Quantum Machine Learning 4 Africa

Deep Learning Indaba
Kigali, Rwanda
22 August 2025

The Dream Team

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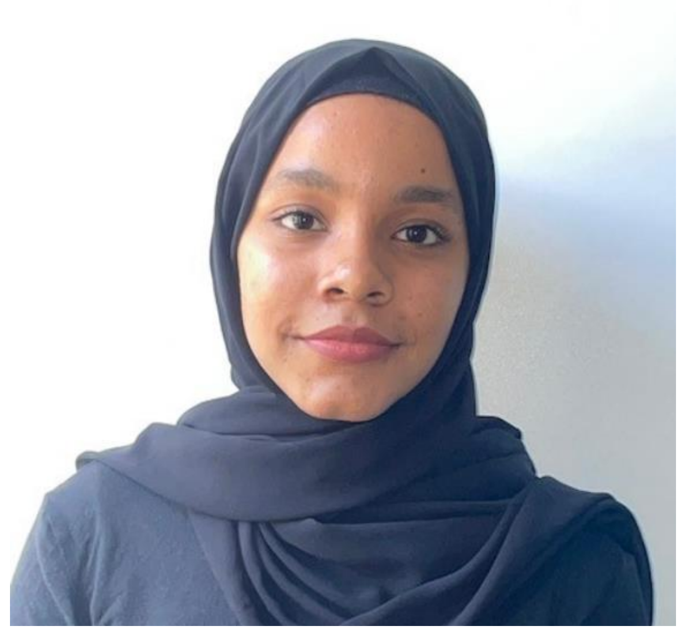

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Link to Repo

DEEP LEARNING INDABA

QML4AFRICA WORKSHOP

Quantum Machine Learning for Africa

22 AUGUST 2025 Kigali, Rwanda

AGENDA & SPEAKERS

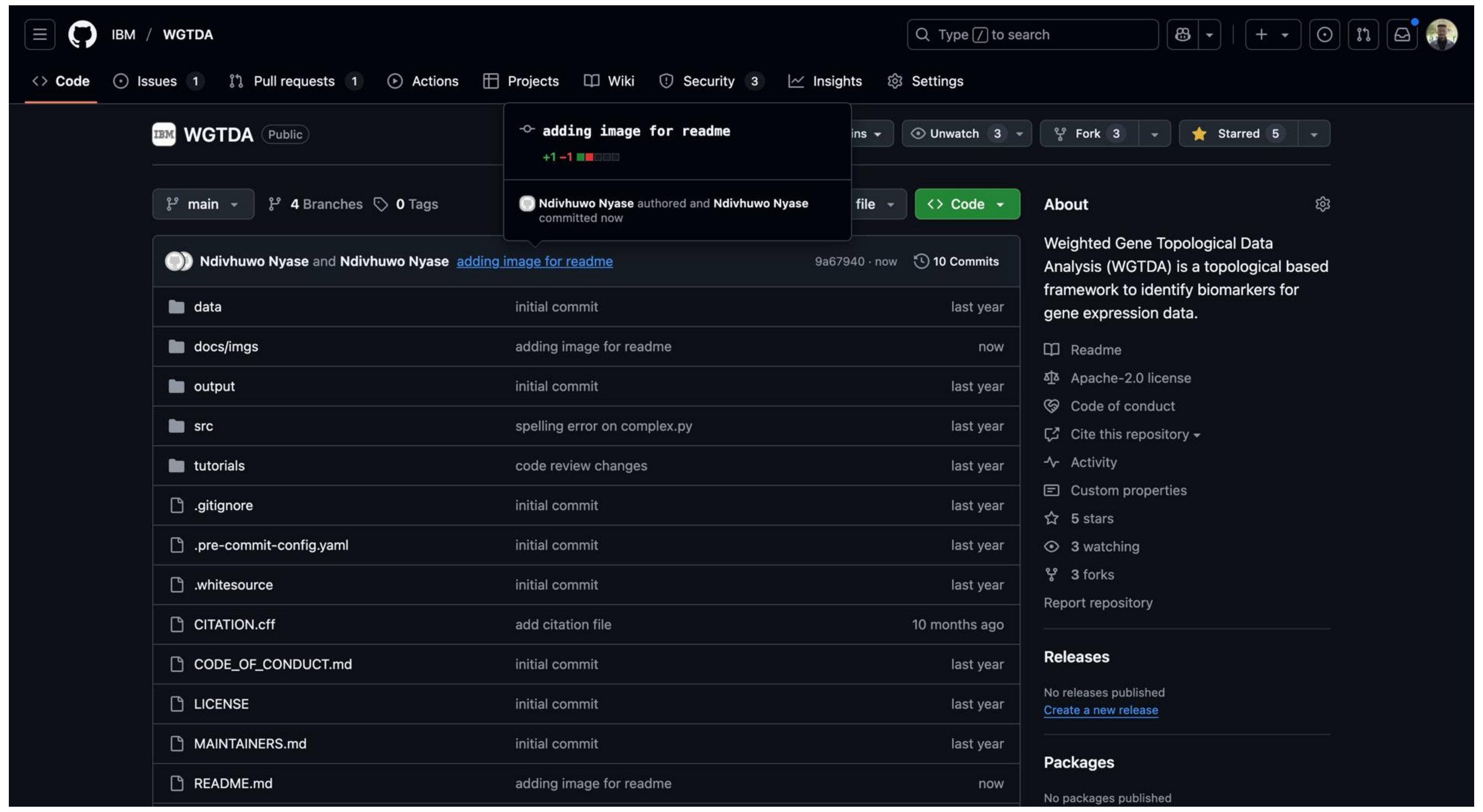
Time	Topic
09:00 - 09:10	Introductions and House Rules
09:10 - 09:40	Dr Ryan Sweke: QML Foundations and Africa's Potential
09:40 - 10:00	Ndivhuwo Nyase: Introduction to QC
10:00 - 10:30	Yousra Farhani: Introduction to QML
10:30 - 11:00	Presentations from top abstract/poster submissions
11:00 - 11:30	Posters and Networking
11:30 - 12:30	Practical Session: Introduction to Qiskit
12:30 - 13:00	Panel: Africa's Role in Global Computing

