PASQAL

QUANTUM DISCOVERY

Superposition, entanglement, and interferences

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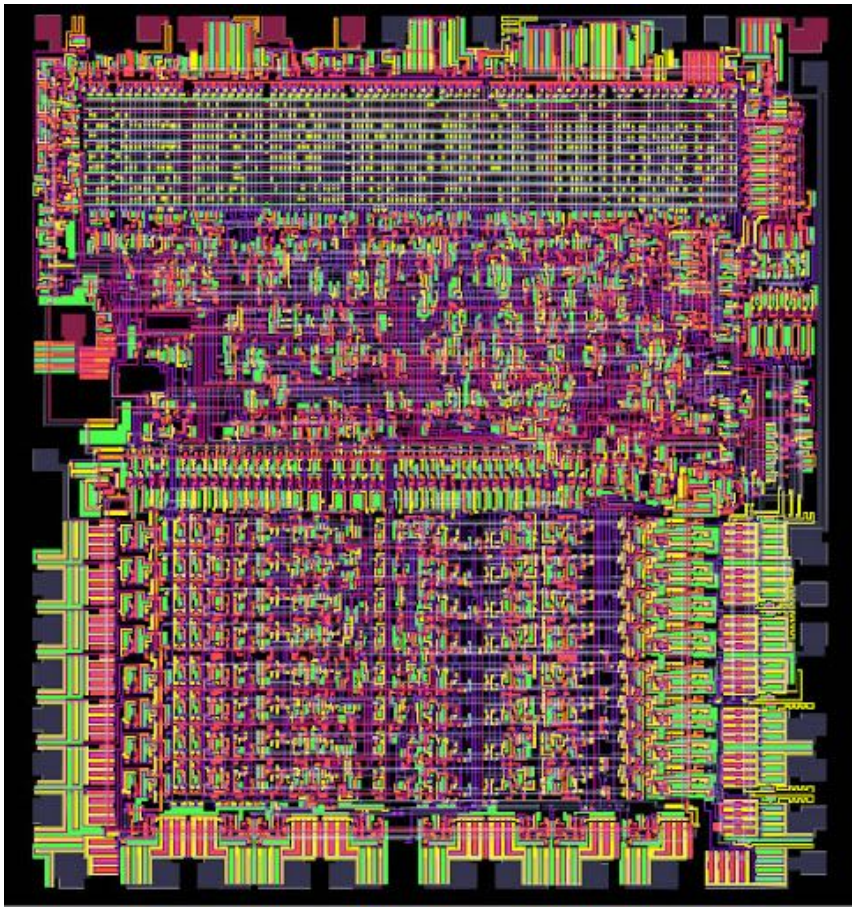
Classical computing

Microprocessor chip



Central processing unit (CPU)

- A transistor is a physical realization of a bit
- CPUs are integrated circuits made of billions of transistors
- At processor level, programs are series of instructions in the form of logical operations (AND, OR, XOR, NOT, *etc*)

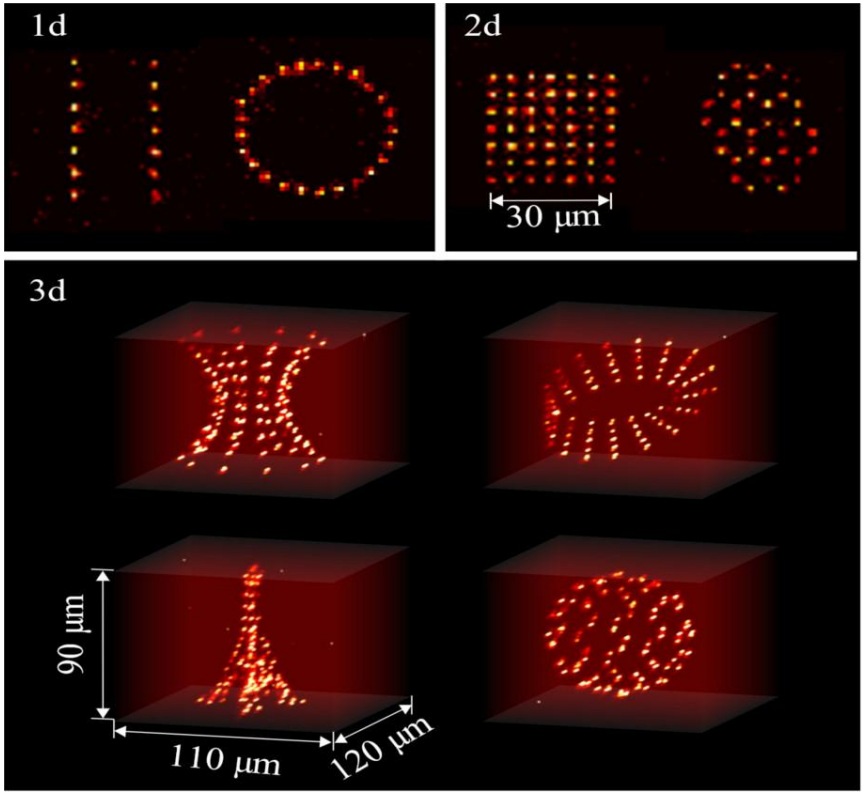
Quantum computing

Quantum processing unit (QPU)

Quantum processing units exploit three phenomena:

- **Superposition:** to describe the state of a quantum bit or an ensemble of quantum bits at any time
- **Entanglement:** to understand some special correlations quantum bits exhibit when they interact with each other
- **Interference:** to understand what is going on when acting on quantum bits either globally (i.e. analog quantum computing) or locally (i.e. digital quantum computing)

