Bloch sphere

The Bloch sphere is a geometric representation used in quantum computing to visualize the state of a single qubit, the basic unit of quantum information. It provides a convenient way to understand and manipulate the quantum states of a qubit.

Here's a breakdown of how it works:

1. Representation of a Qubit State: In classical computing, a bit can be in one of two states: 0 or 1. In quantum computing, a qubit can exist in a superposition of both states simultaneously. The Bloch sphere provides a graphical representation of all possible states a qubit can be in.

2. Spherical Coordinates: The Bloch sphere is a sphere where the north and south poles represent the pure states $|0\rangle$ and $|1\rangle$, respectively. The equator represents superposition states, where the qubit has an equal probability of being in state $|0\rangle$ or $|1\rangle$. The points inside the sphere represent mixed states, which are probabilistic combinations of $|0\rangle$ and $|1\rangle$.

3. Quantum Gates and Operations: Quantum gates, which are analogous to classical logic gates, manipulate the state of qubits. These gates correspond to rotations on the Bloch sphere. For example, a Pauli-X gate flips the state of a qubit, which corresponds to a rotation around the x-axis of the Bloch sphere by π radians.

4. Measurement: When a qubit is measured, its state collapses to either $|0\rangle$ or $|1\rangle$ with certain probabilities determined by the amplitudes of its superposition state. This collapse corresponds to a projection onto either the north or south pole of the Bloch sphere.

Spherical coordinate systems

In spherical coordinate systems, the polar angle and azimuthal angle are two angular coordinates used to specify the position of a point in three-dimensional space. These angles are used in various fields such as physics, engineering, and astronomy to describe the direction or orientation of an object relative to a reference point or axis.

1. Polar Angle (θ):

The polar angle, denoted by θ (theta), measures the angle formed between the positive z-axis and the vector pointing to the point of interest.

It ranges from 0 to π (0 to 180 degrees), where 0 corresponds to the positive z-axis direction (north pole) and π corresponds to the negative z-axis direction (south pole).

In the context of the Bloch sphere in quantum computing, the polar angle represents how "north" or "south" the qubit state vector points relative to the reference states $|0\rangle$ and $|1\rangle$.

2. Azimuthal Angle (ϕ):

The azimuthal angle, denoted by ϕ (phi), measures the angle formed in the xy-plane between the positive x-axis and the projection of the vector onto the xy-plane.

It ranges from 0 to 2π (0 to 360 degrees), representing a full circle around the z-axis.

In the context of the Bloch sphere, the azimuthal angle represents the rotation of the qubit state vector around the z-axis. It determines the phase of the superposition state relative to the reference states $|0\rangle$ and $|1\rangle$.

The polar angle determines how far "up" or "down" a point is from a reference axis (the z-axis in Cartesian coordinates), while the azimuthal angle specifies the rotation around that axis in the xy-plane. Together, these two angles uniquely specify the position of a point in spherical coordinates.