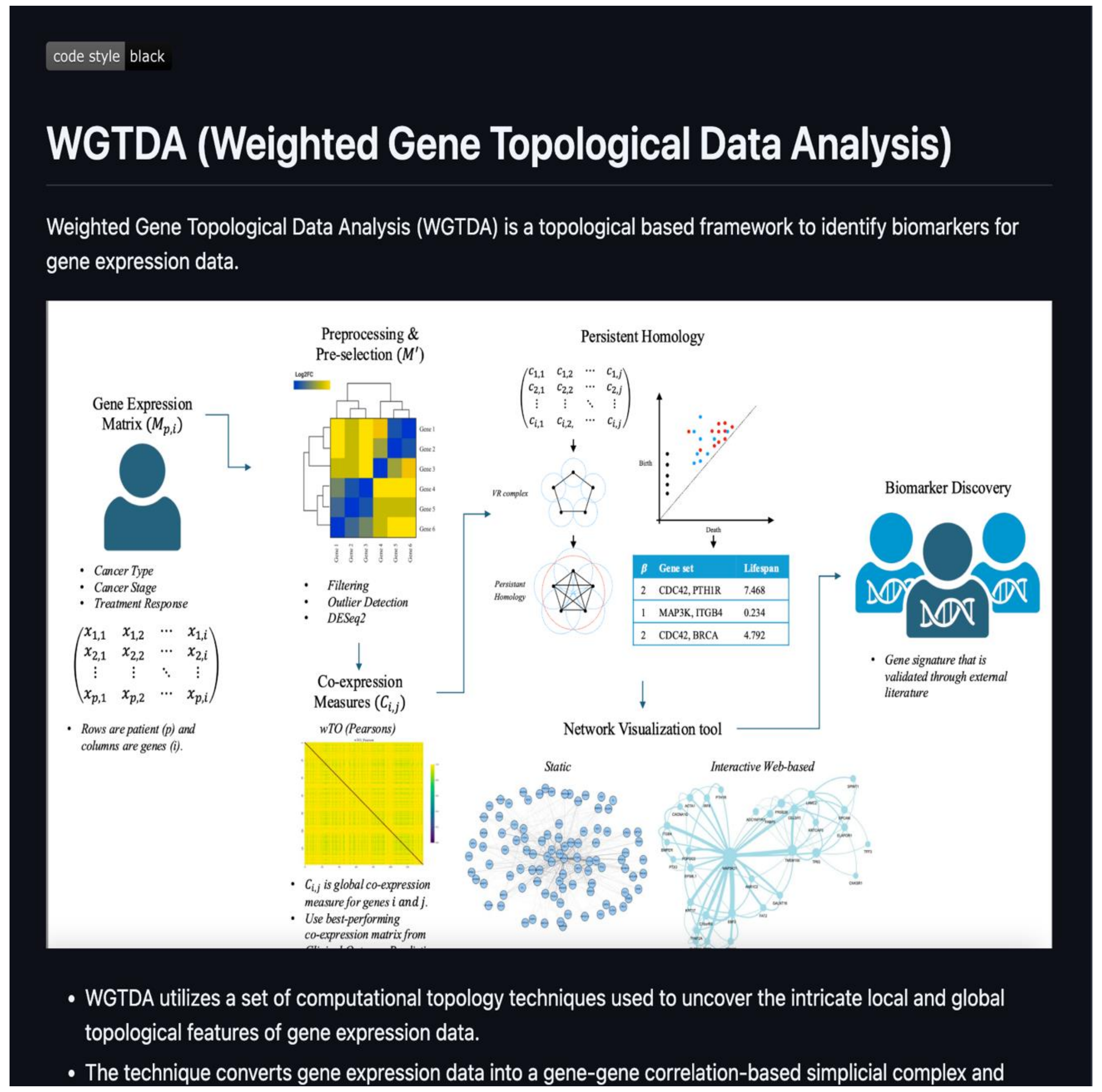
Dr. Stephanie Müller
IBM Research Africa

Dr. Ryan Sweke
AIMS

Yousra Farhani
Quantum Africa

Ndivhuwo Nyase
IBM Research Africa





Ndivhuwo Nyase

Research Scientist
Quantum Applications
IBM Research Africa

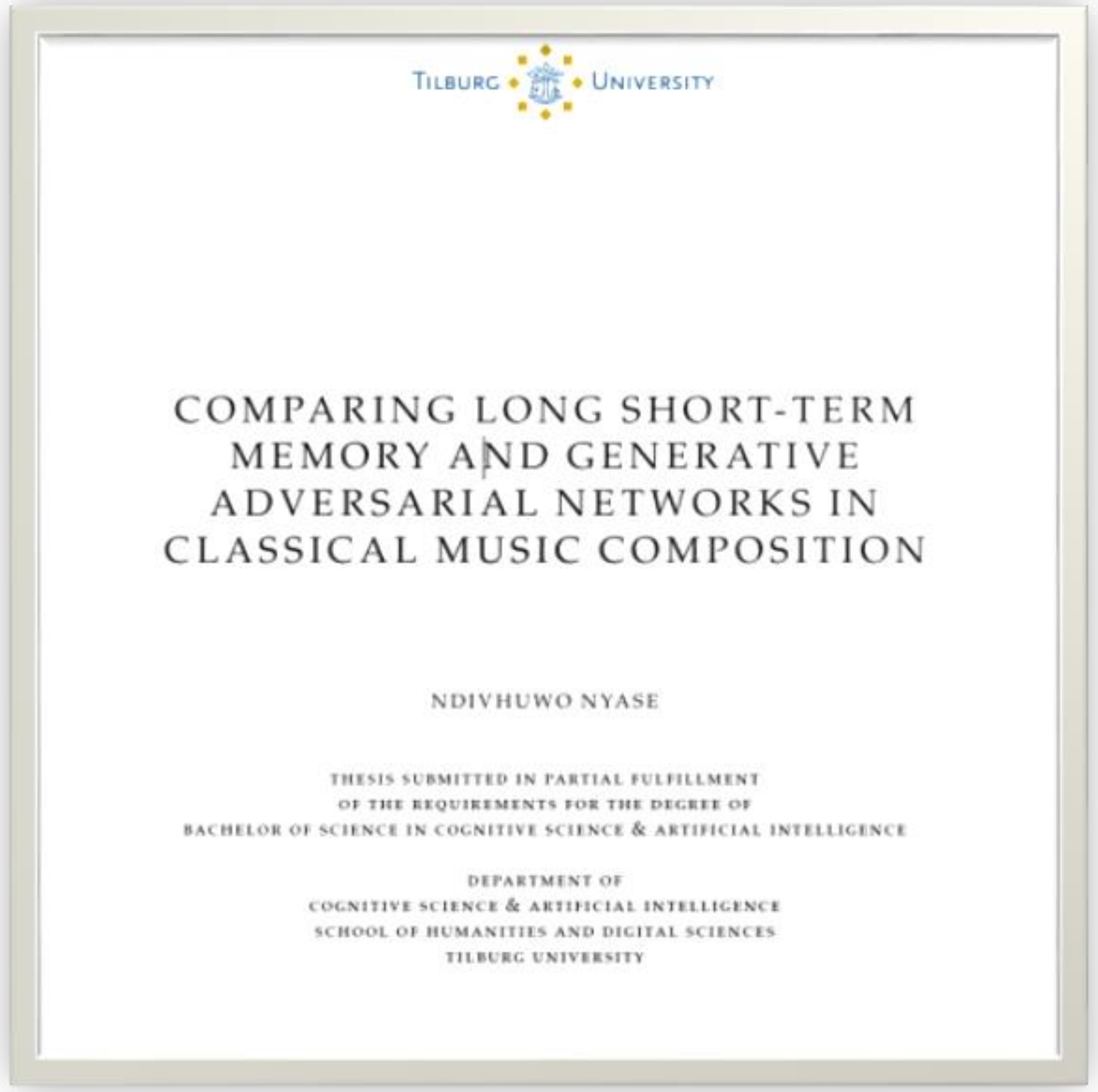
2024

Weighted Gene Topological Data Analysis (WGTDA)

WGTDA serves as both a data mining methodology and an open-source Python package, designed to uncover key topological features within gene expression data that can potentially serve as prognostic biomarkers for complex diseases