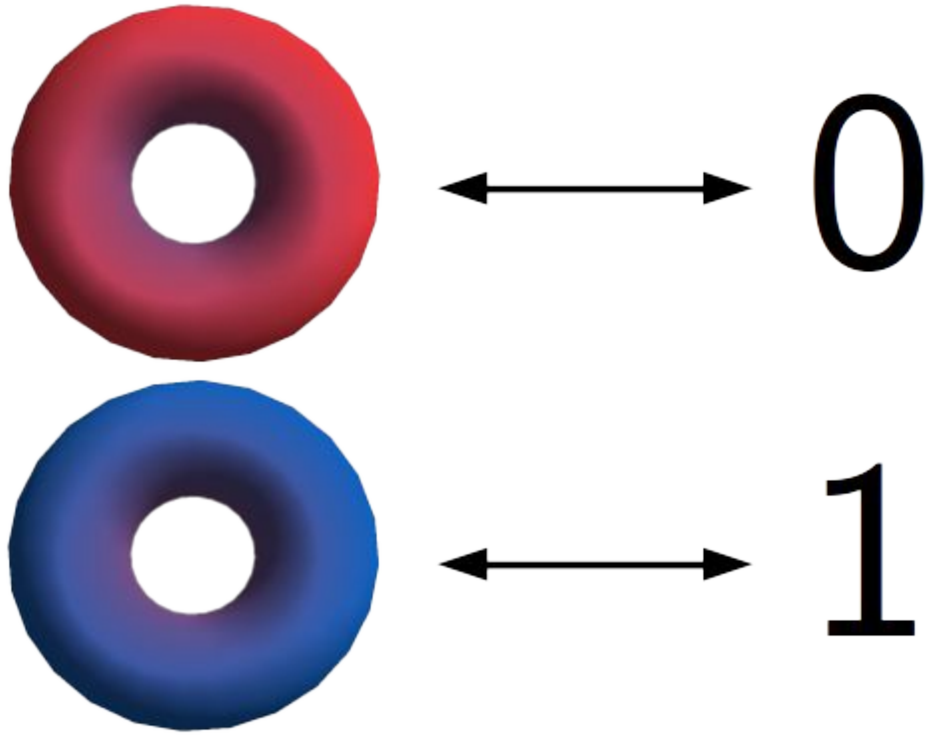
Neutral atom arrays



Superposition

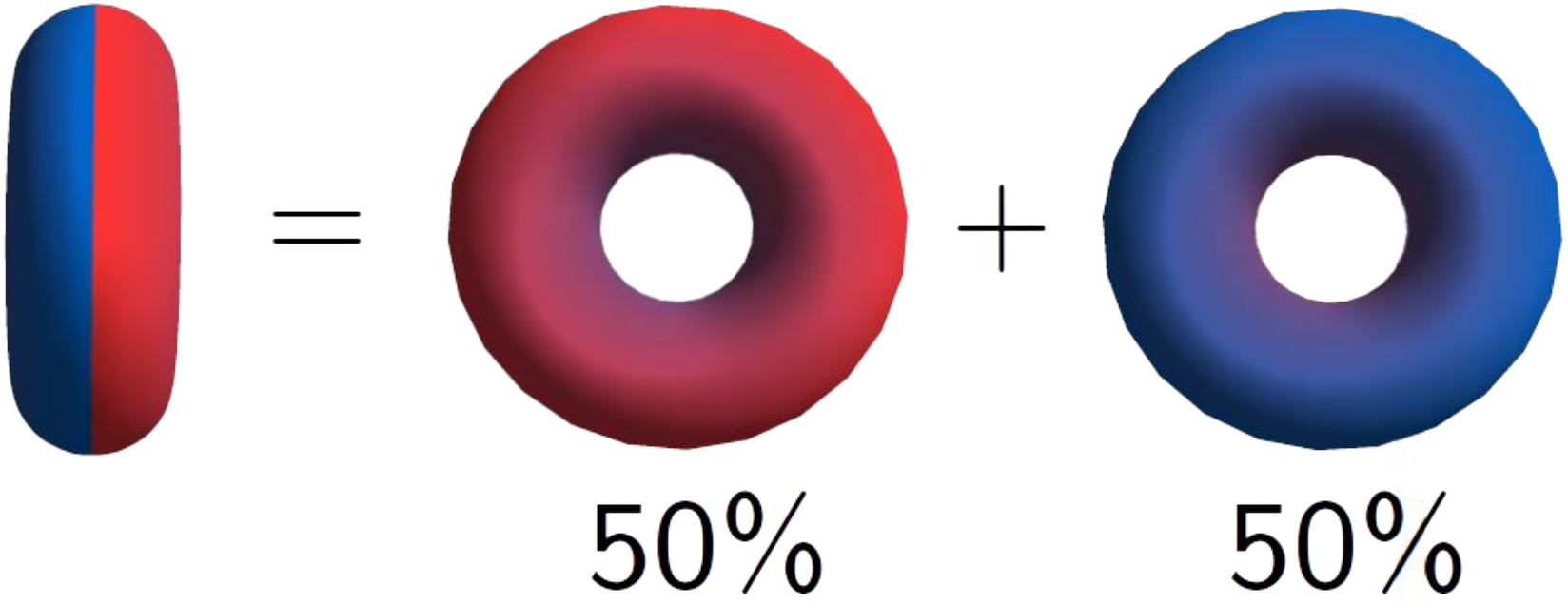
Superposition

Classical bit



Superposition

Superposition principle



Superposition

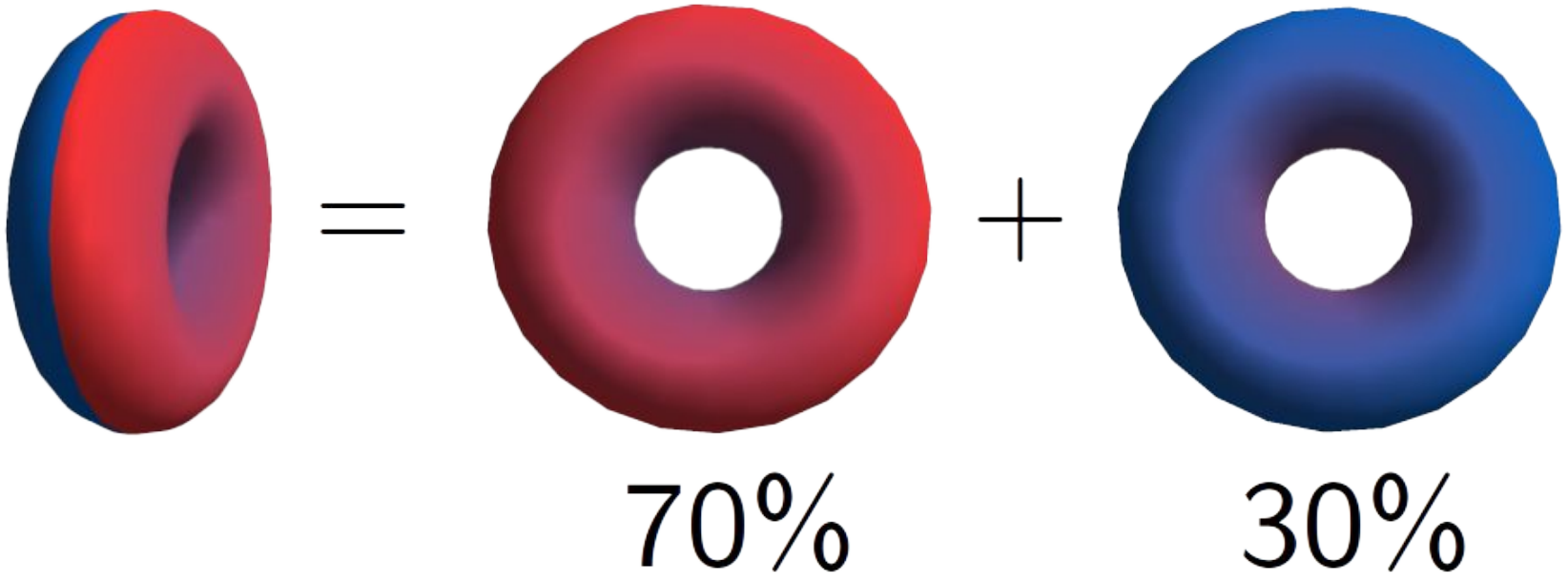
Measurement

50%

50%

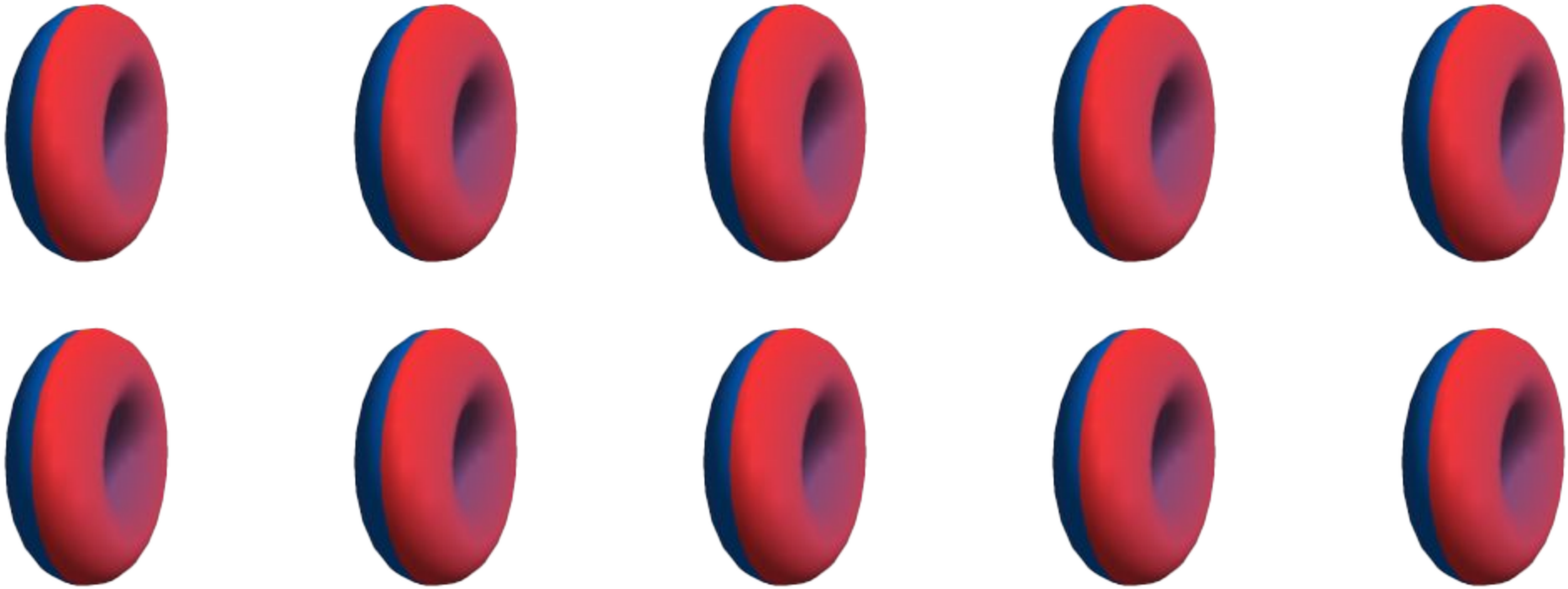
Superposition

Superposition principle



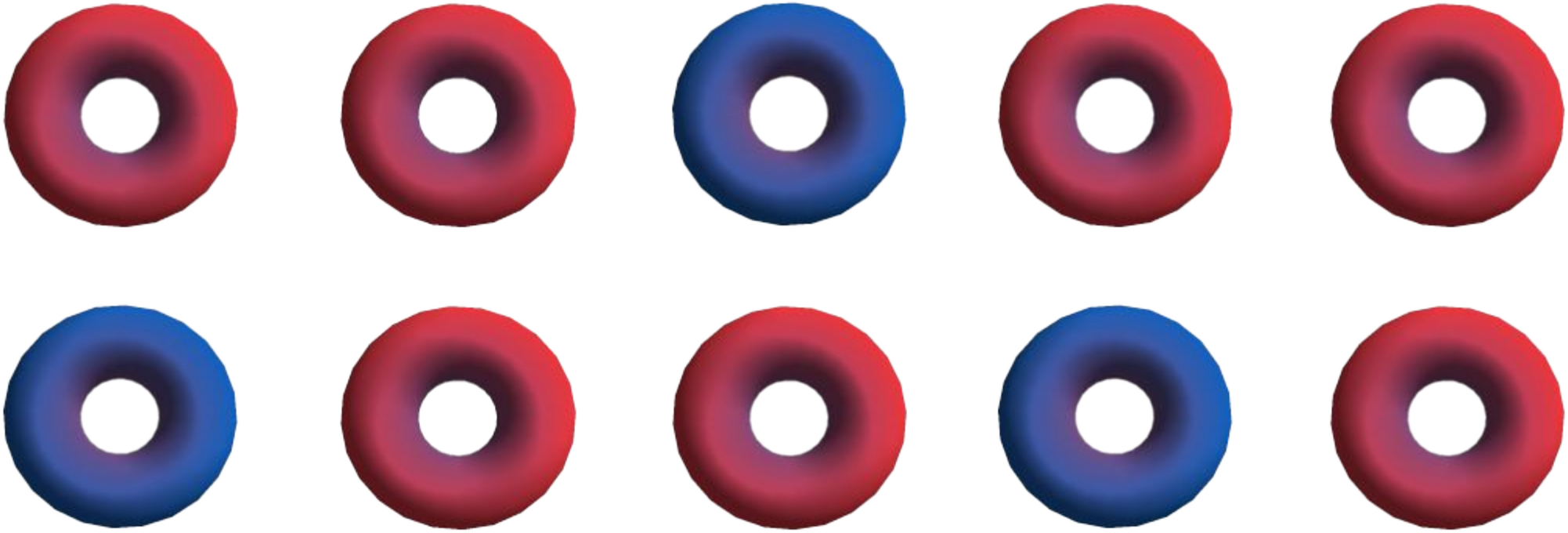
Superposition

Multiple qubits



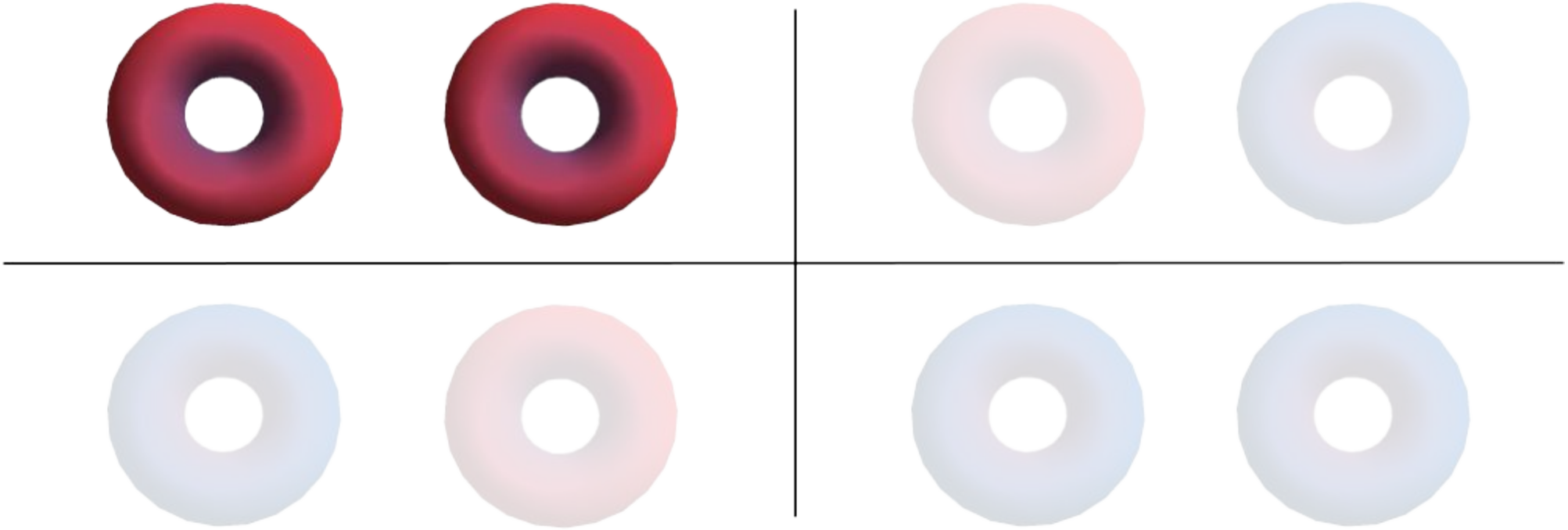
Superposition

