Helium Qubit
  - Cavity Quantum Electrodynamics

- Magnetic molecules
- Nuclear Magnetic Resonance QC