Ndivhuwo Nyase

Research Scientist
Quantum Applications
IBM Research Africa



Tilburg University

COMPARING LONG SHORT-TERM MEMORY AND GENERATIVE ADVERSARIAL NETWORKS IN CLASSICAL MUSIC COMPOSITION

NDIVHUWO NYASE

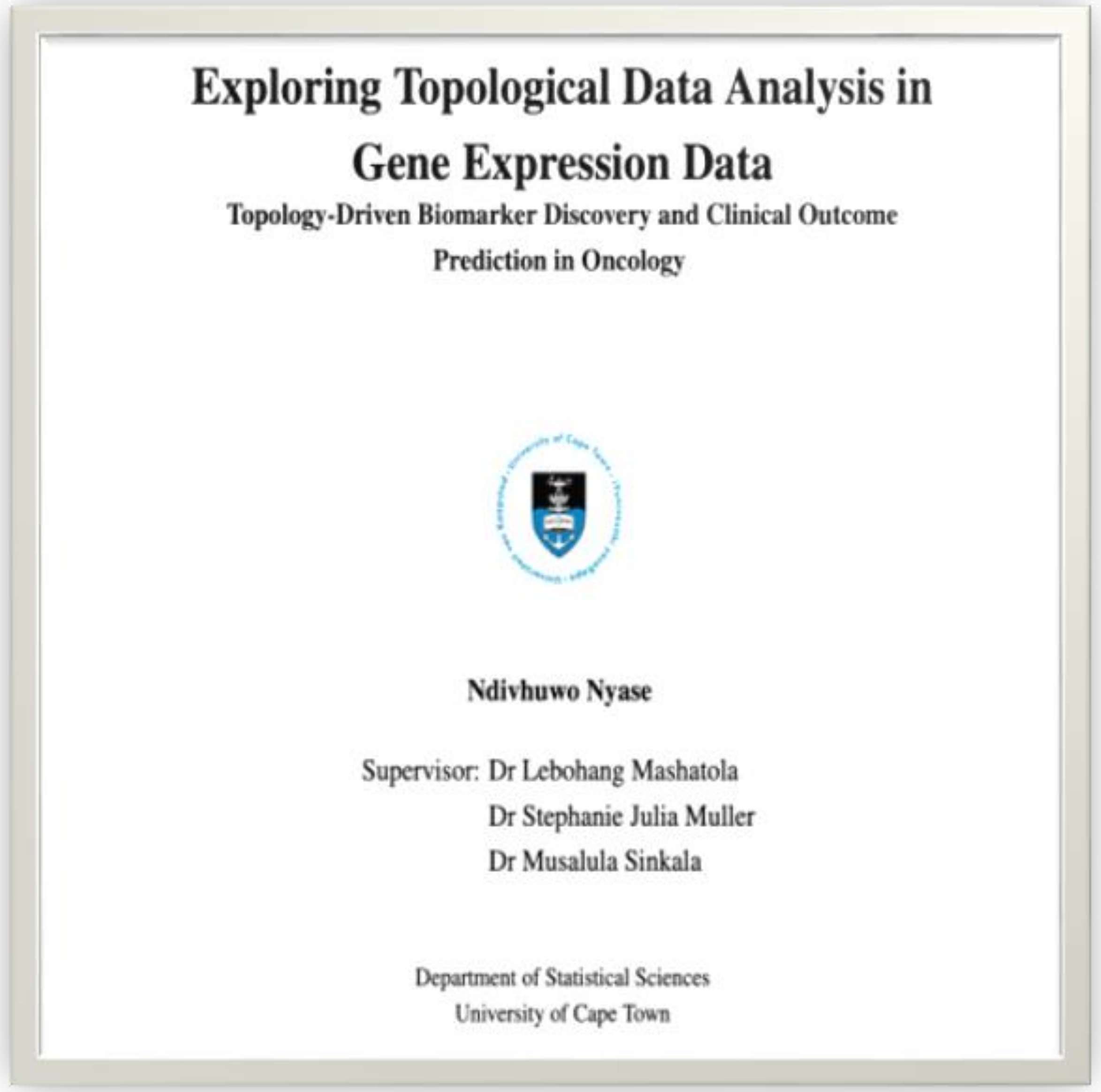
THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
BACHELOR OF SCIENCE IN COGNITIVE SCIENCE & ARTIFICIAL INTELLIGENCE

DEPARTMENT OF
COGNITIVE SCIENCE & ARTIFICIAL INTELLIGENCE
SCHOOL OF HUMANITIES AND DIGITAL SCIENCES
TILBURG UNIVERSITY

2018-2022

BSc Artificial Intelligence
and Cognitive Science

Tilburg University
Netherlands



Exploring Topological Data Analysis in Gene Expression Data

Topology-Driven Biomarker Discovery and Clinical Outcome Prediction in Oncology

Ndivhuwo Nyase

Supervisor: Dr Lebohang Mashatola
Dr Stephanie Julia Muller
Dr Musalula Sinkala

Department of Statistical Sciences
University of Cape Town

2023-2024

MSc Data Science

University of Cape Town,
South Africa

IBM

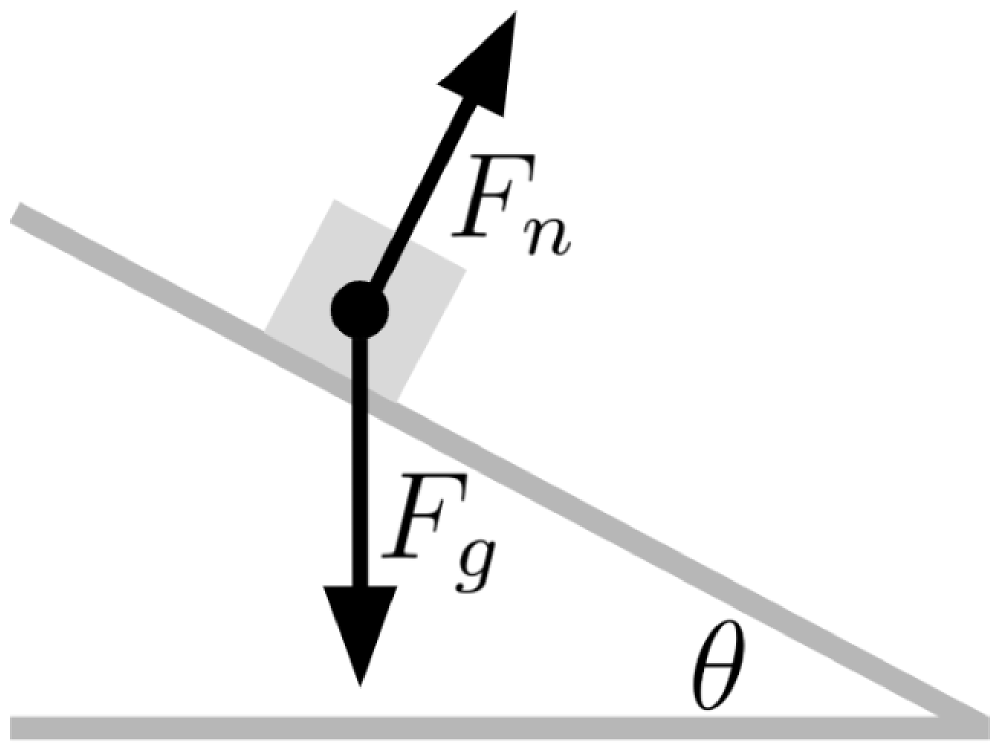
“Quantum computers use qubits that are both 0 and 1 at the same time.”