Multiple qubits



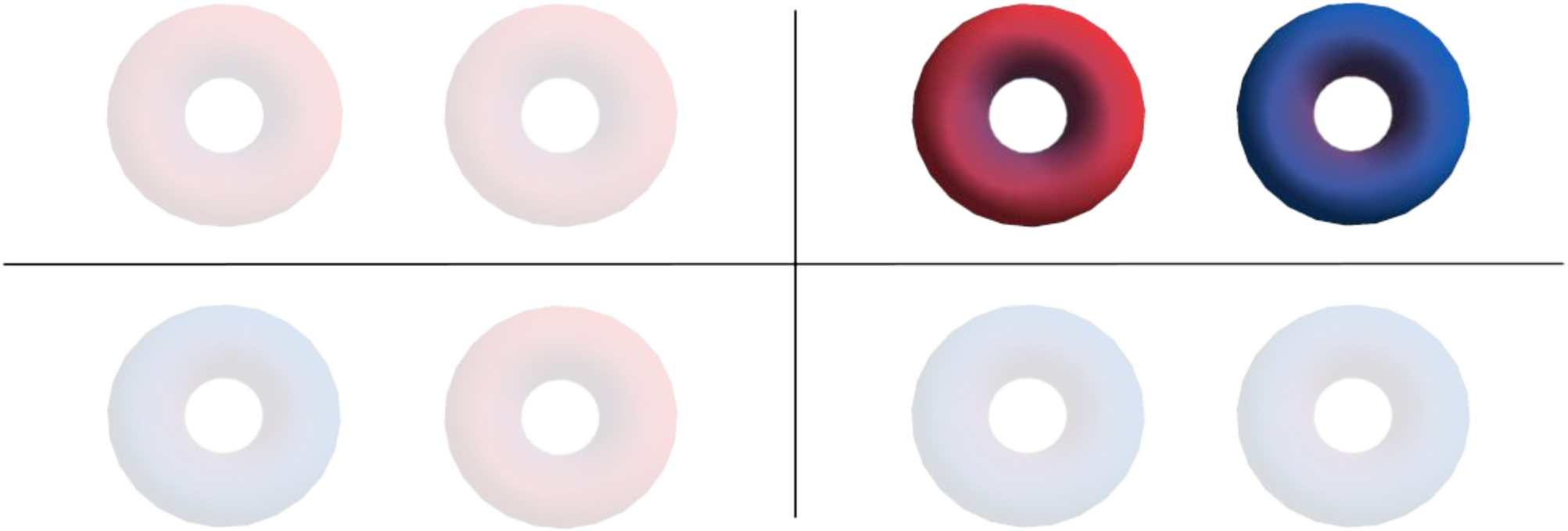
Superposition

Two classical bits



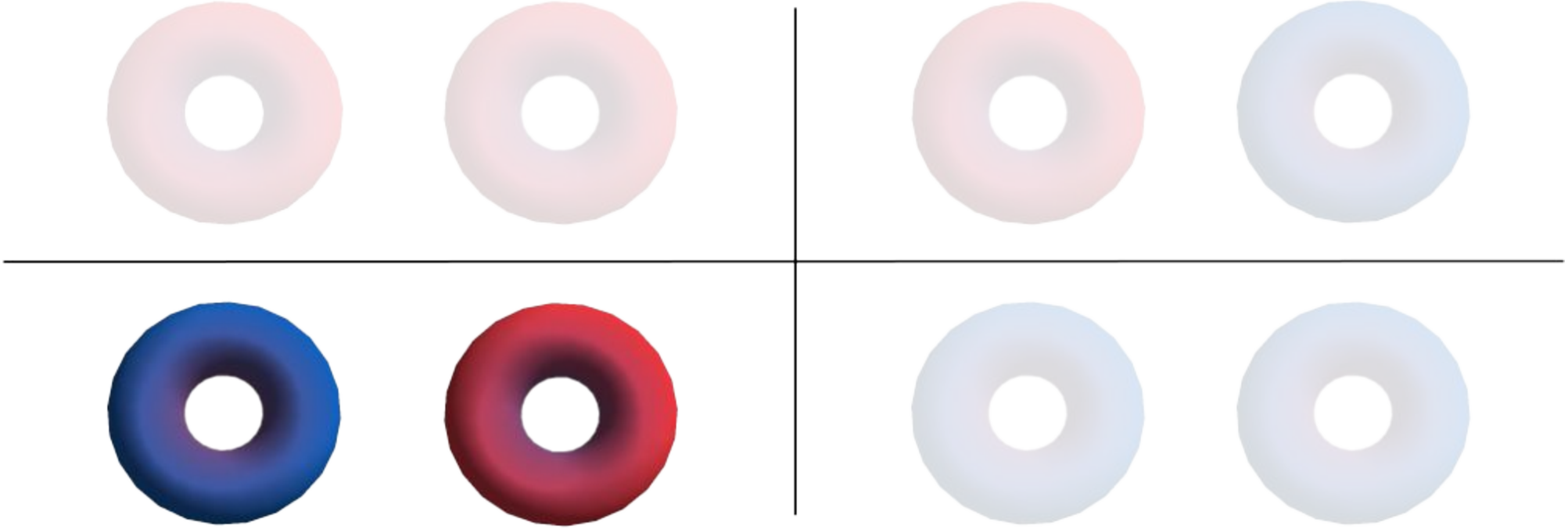
Superposition

Two classical bits



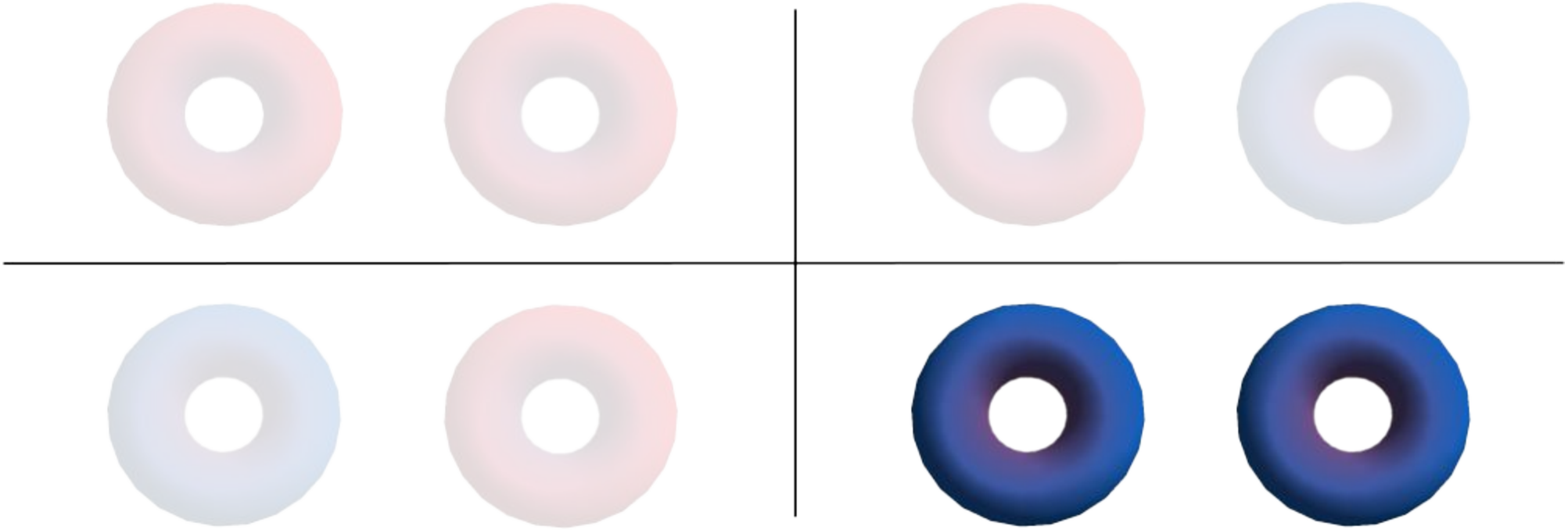
Superposition

Two classical bits



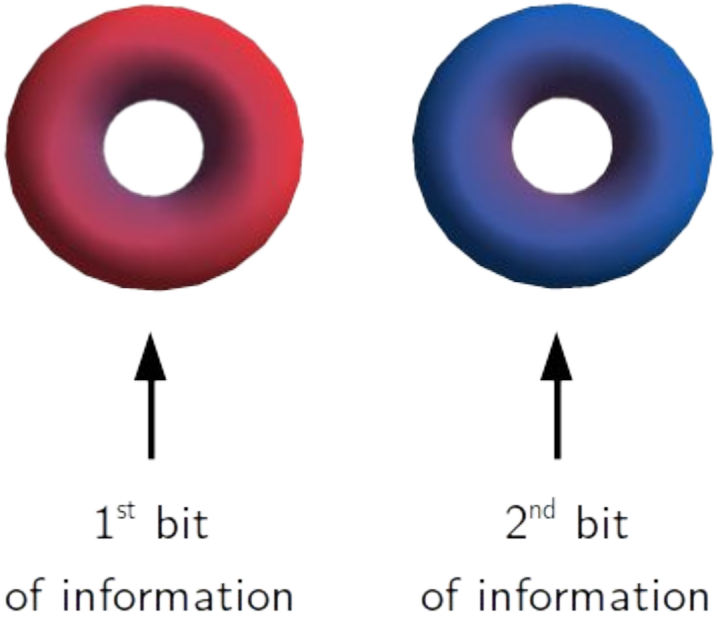
Superposition

Two classical bits



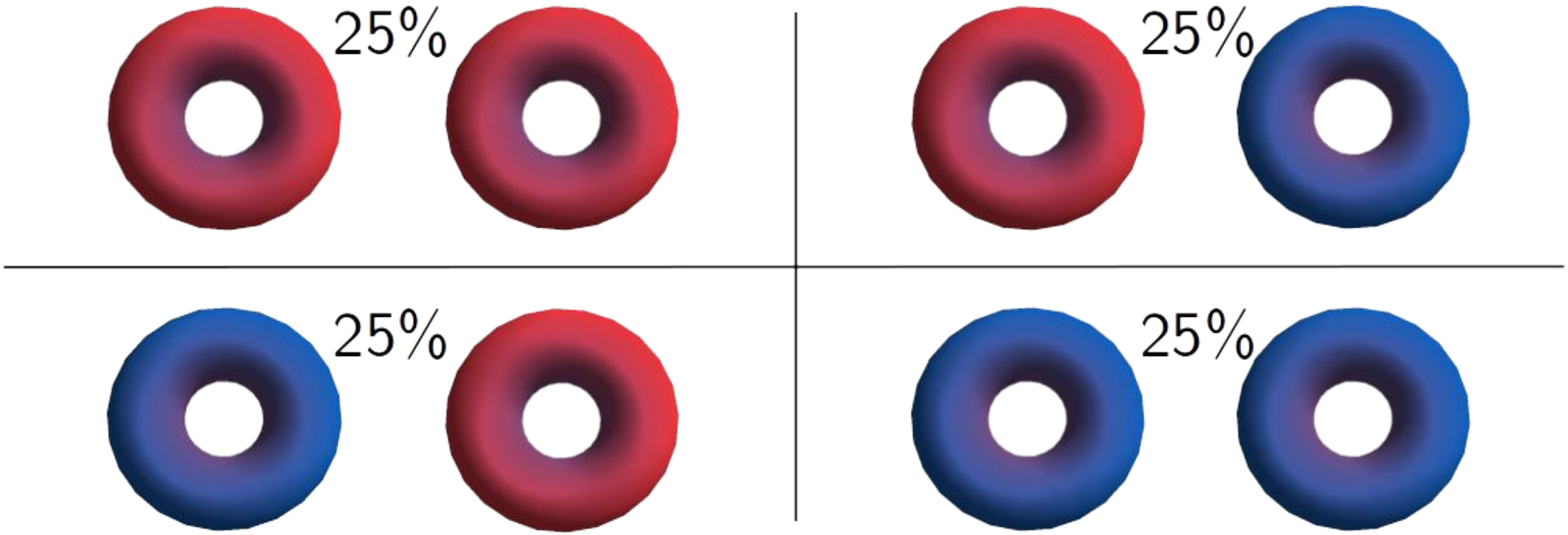
Superposition

Two classical bits



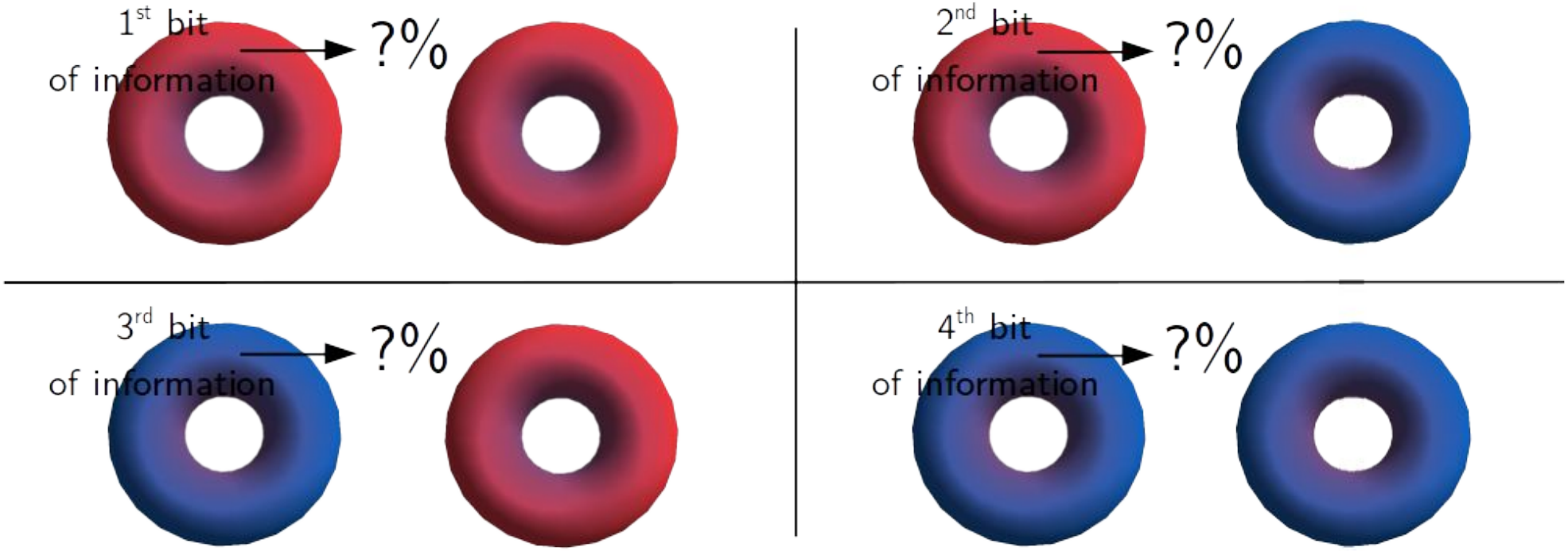
Superposition

Two quantum bits



