Greenberger-Horne-Zeilinger (GHZ)

The Greenberger-Horne-Zeilinger (GHZ) state is a fascinating example of quantum entanglement, a cornerstone of quantum mechanics.

The GHZ state (Greenberger-Horne-Zeilinger state) is a specific type of entangled state involving multiple qubits (quantum bits).

- In a 3-qubit GHZ state, all three qubits are either in state 0 (|000>) or state 1 (|111>), perfectly correlated.

  Explanation:

Imagine flipping three coins. You want them to all land on heads or all tails (the GHZ state). You perform many flips, discarding results where the coins don't match (not GHZ) and keeping only those where all three land on the same side (the desired GHZ state). This "filtering" is similar to the projection post-selection technique.

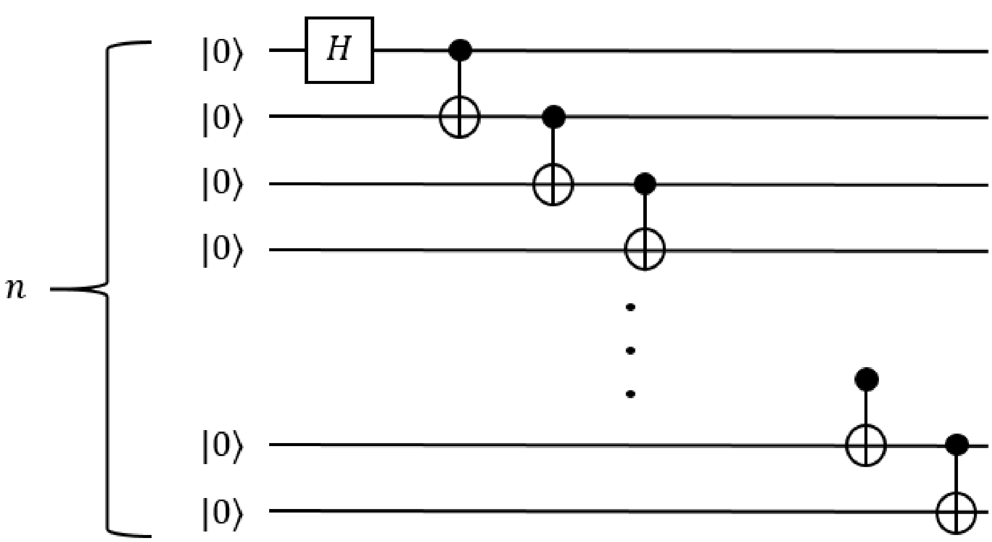
Let's delve deeper into its properties, applications, and challenges.

Properties:

- **Multi-Qubit Entanglement:** Unlike Bell states involving two qubits, the GHZ state involves entanglement between **multiple qubits**. A common example is a 3-qubit GHZ state, represented as:
- **Three- qubits,maximally entangled :**

  ```
  |GHZ> = (|000> + |111>) / sqrt(2)
  ```

  Here, all three qubits are either in the state |0> (0) or |1> (1), perfectly correlated. Measuring one qubit instantly reveals the state of the others, regardless of distance.



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Explanation of the circuit:

- **GHZ states are Entangled states that consist of at least 3 qubits.**
- **Creating n-qubits entangled states is possible with an H gate and (n-1) CNOT gates.**

1. **Hadamard Gates:** The first Hadamard gate (H) prepares the first qubit in a superposition state of |0> and |1>. The second and third Hadamard gates do the same for the second and third qubits, respectively.
2. **Controlled-NOT Gates (CNOT):** The CNOT gates create the entanglement between the qubits. The first CNOT gate uses the first qubit as the control qubit and the second qubit as the target qubit. If the control qubit is |1>, the CNOT flips the target qubit. Otherwise, it leaves the target qubit unchanged.

The second CNOT gate uses the second qubit as the control qubit and the third qubit as the target qubit. It essentially performs the same operation based on the state of the second qubit.

As a result of these gates, all three qubits become entangled in the GHZ state. Measuring any one qubit will instantly determine the state of the others.

- **Non-local Correlation:** This correlation is **non-local**. Even if the qubits are separated by vast distances, a measurement on one instantaneously determines the state of the others, defying classical physics where information transfer has a speed limit.
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Applications:

- **Quantum Key Distribution (QKD):** GHZ states can be used for ultra-secure communication through QKD. The eavesdropping attempt by a third party would disrupt the entanglement, alerting legitimate users.
- **Quantum Teleportation:** Teleportation of quantum information becomes possible with GHZ states. By sharing a GHZ state and performing specific operations on one half along with classical communication, the state of another qubit can be "teleported" instantaneously.
- **Quantum Error Correction:** GHZ states are valuable for implementing error correction schemes in quantum computation. By encoding information across multiple entangled qubits, errors can be detected and potentially corrected.

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Challenges:

- **State Preparation:** Creating a perfect GHZ state is challenging due to factors like qubit decoherence (loss of quantum information) and limited control capabilities. Local preparation requires sophisticated techniques and is susceptible to errors. Cloud-based quantum computers might offer advantages with their potentially larger number of qubits and advanced control systems.
- **Scalability:** As the number of qubits involved increases, preparing and maintaining the GHZ state becomes significantly more complex. Techniques and hardware advancements are needed for large-scale applications.
- **Experimental Verification:** While the theoretical framework of the GHZ state is well-established, experimentally verifying its properties with high accuracy remains an ongoing challenge.

Future:

- **Scalability:** Creating and maintaining the GHZ state with a larger number of qubits remains a challenge. Techniques and hardware advancements are needed for large-scale applications.
- **Experimental Verification:** While the theoretical framework is well-established, experimentally verifying its properties with high accuracy is an ongoing pursuit.
- **Quantum Computing:** GHZ states are fundamental for various quantum algorithms and protocols. As quantum computers become more powerful, the applications will likely expand significantly.

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EPR theorem (Einstein, Podolsky and Rosen)(1935)

The EPR (**Einstein, Podolsky and Rosen)** theorem says that quantum mechanics does not provide a complete description of an individual quantum system. This result, commonly known as the EPR paradox.

The GHZ’s theorem says that the EPR hypotesis contradict quantum mechanics.