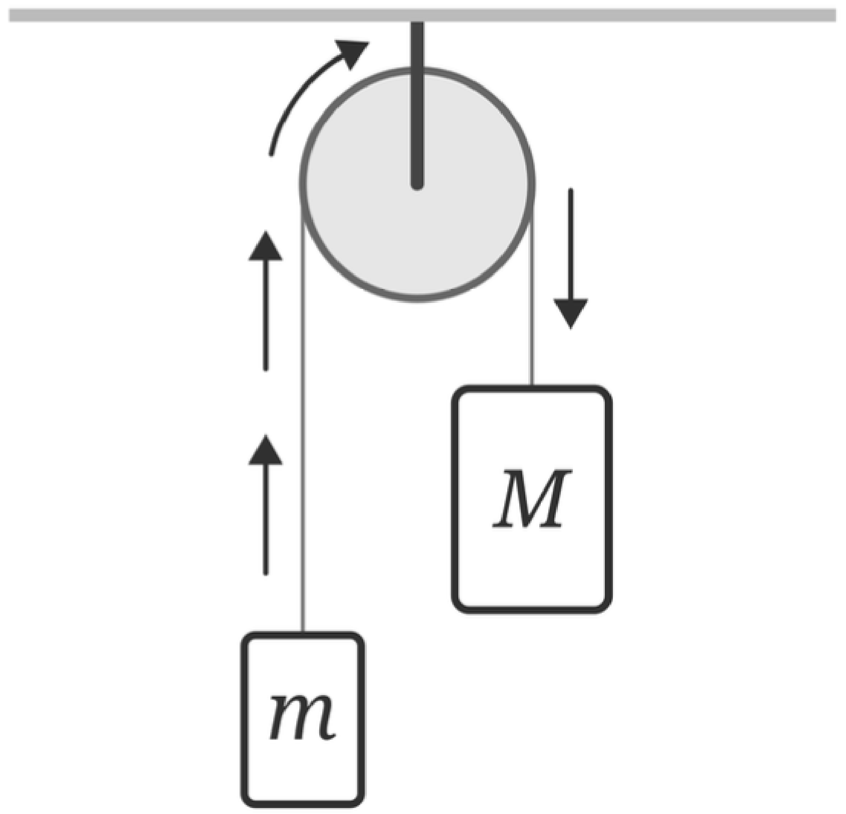
”Quantum Computers will break RSA encryption.”

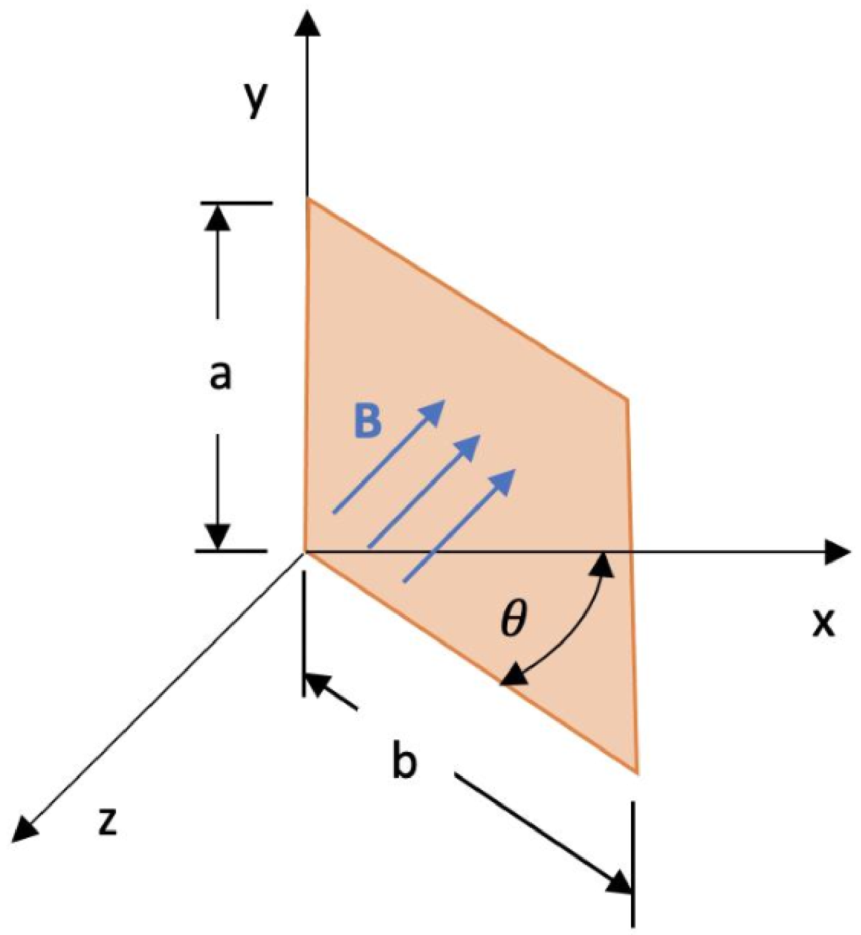
“Bigger and faster versions of high performance super computing.”

Foundations of Quantum Mechanics

“There is nothing new to be discovered in physics now. All that remains is more and more precise measurement.”







Before the 20th century, physics was dominated by Newtonian mechanics and Maxwell's electromagnetism.

These classical physics frameworks worked great for everyday stuff, but couldn’t explain some odd behaviour's seen at the atomic level.

What is Quantum Mechanics

Quantum mechanics is the branch of mathematics and physics that describes how matter and energy behave at the smallest scales, like atoms, electrons, and photons.