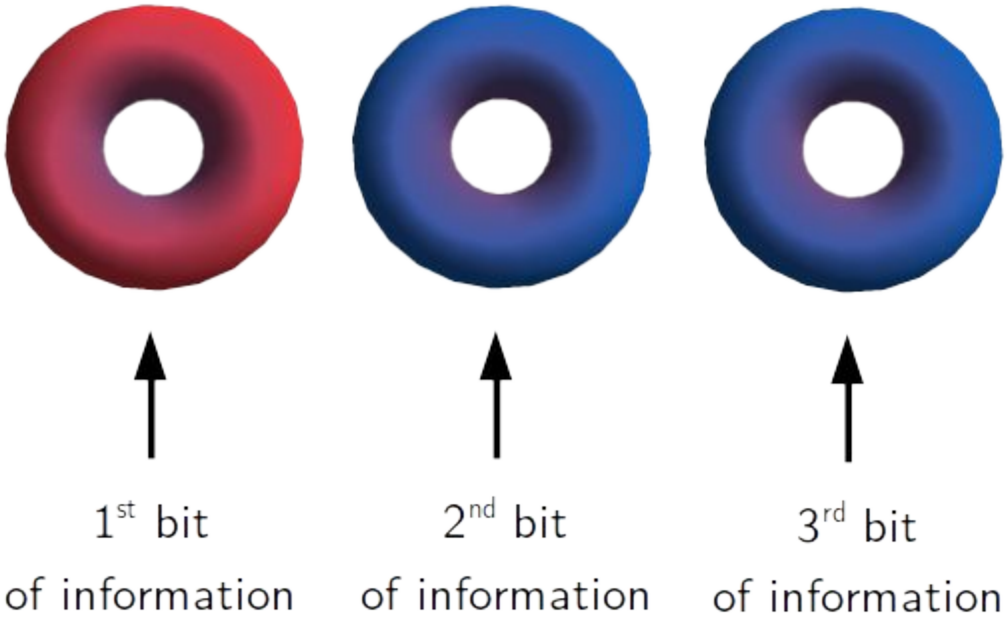
Superposition

Two quantum bits



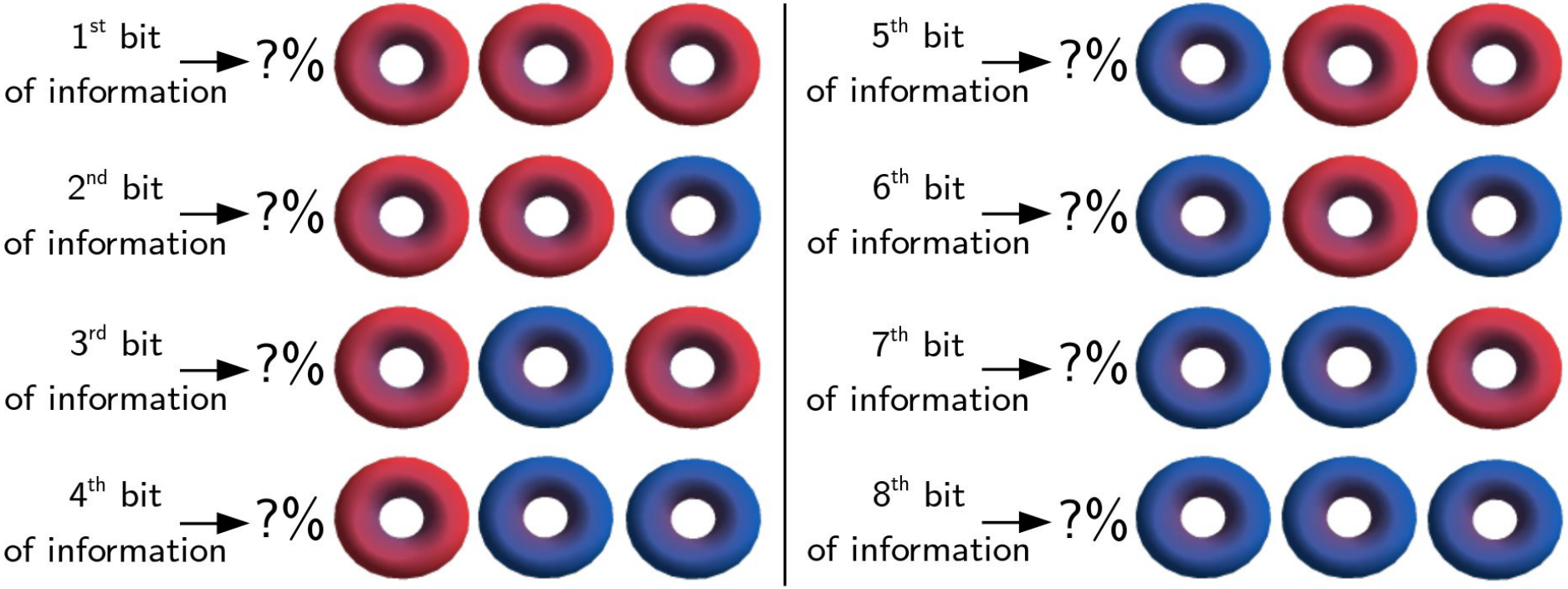
Superposition

Three classical bits



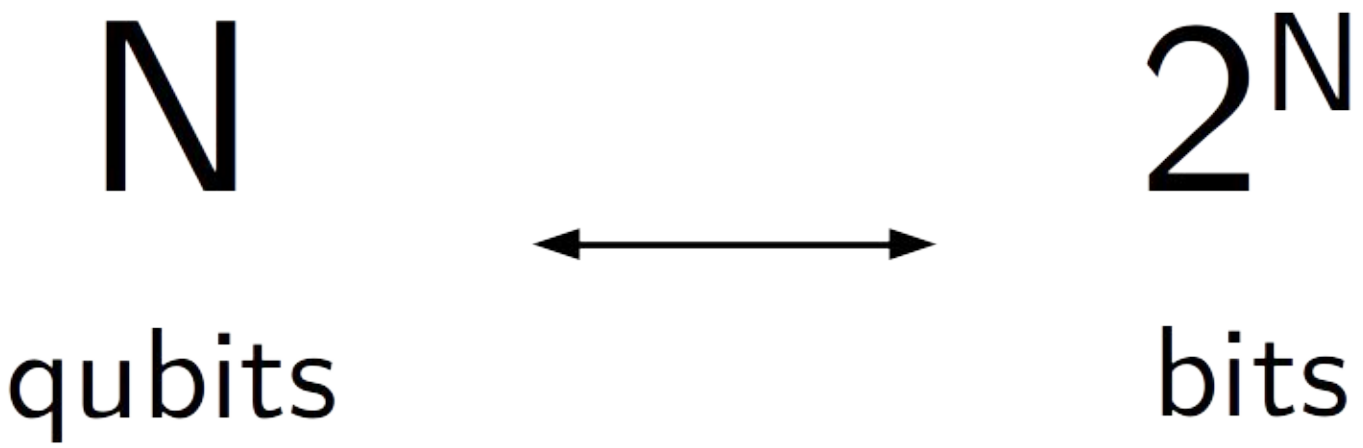
Superposition

Three quantum bits



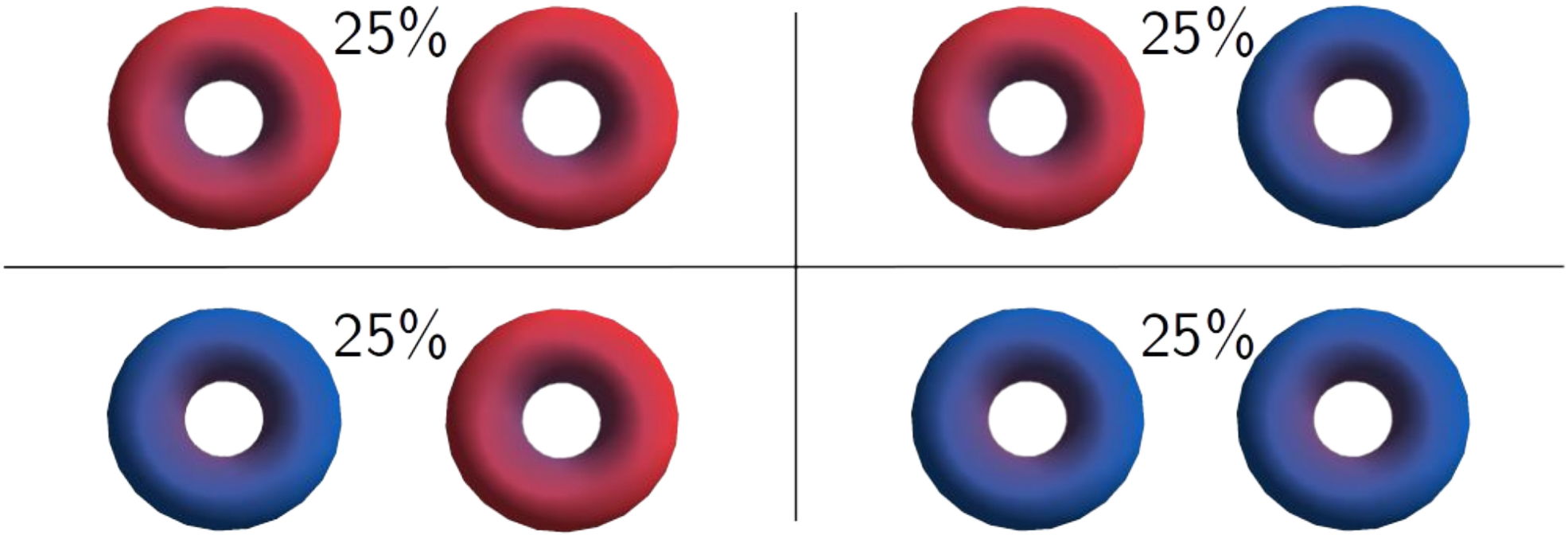
Superposition

Memory space



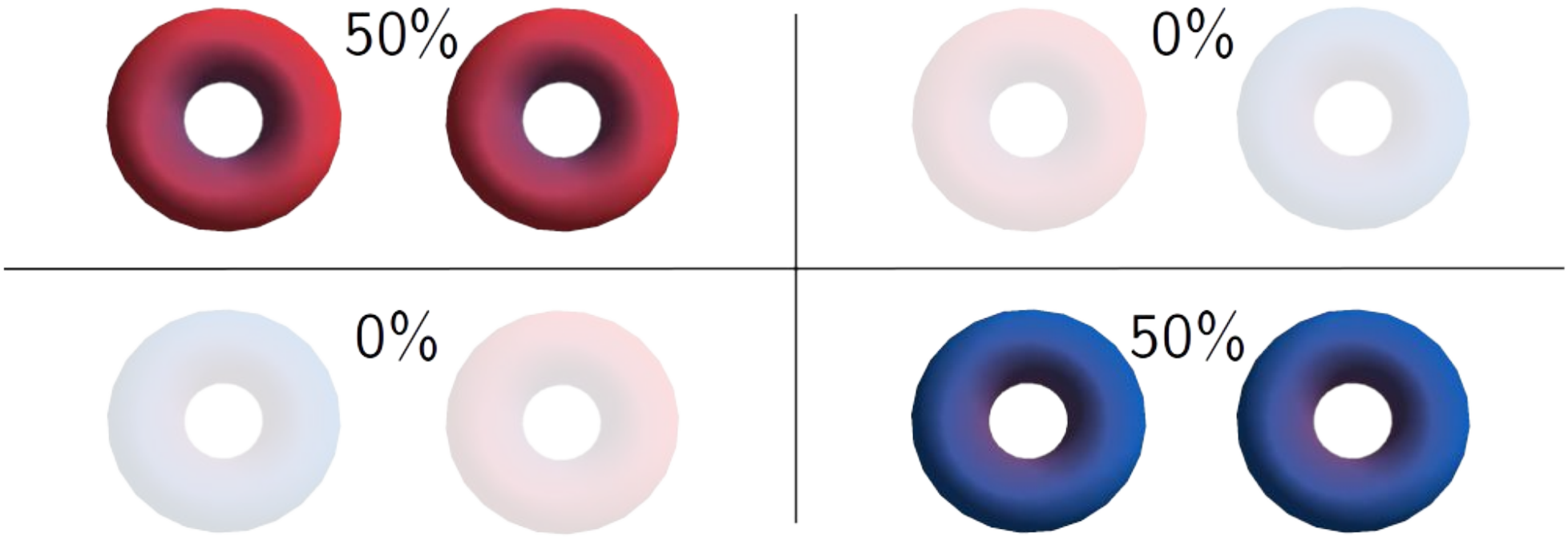
Entanglement

Separable state



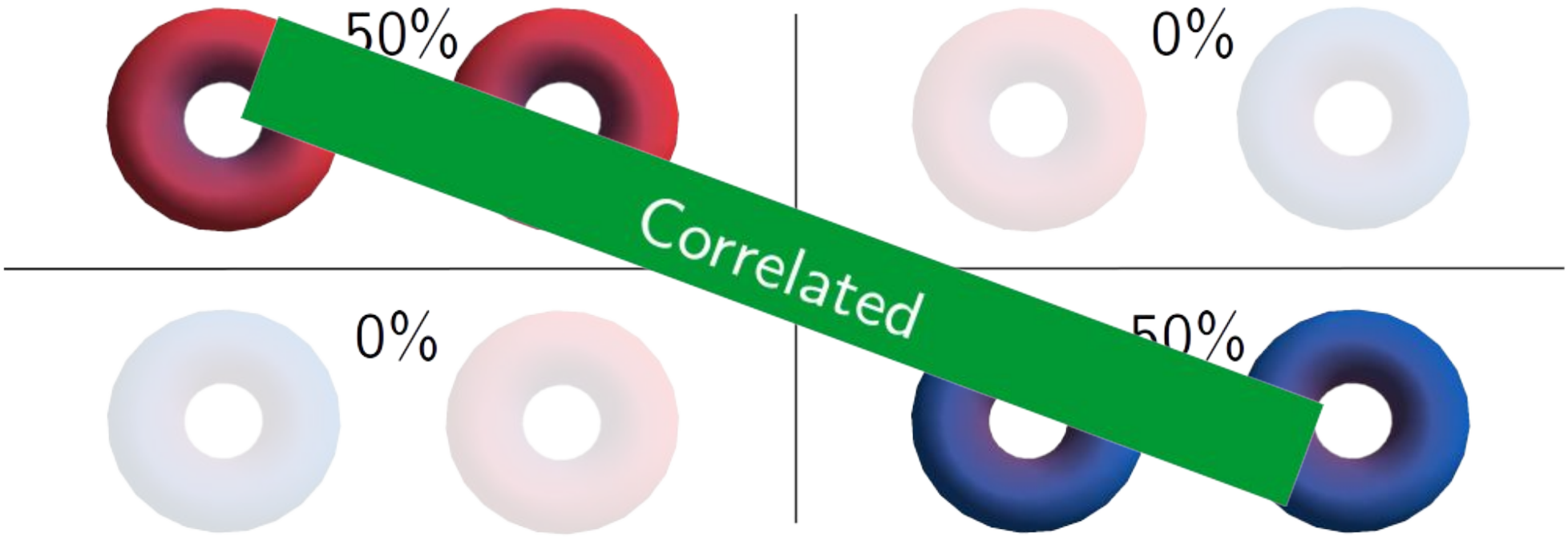
Entanglement

Entangled state



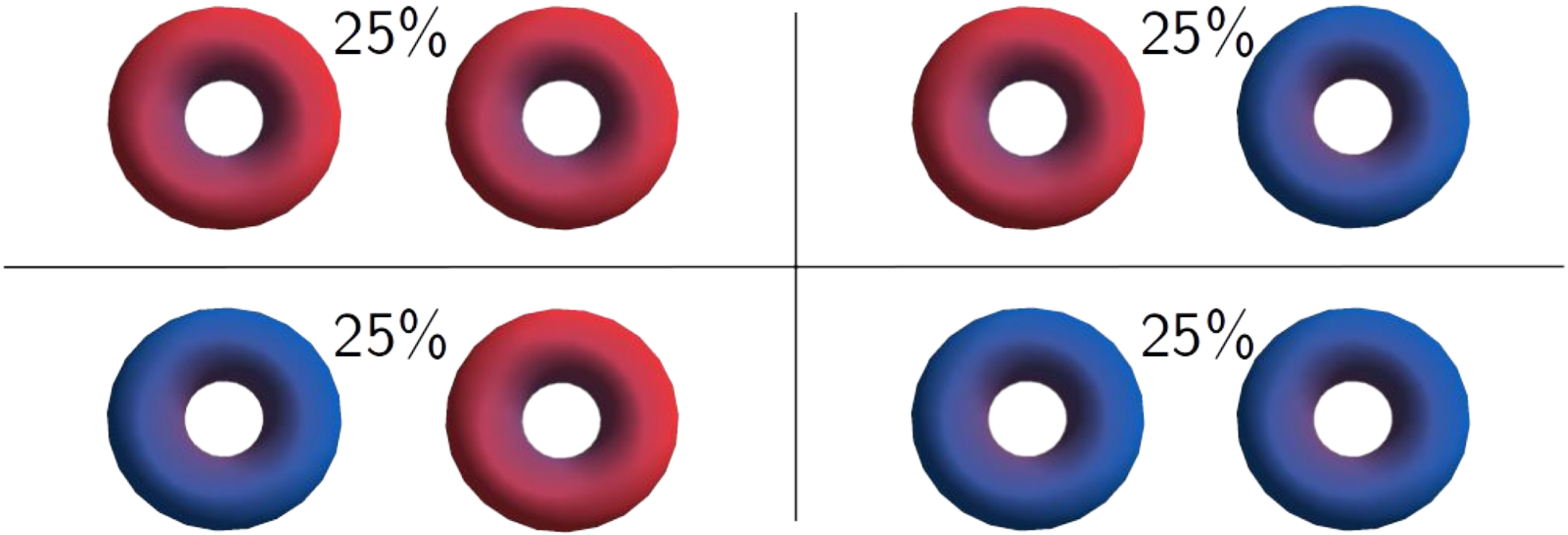
