Summary of Quantum Galton Boards:

1. Introduction:

A **Classical Galton board (CBG)** is a machine that shows how randomness works. When we drop balls through a triangle of pegs, they bounce left or right randomly but in equal probability. There is more probability to get to the centre than the sides so most balls land in the center and form a bell curve. It demonstrates the binomial distribution of random events.This is also known as **random walk**.

The **Quantum Galton Board (QGB)** is the quantum version of this machine, and it shows how the quantum world is *not* random in the same way. It is also known as the **Quantum Walk.** It uses a tiny quantum particle (like an electron or a photon known as a **Walker**) instead of a ball. This particle operates on the principles of superposition (It can exist in multiple places at once) and interference (its overlapped paths can add up or cancel out like waves). This document provides a summary of the concepts behind the QGB and the methods for its implementation.

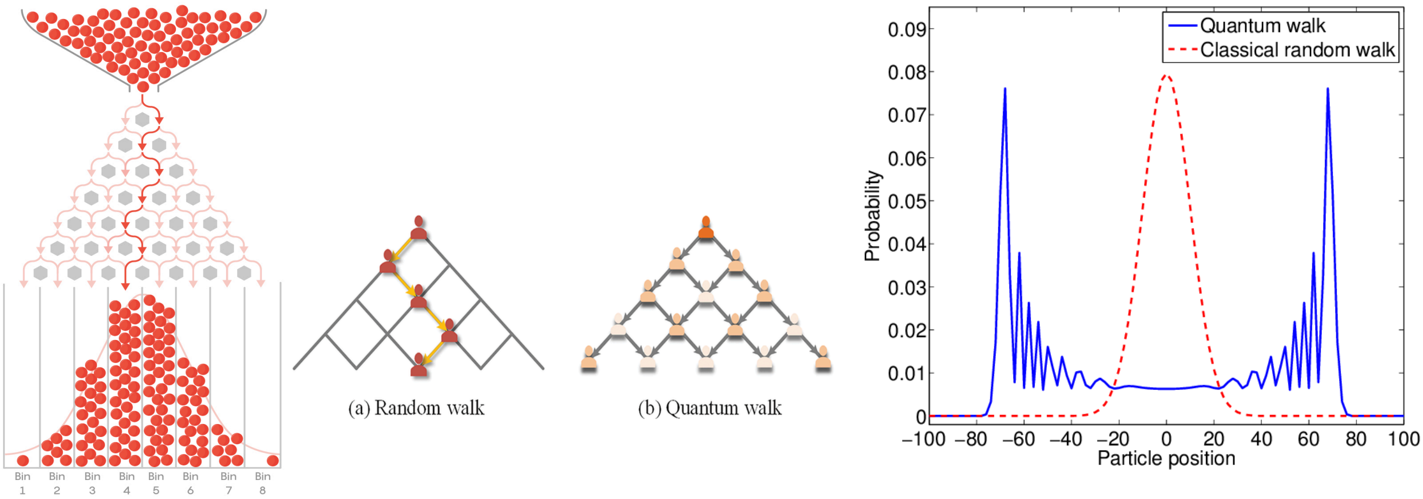

Fig 1: A group of images illustrating (a) a Classical Galton Board, (b) a comparison of Classical and Quantum Galton Boards, and (c) a comparison of the probability distributions resulting from classical and quantum walks.

2. Comparison of CGB and QGB:

Feature	Classical Random Walk (CGB)	Quantum Walk (QGB)
The "Walker"	A physical object (e.g., a ball).	A quantum particle (e.g., a photon or electron).
The Process	**Stochastic (Random)**: The walker randomly chooses left or right at each step.	**Deterministic (Rule-Based)**: The walker's path is perfectly predictable if we know the rules.
Governing Principle	Classical Probability.	**Superposition & Interference**.
Behavior at a "Peg"	It must choose one path (either left or right).	It takes all possible paths at the same time.
Spreading Speed	**Slow**: The final spread is proportional to the square root of the number of steps.	**Fast**: The final spread is directly proportional to the number of steps.
Final Distribution	A **Bell Curve** (Binomial Distribution). Most walkers end up in the center.	An **Interference Pattern**. Walkers are most likely to be found at the edges, not the center.

Table 1: Classical Walk vs Quantum Walk

3. Mechanism of Quantum Walk / QGB:

A QGB uses quantum walk in a system similar to CGB. It uses quantum particles and a series of "quantum coins" and "shift" operations. At each step (peg), a "quantum coin" operation is applied to the walker. This is a unitary transformation (often a Hadamard gate in quantum computing) that puts the walker's internal state (e.g., spin or polarization) into a superposition. After this, a "shift" operator moves the walker to the left or right depending on its internal state. This gives the characteristic interference patterns of a quantum walk.

4. How to build a QGB:

There are a few different ways scientists can build a Quantum Galton Board. Here are the most common methods.

4.a. Using Light Beams:

- **On a Tiny Chip:** Scientists can build it on a small chip, like a computer chip, using a network of **directional couplers** or **beam splitters** that act as the "pegs." When a light particle hits a splitter, it's guided to go down both the left and right paths at the same time. The final position of the photons is measured by an array of single-photon detectors at the output of the circuit.
- **On a Lab Table:** You can also build this using regular-sized mirrors and lenses on a large table. It works the same way but is much bigger and easier to adjust.

4.b. Using a Quantum Computer:

We can also create a perfect simulation of QGB using a quantum computer. To do this, we use the basic building blocks of quantum computing:

- **Qubits:** A register of qubits is used to represent the position of the walker and its internal "coin" state.
- **Quantum Gates:**
  - An **X gate** is used to initialize the "ball" (the walker) at a starting position.
  - **Hadamard gates** are used to implement the "quantum coin" flip, putting the coin qubit into a superposition.
  - **Controlled-SWAP (CSWAP) gates** or a series of controlled-NOT (CNOT) gates are used to implement the conditional "shift" operation, moving the walker based on the state of the coin qubit.
- **Measurement:** The final positions of the walkers are determined by measuring the qubits that represent the position space.

The paper "Universal Statistical Simulator" (arXiv:2202.01735v1) provides a detailed explanation for constructing a QGB on a quantum computer and is claimed to be exponentially faster than a classical simulation.

4.c. Other Methods:

- **Using Floating Atoms:** They can use lasers to trap and hold tiny, individual atoms in place. They then use other lasers to command these atoms to perform a quantum walk.
- **Using a Special MRI Machine:** A technique called NMR, which is like a small-scale version of a hospital MRI, can be used to control molecules and make them behave like walkers on a quantum board.

5. Applications:

- **Quantum Computing:** QGB can give solutions to certain computational problems faster.
- **Quantum Simulation:** QGBs can be used to simulate and study complex quantum phenomena and the behavior of quantum systems.
- **Fundamental Physics:** QGB can be used to explore the fundamental principles of quantum mechanics and the transition from the quantum to the classical world.