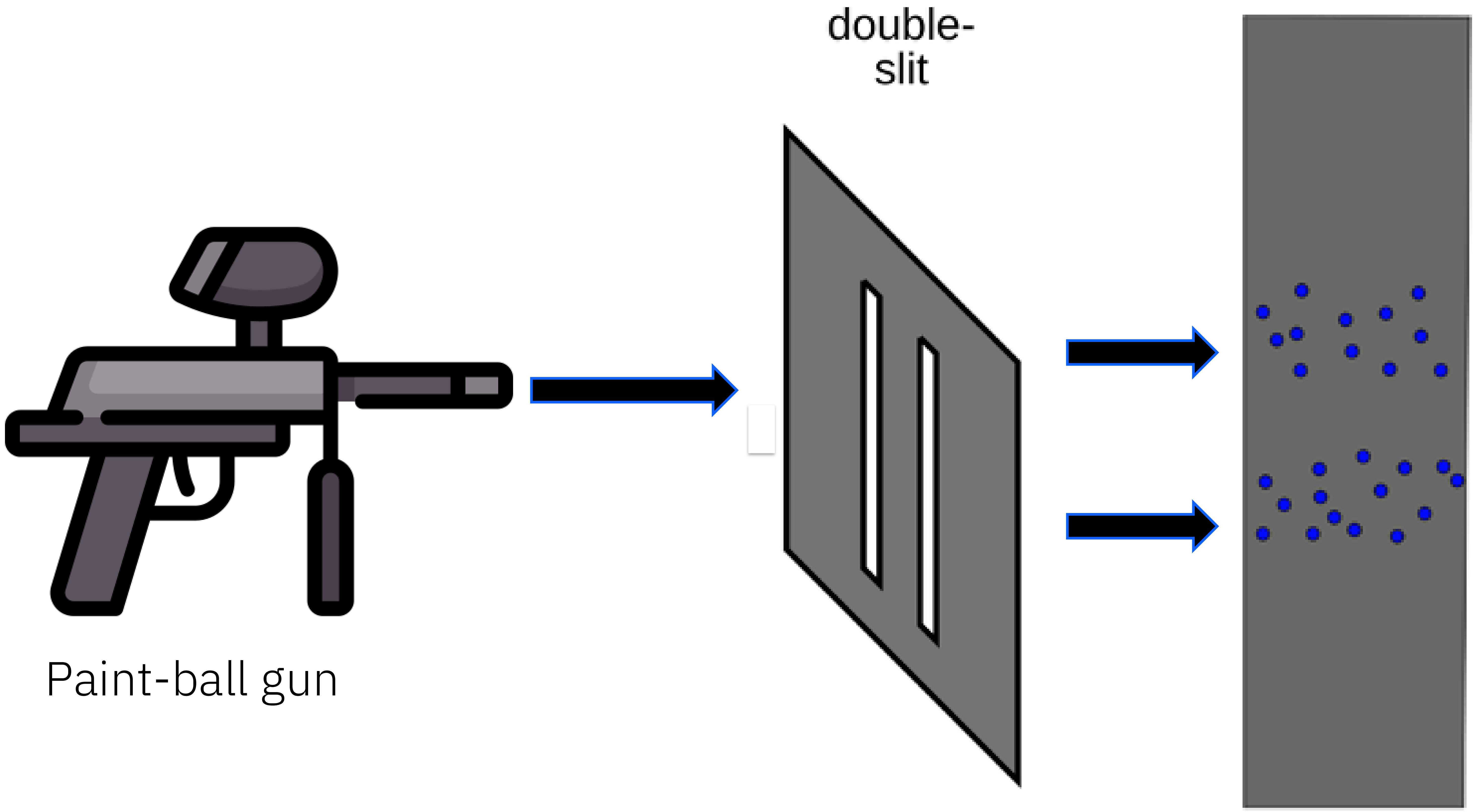
Unlike classical physics, quantum mechanics introduces radical new ideas:

- Matter and energy are quantized (come in discrete packets)
- Particles can exist in superposition (multiple states at once)
- Measurement affects reality: observing a quantum system collapses it into a definite state
- Particles can be entangled, meaning their states are linked across space

Quantum mechanics is a probabilistic theory of waves and particles.

Wave–Particle Duality — The Double-Slit Experiment

Life is strong and fragile. It's a paradox. It's both things, like quantum physics:
It's a particle and a wave at the same time.



Paint-ball gun

A particle is a small, discrete unit of matter or energy.

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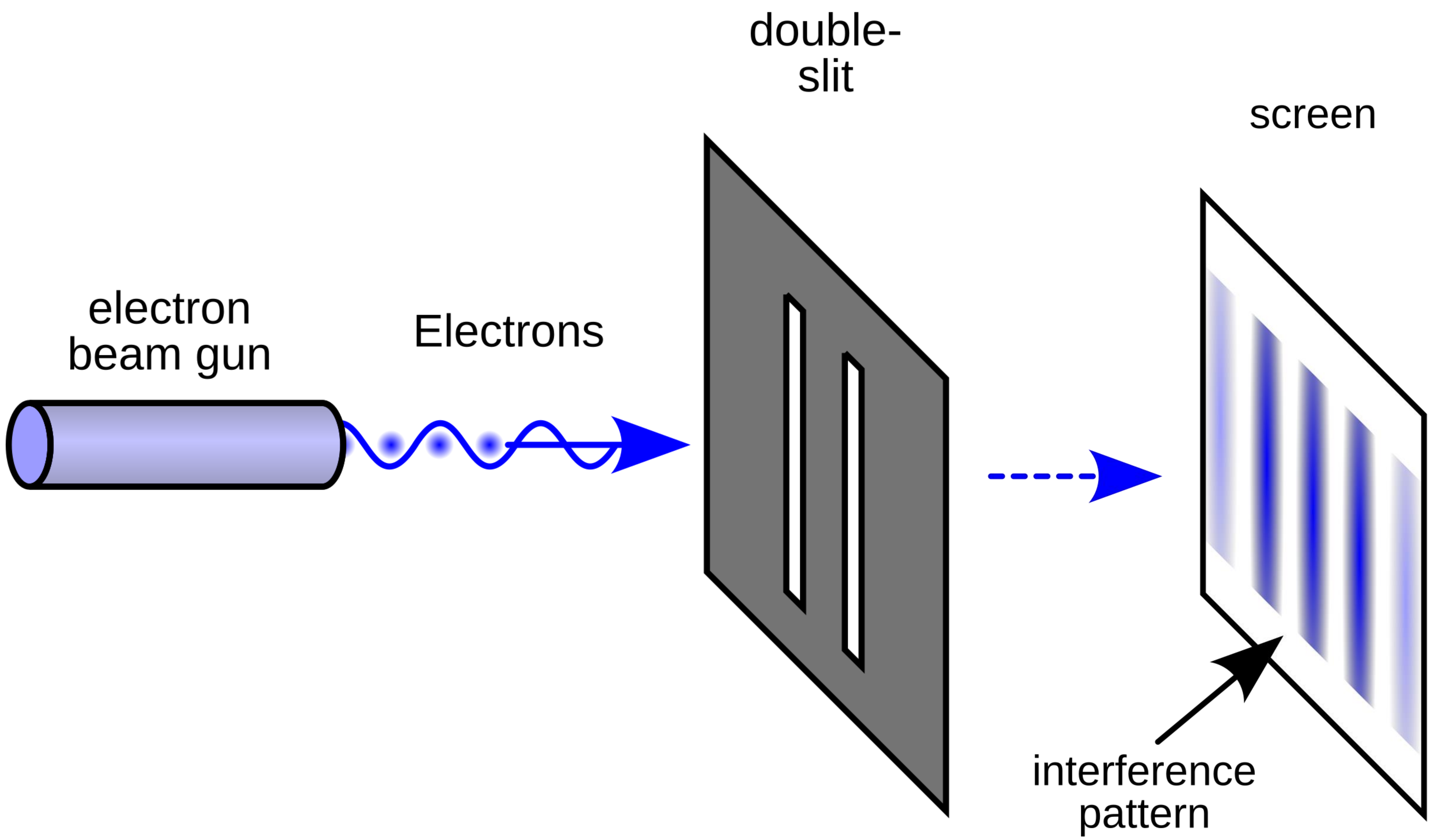