Entanglement

Entangled state



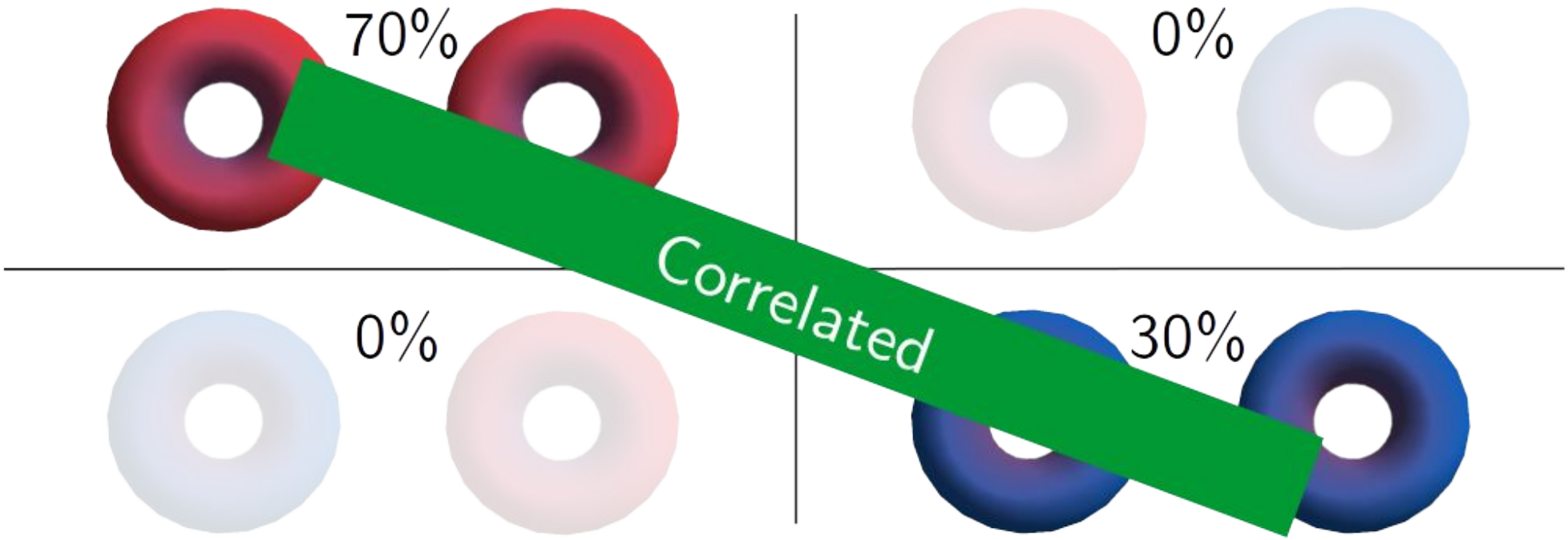
Entanglement

Separable state



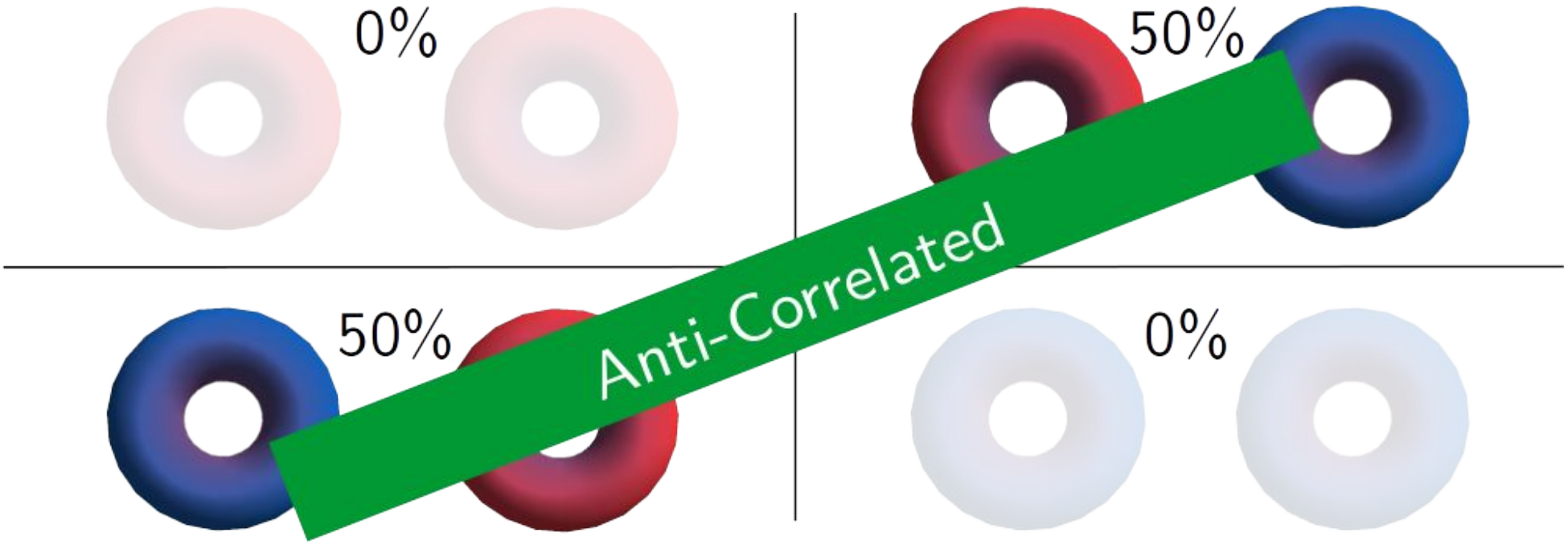
Entanglement

Entangled state



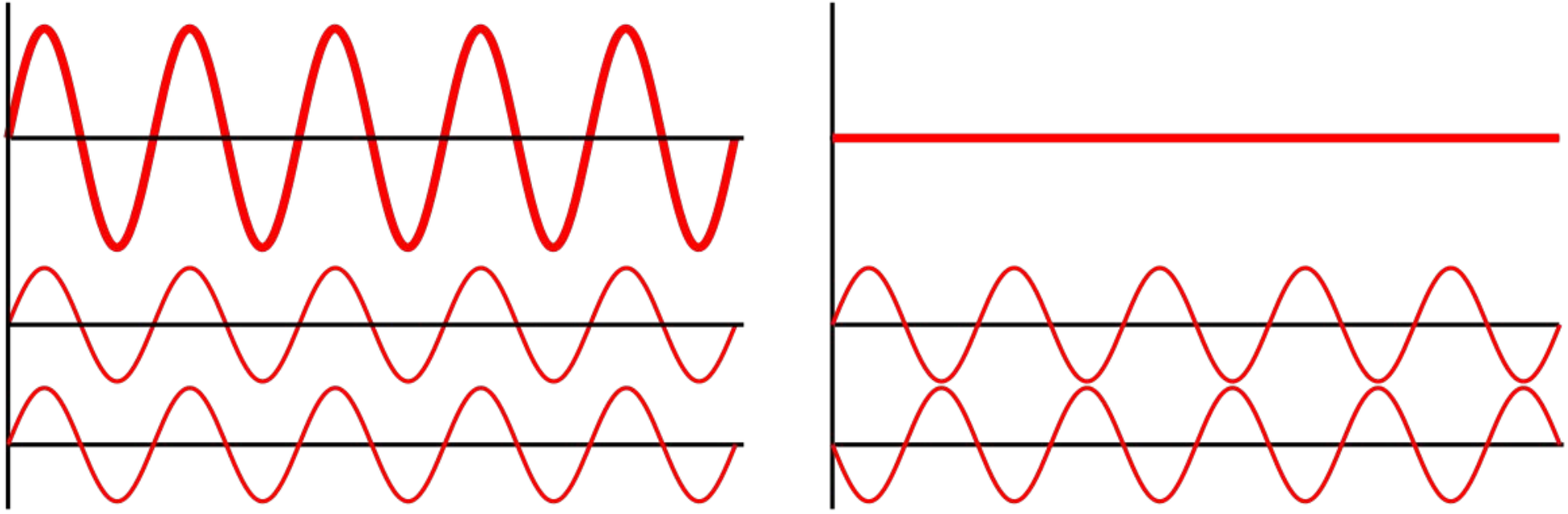
Entanglement

Entangled state



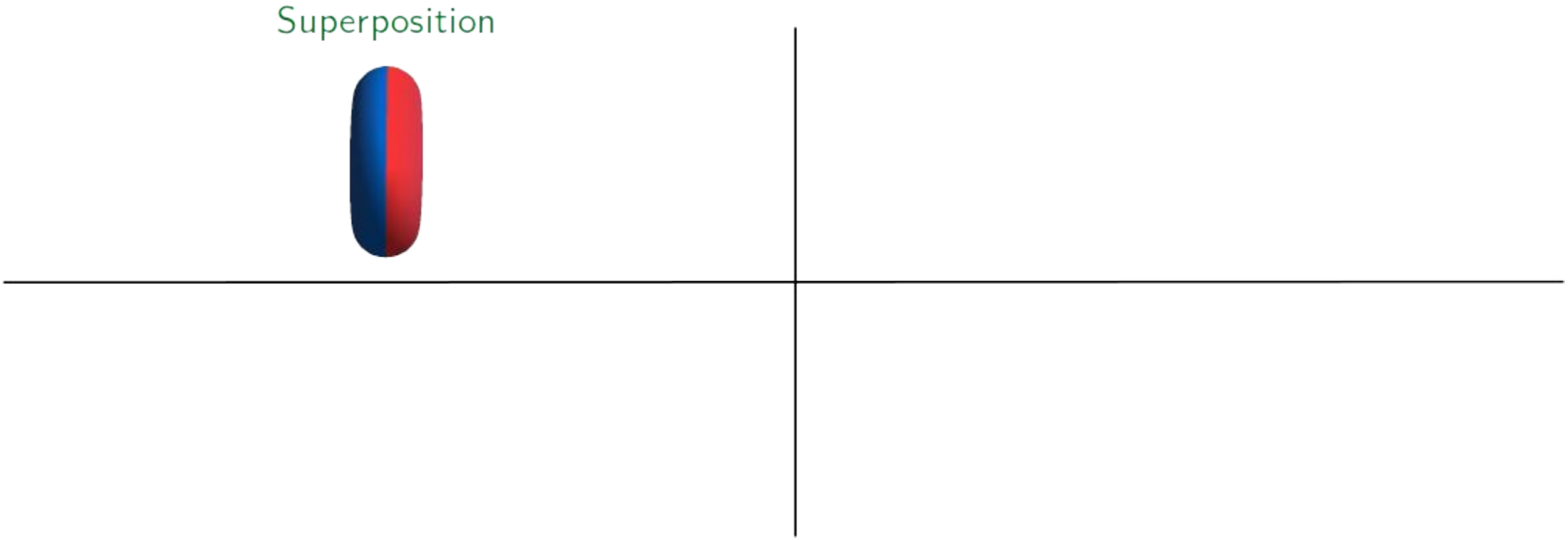
Interference

Physical interpretation



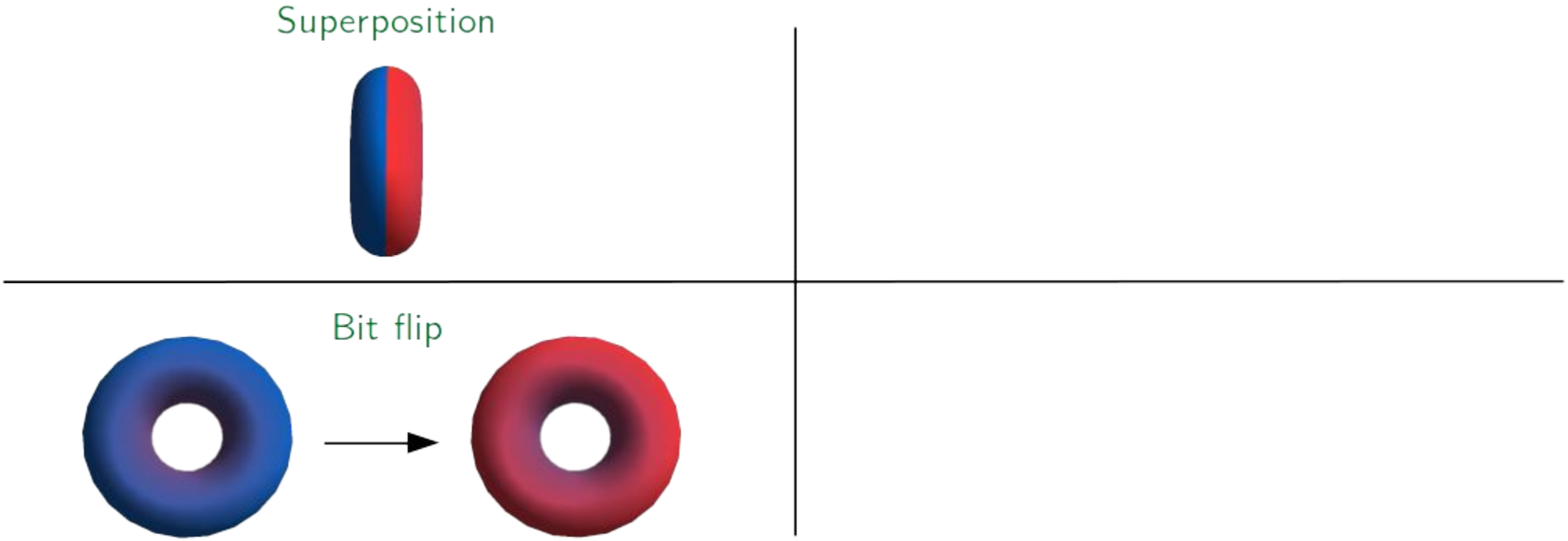
Interference

Example operations on quantum bits



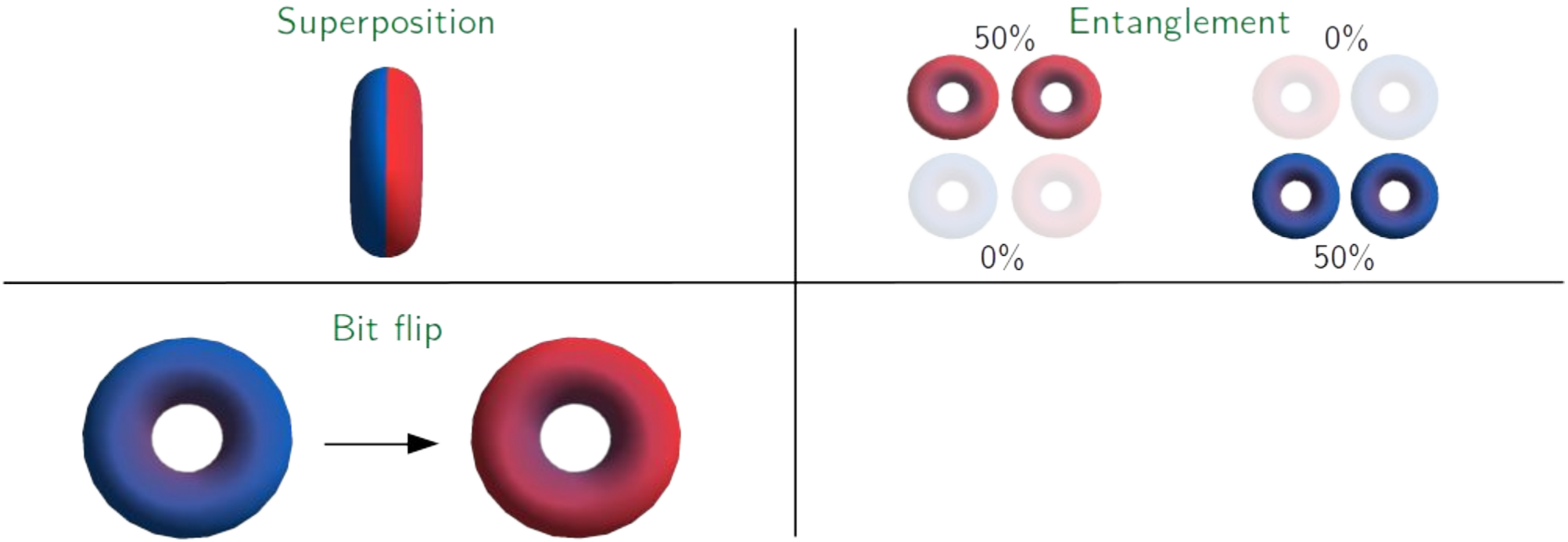
Interference

Example operations on quantum bits



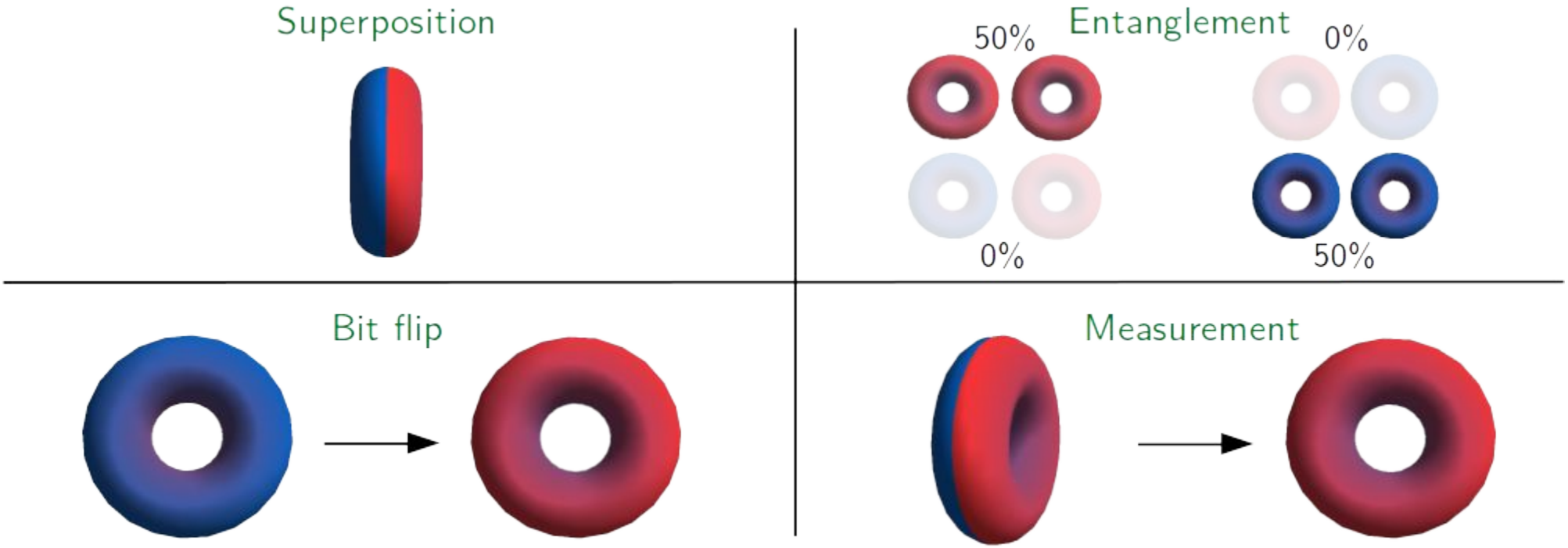
Interference

Example operations on quantum bits



Interference

Example operations on quantum bits



Interference

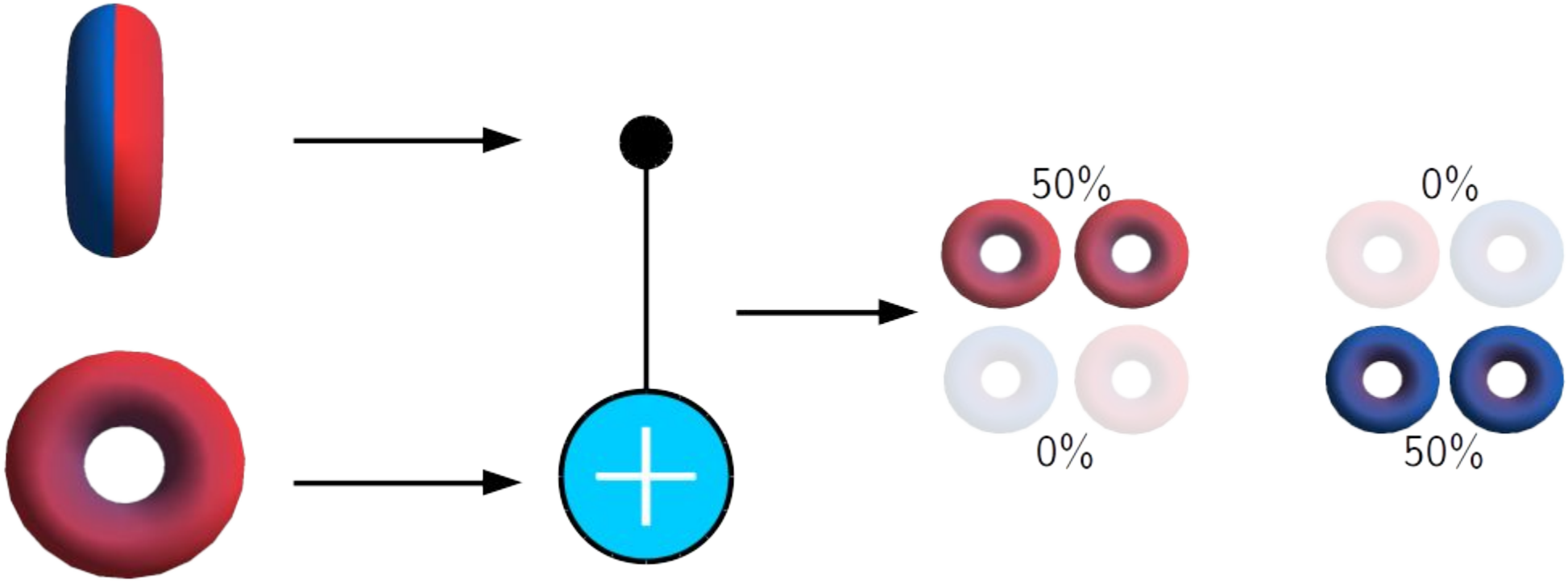
Hadamard H-gate

Interference

Bit-flip X-gate

Interference

C-NOT gate

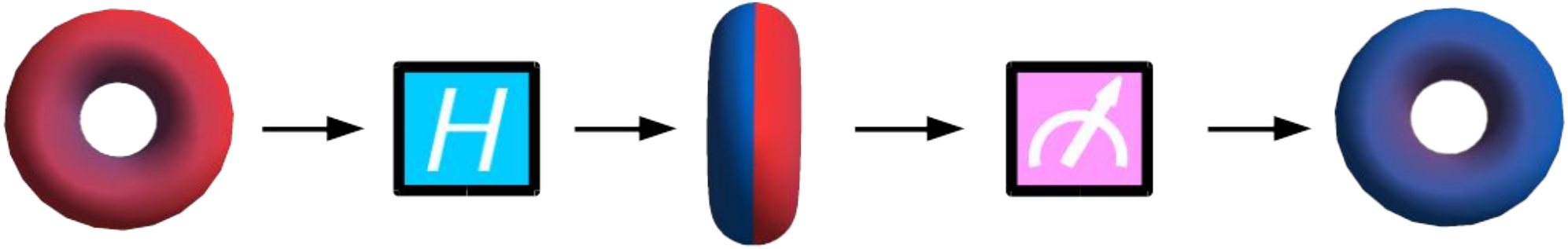


Interference

Measurement

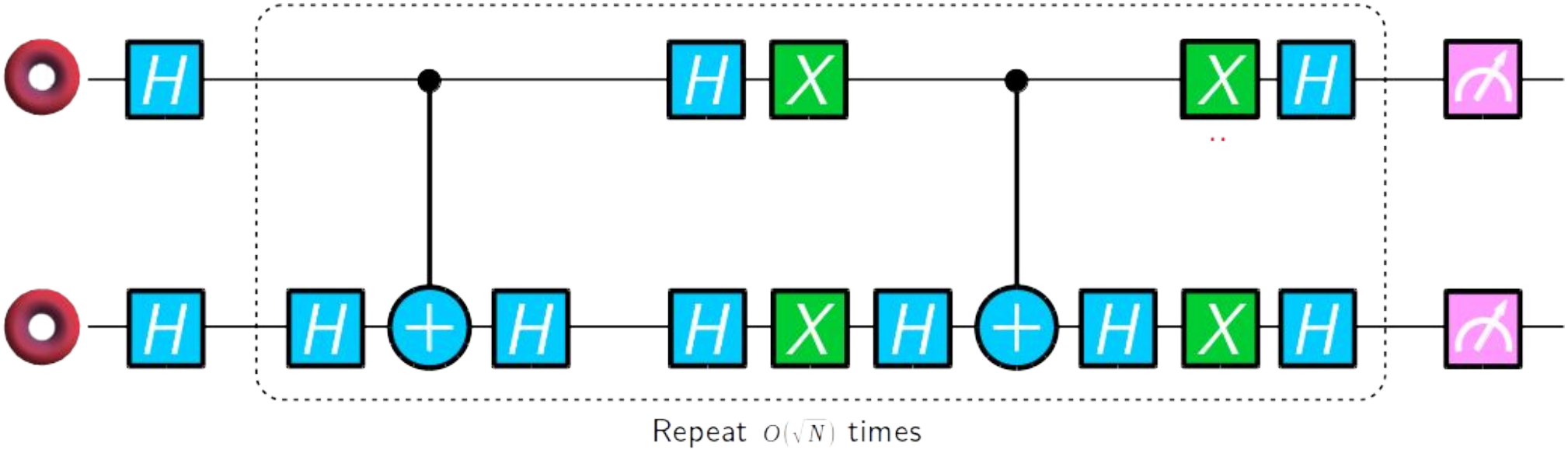
Interference

Quantum circuit - Quantum random number generator (QNRG)