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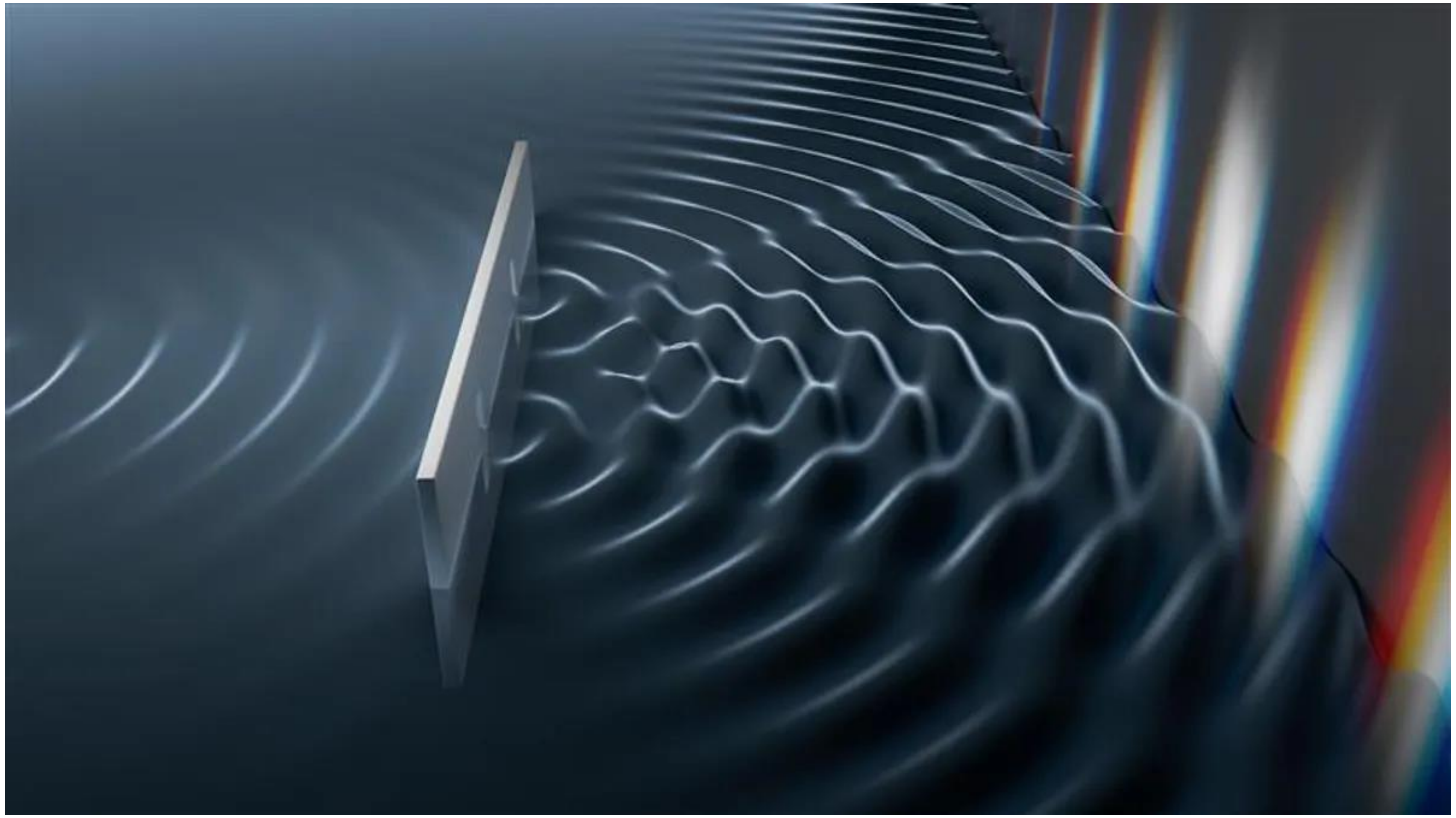

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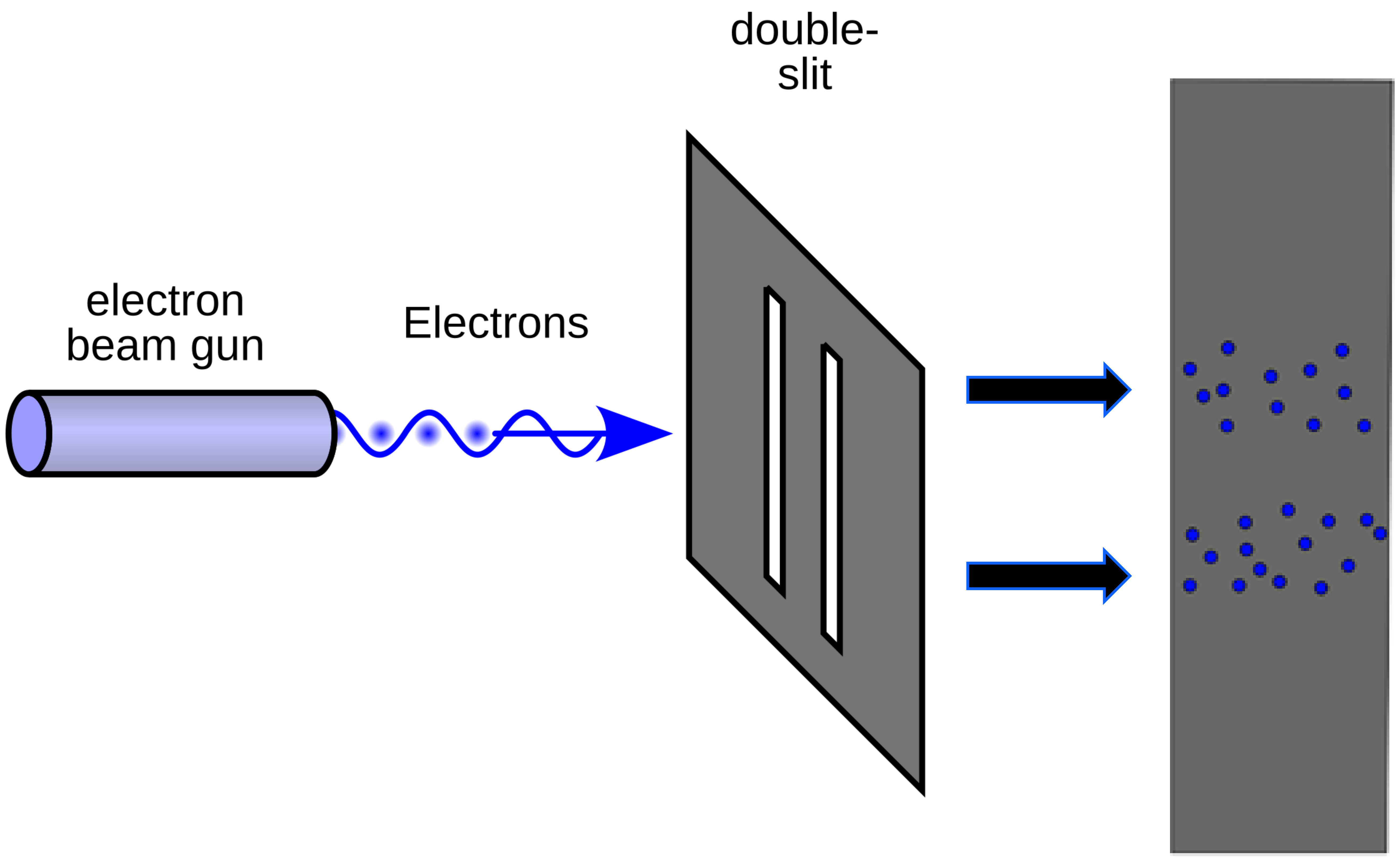

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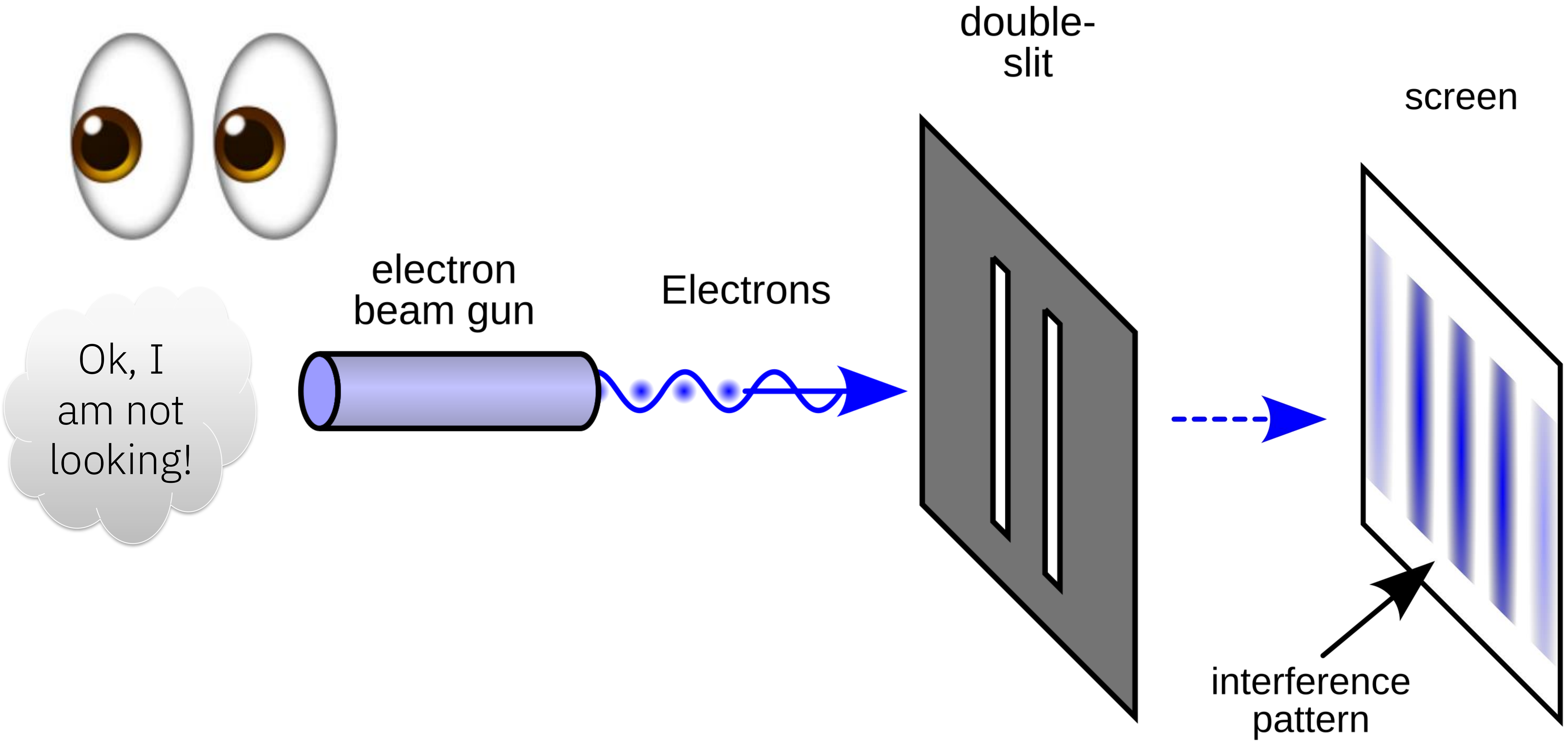


A particle is a small, discrete unit of matter or energy.

Heisenberg Uncertainty Principle

The more precisely we determine a particle's position, the less precisely we can know its momentum.

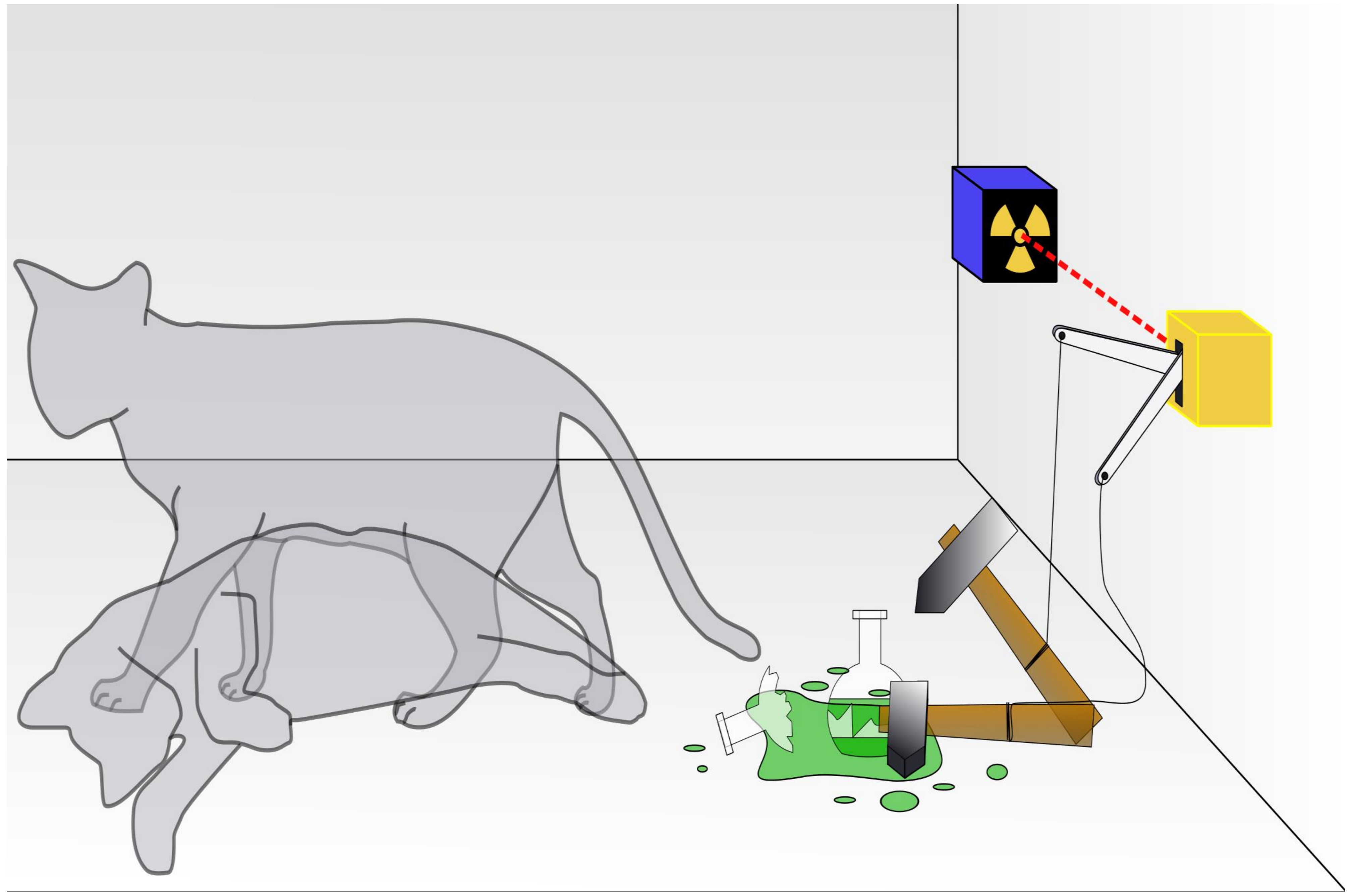
$$\Delta x \cdot \Delta p \geq \frac{\hbar}{2}$$