Interference

Quantum circuit - Grover's search algorithm



Interference

Quantum circuit - Grover's search algorithm

Interference

Quantum circuit - Grover's search algorithm

Interference

Quantum circuit - Grover's search algorithm

Classical

4

tries

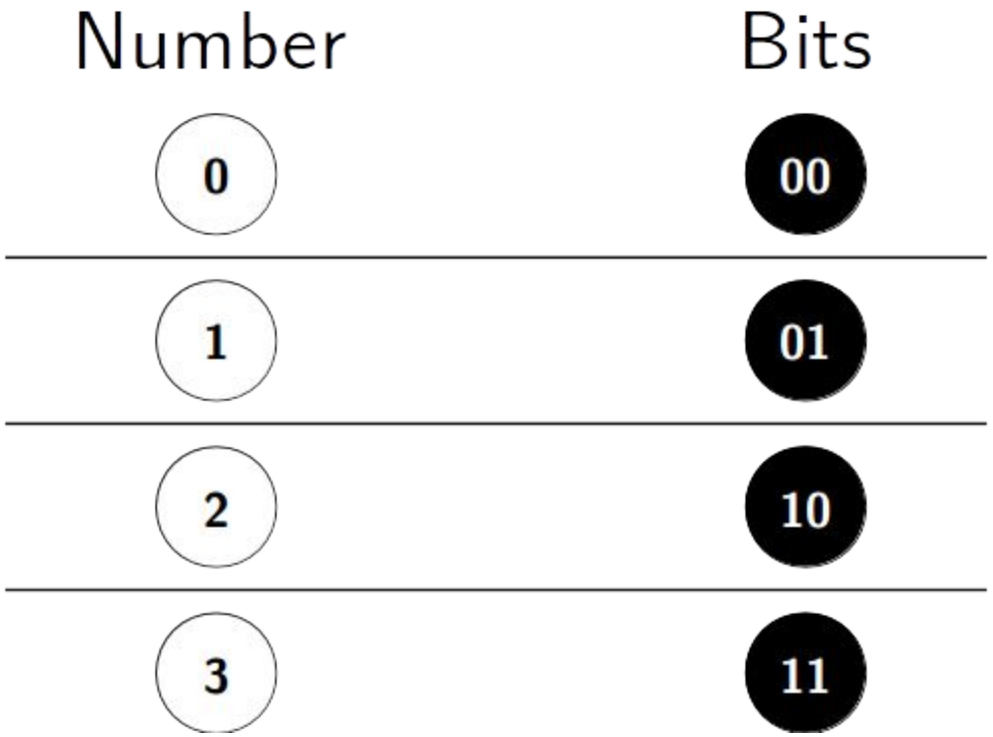
Quantum

1

try

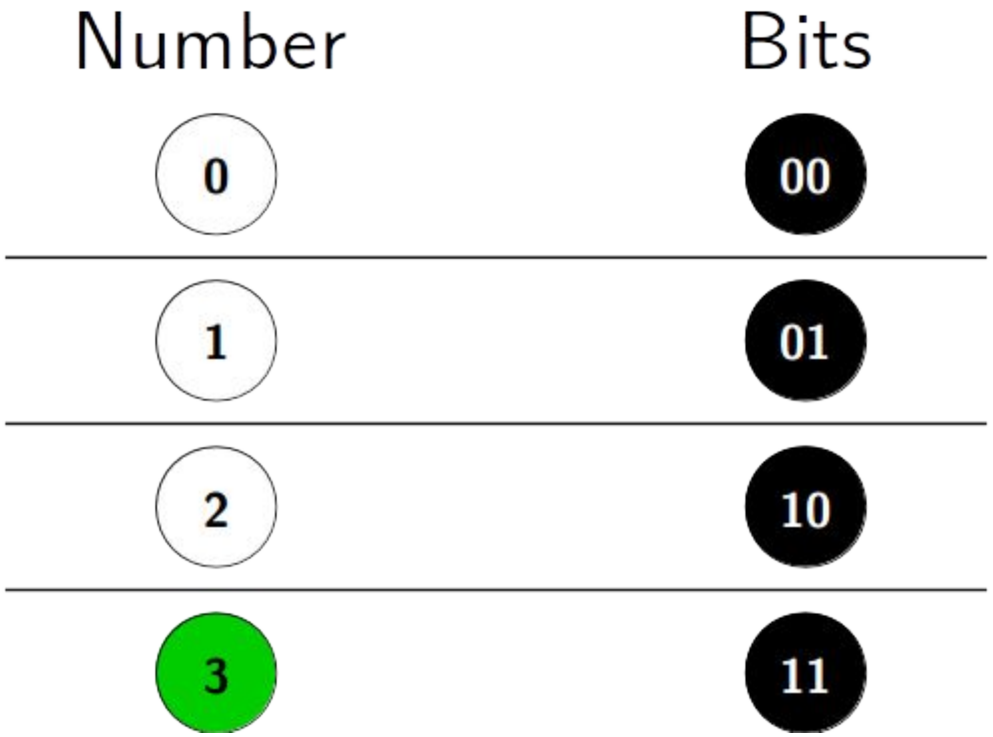
Interference

Quantum circuit - Grover's search algorithm



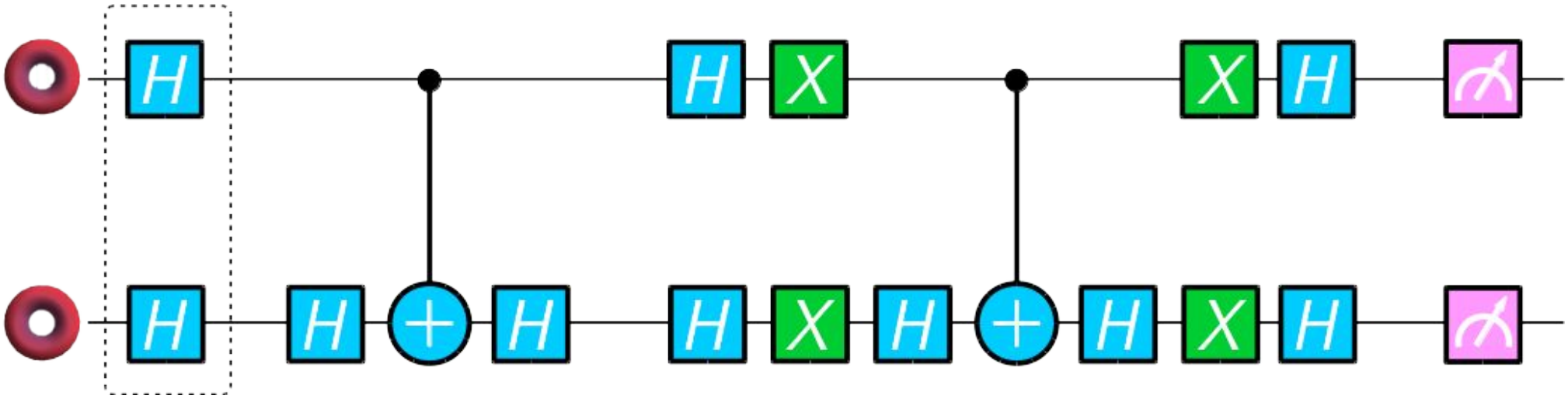
Interference

Quantum circuit - Grover's search algorithm



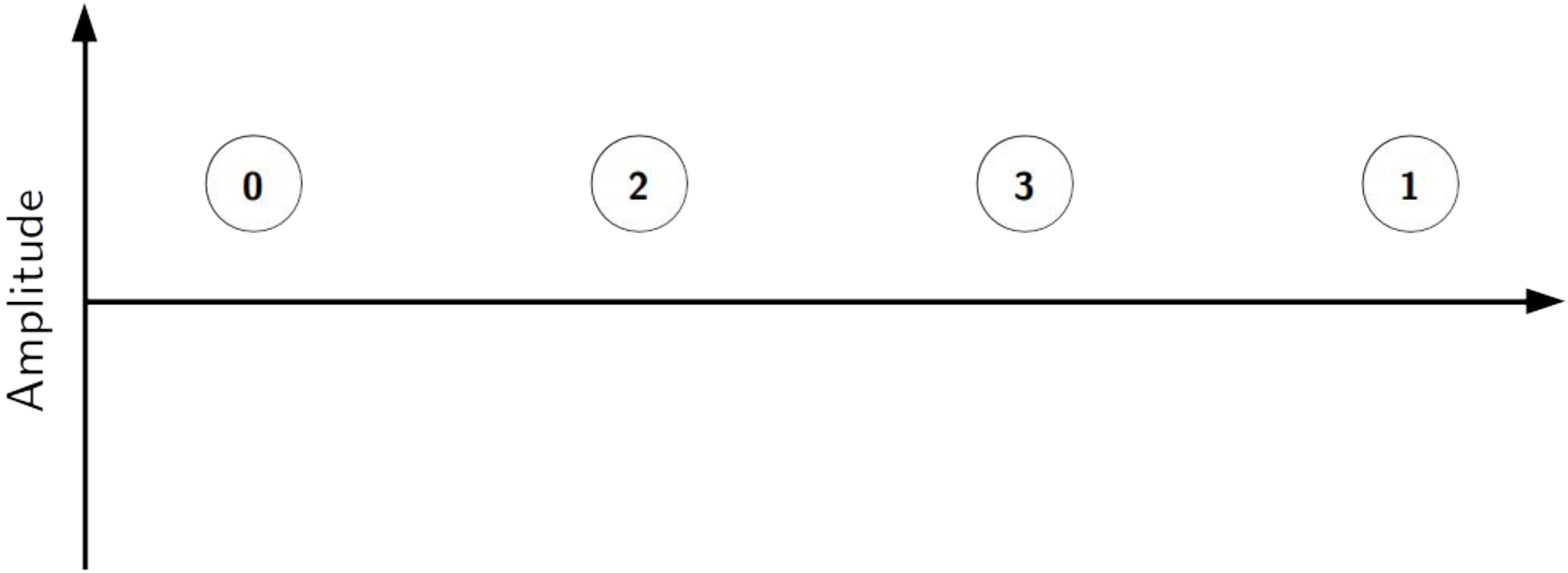
Interference

Quantum circuit - Grover's search algorithm: **Step 1 - Superposition**



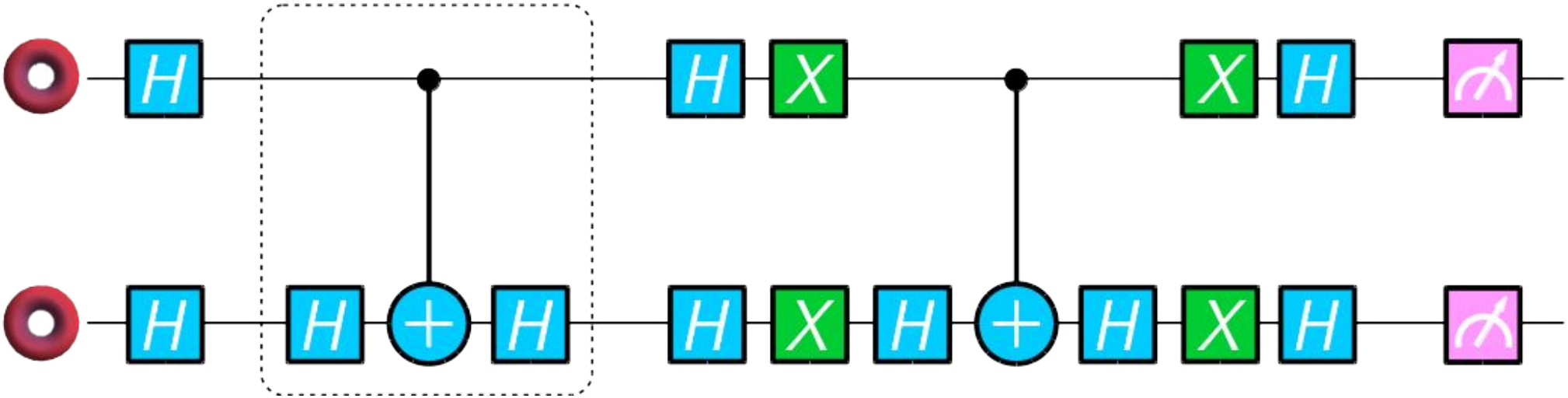
Interference

Quantum circuit - Grover's search algorithm: **Step 1 - Superposition**



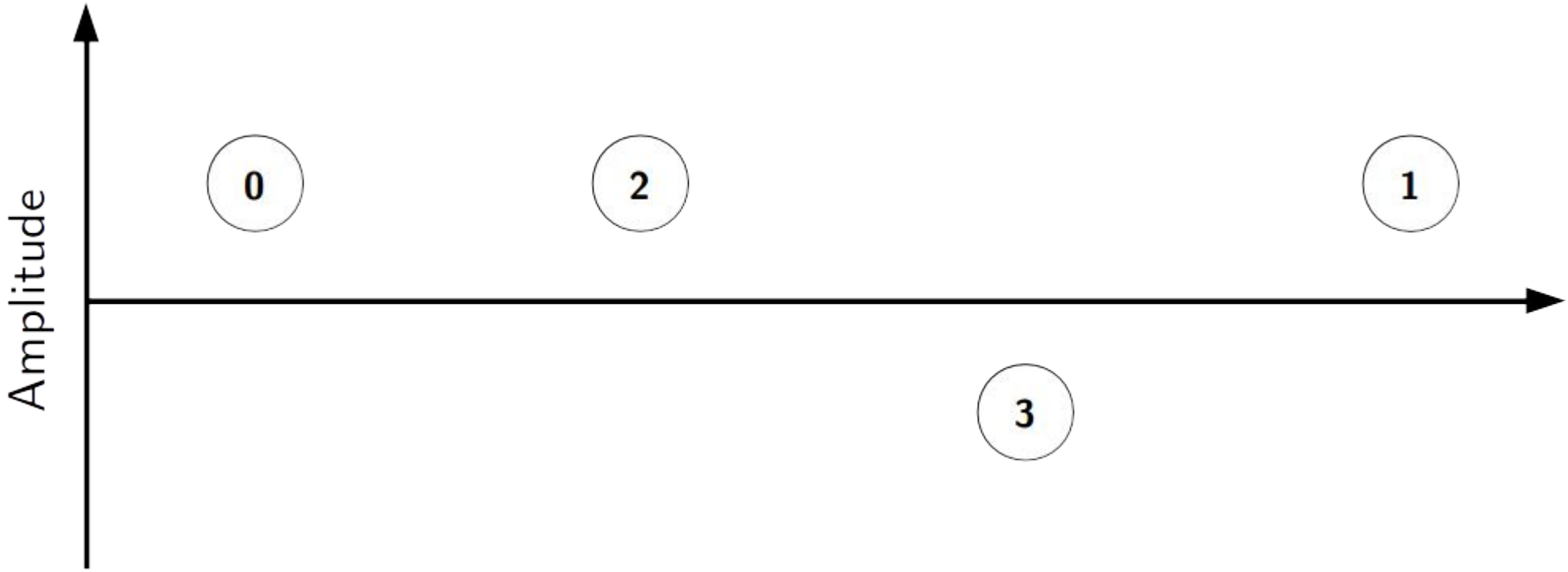
Interference

Quantum circuit - Grover's search algorithm: **Step 2 - Oracle**



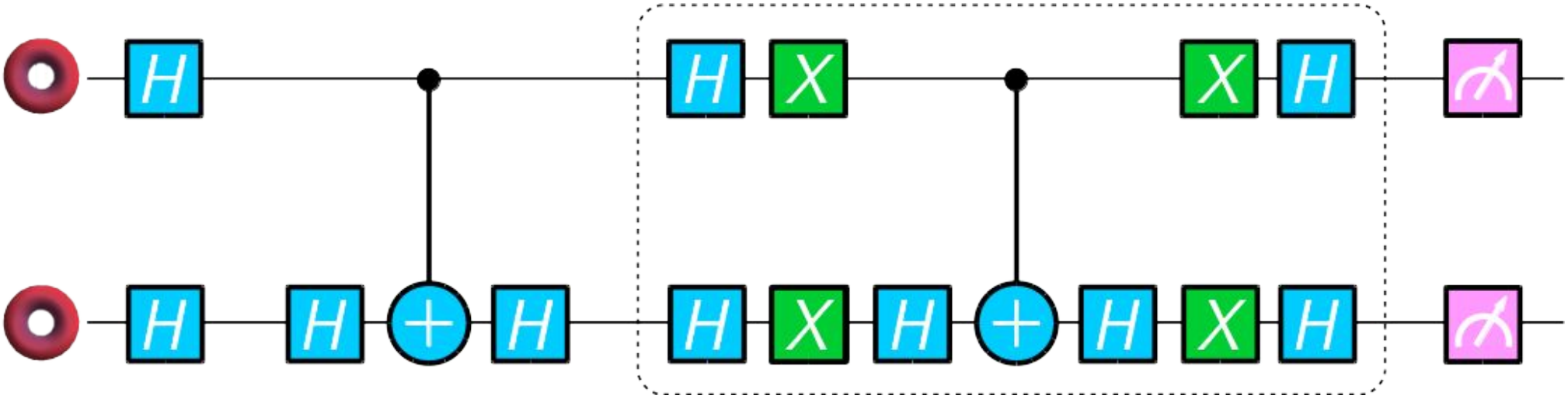
Interference

Quantum circuit - Grover's search algorithm: **Step 2 - Oracle**



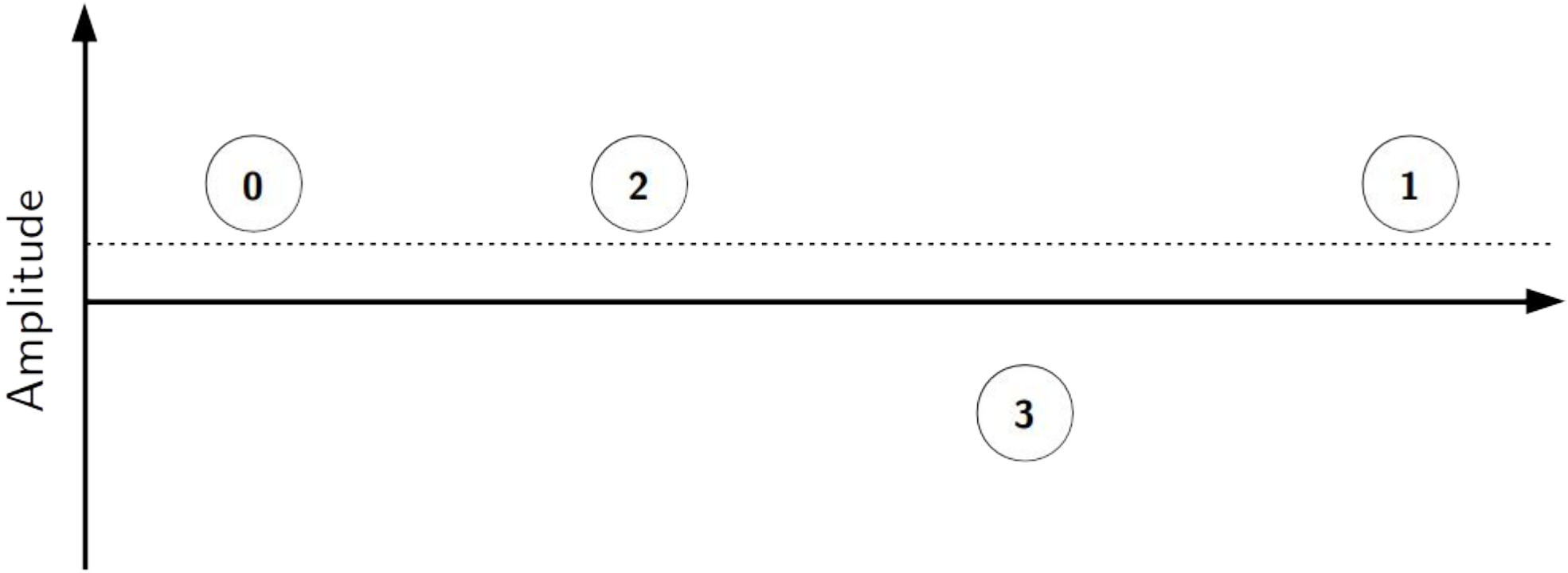
Interference

Quantum circuit - Grover's search algorithm: **Step 3 - Reflector**



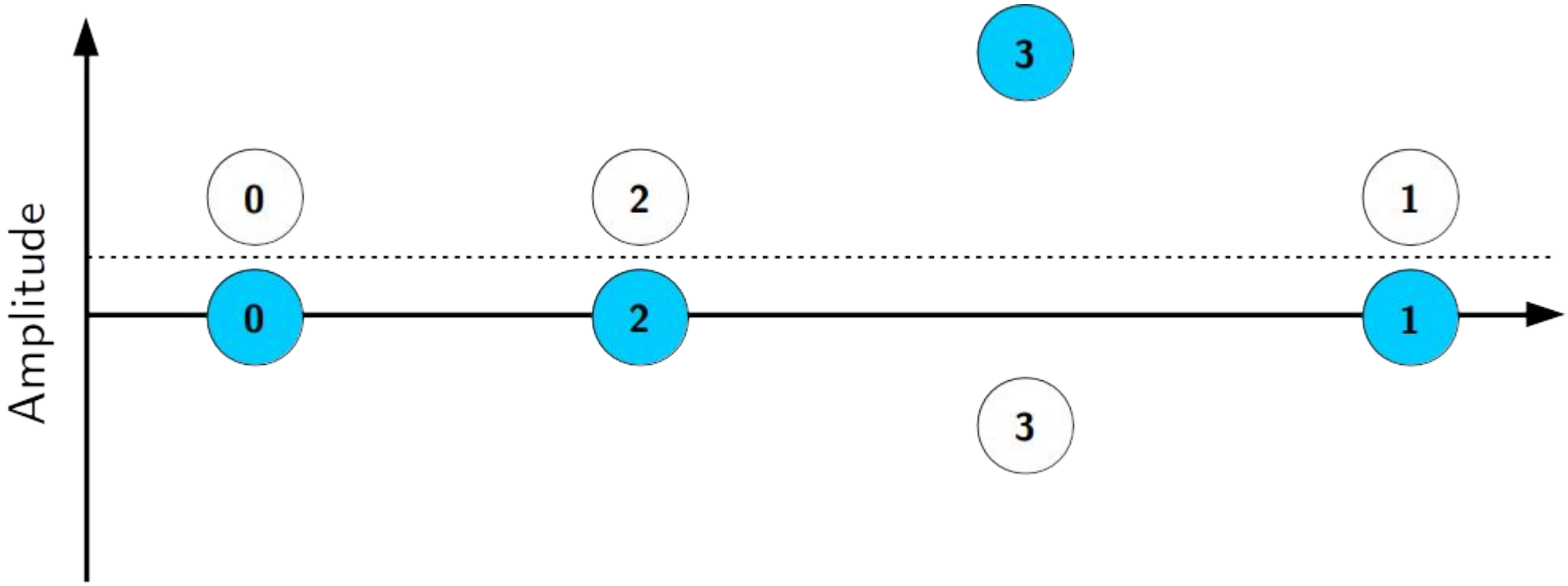
Interference

Quantum circuit - Grover's search algorithm: **Step 3 - Reflector**



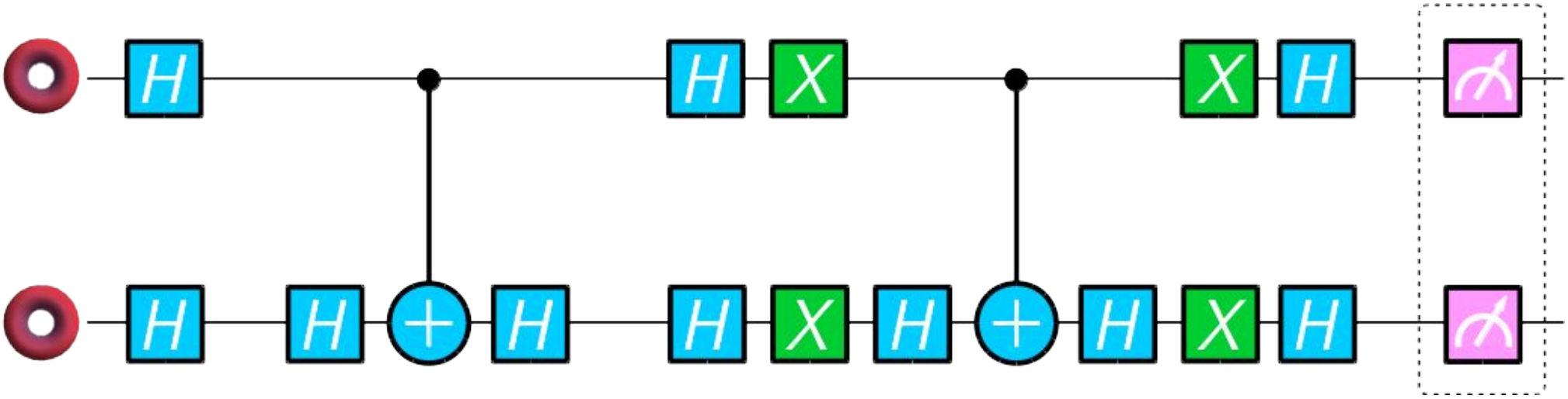
Interference

Quantum circuit - Grover's search algorithm: **Step 3 - Reflector**



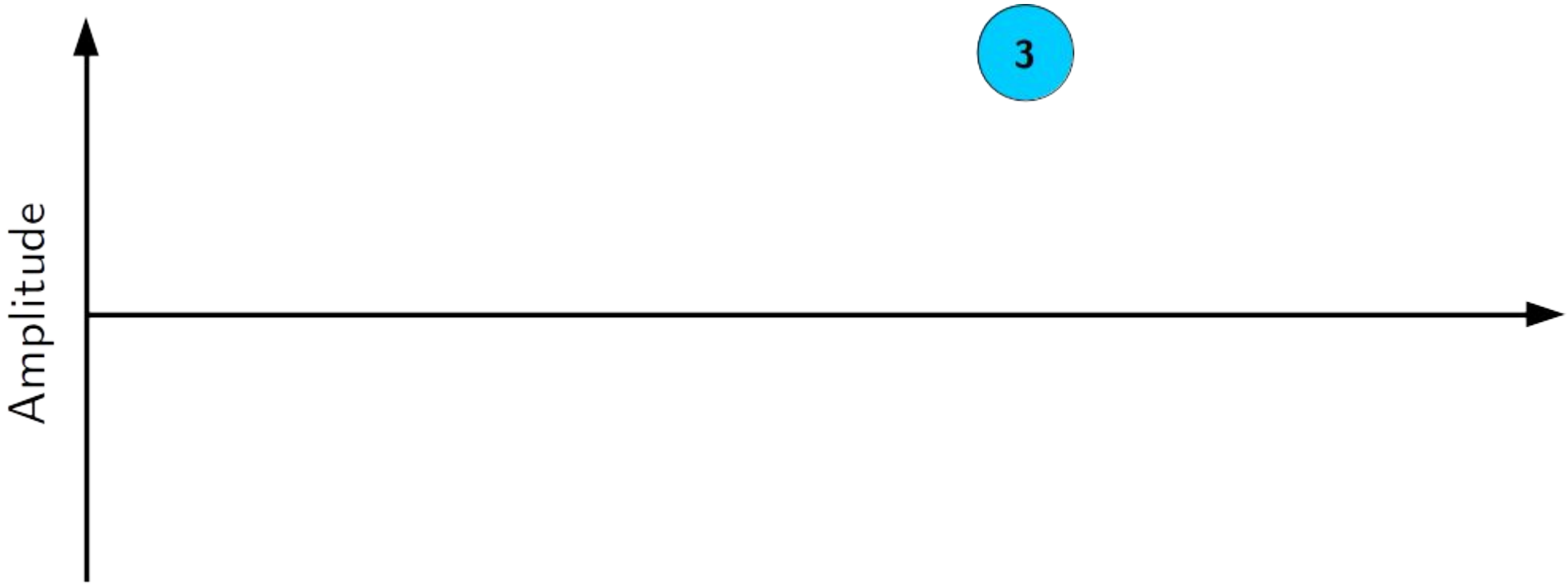
Interference

Quantum circuit - Grover's search algorithm: **Step 4 - Measurement**



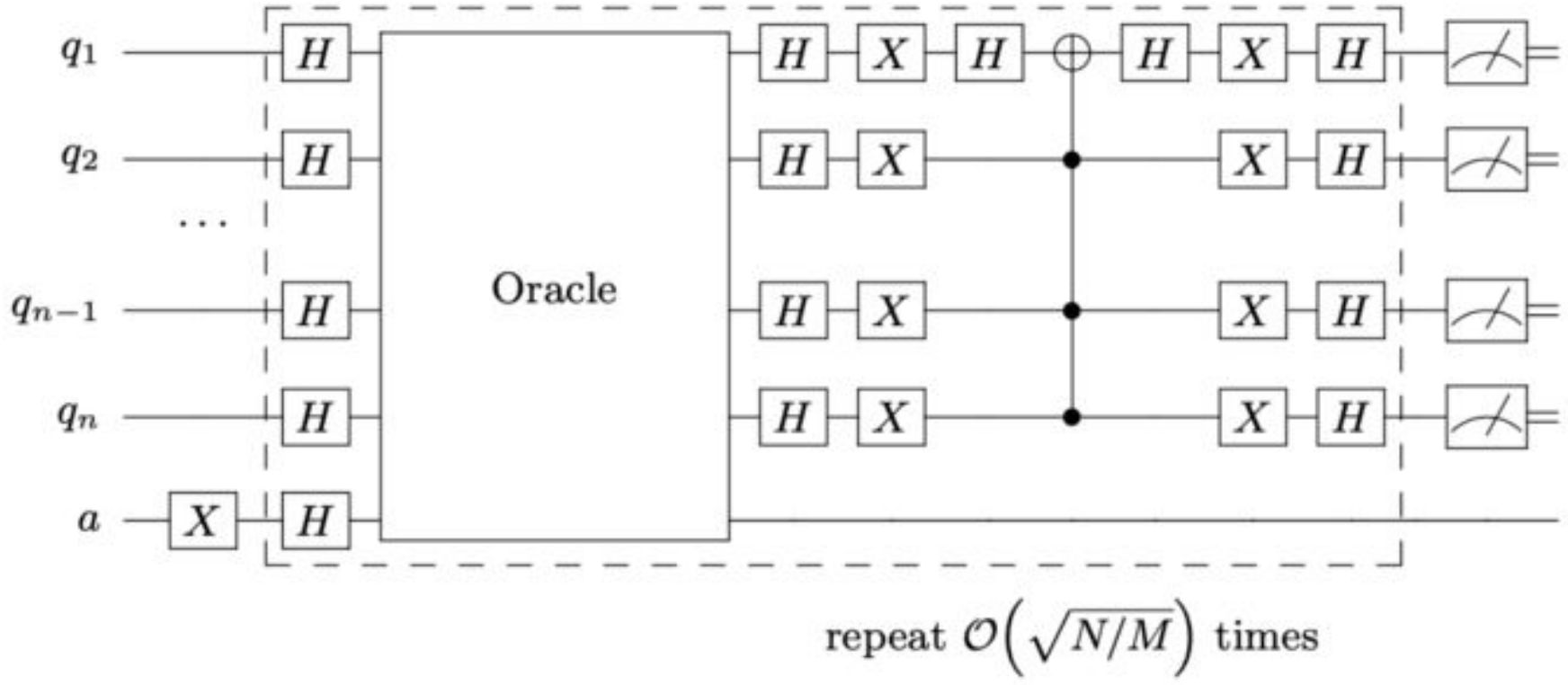
Interference

Quantum circuit - Grover's search algorithm: **Step 4 - Measurement**



Interference

Quantum circuit - Grover's search algorithm: *N*-entries, *M*-target states



Conclusion

- ➔ In quantum computing, a quantum bit - or qubit - is a basic unit of quantum information - the quantum version of the classical binary bit
- ➔ A qubit is a two-state (or two-level) quantum-mechanical system, one of the simplest quantum systems in quantum mechanics
- ➔ Quantum mechanics allows the qubit to be in a coherent superposition of both states simultaneously
- ➔ Operations on qubits modify the amplitudes, i.e. the coefficients in the superposition
- ➔ At physical level, operations on qubits make quantum mechanical systems to interfere with each other
- ➔ Starting from a uniform superposition of all possible configurations, a quantum algorithm implements a serie of interferences that makes the output state belonging to the set of the problem solution