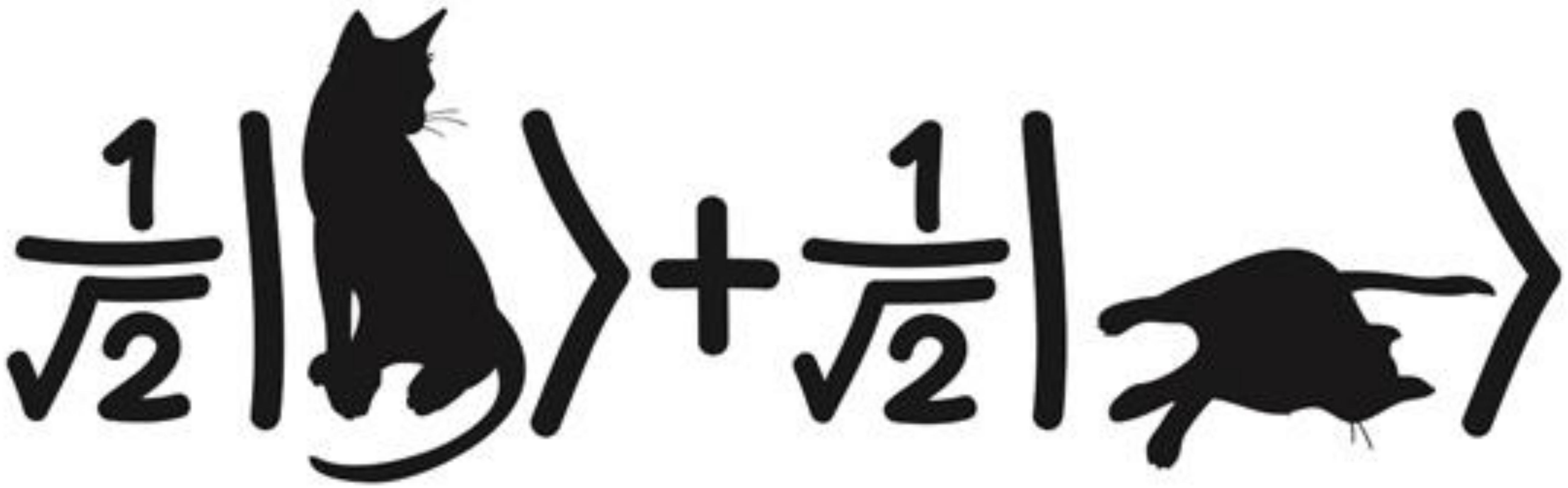
- Δx : Uncertainty in position
- Δp : Uncertainty in momentum
- $\hbar$: Reduced Planck's constant

- Fundamental limit on how precisely we can simultaneously know certain pairs of observables (like position and momentum).

- If you try to observe which slit a particle goes through, you destroy the interference. In other words, gaining knowledge of one property (path) collapses another (wave behaviour).

Schrodinger's Cat – Thought Experiment

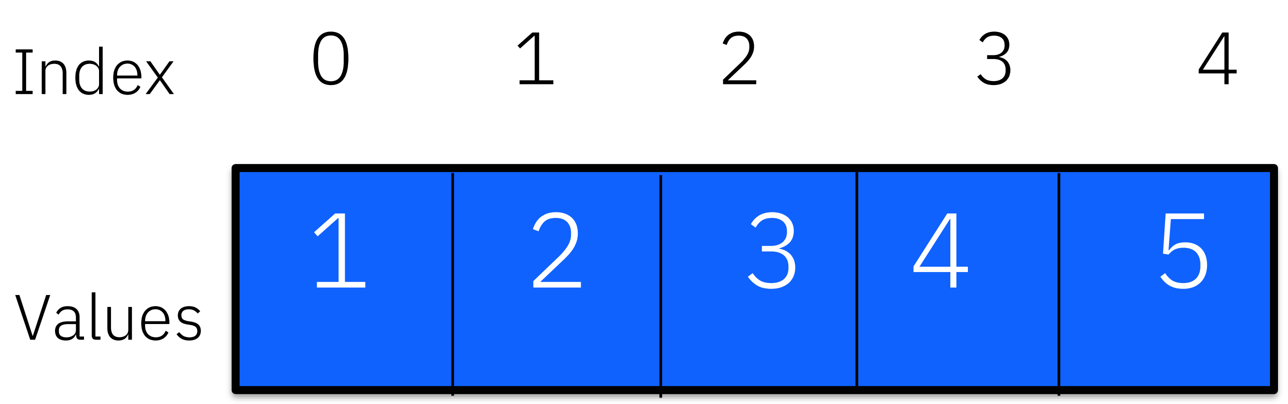




Linear Algebra Perspectives

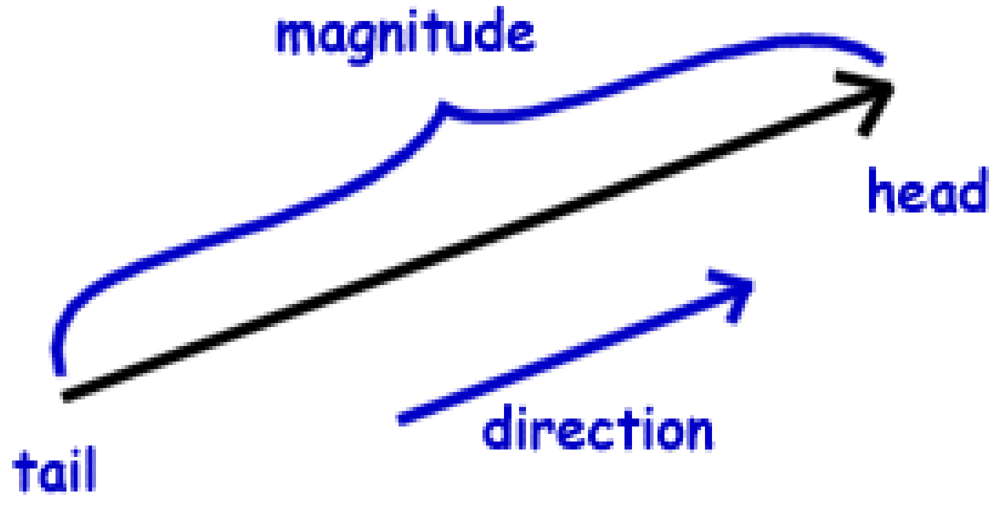
Data Science/Computer Science:

- Efficient computation of large-scale datasets (e.g., images, tensors), statistical analysis and optimization.
- Vectors are one dimensional data structures; matrices for representing multi-dimensional data,
- E.g., Linear algebra operations for machine learning algorithms.



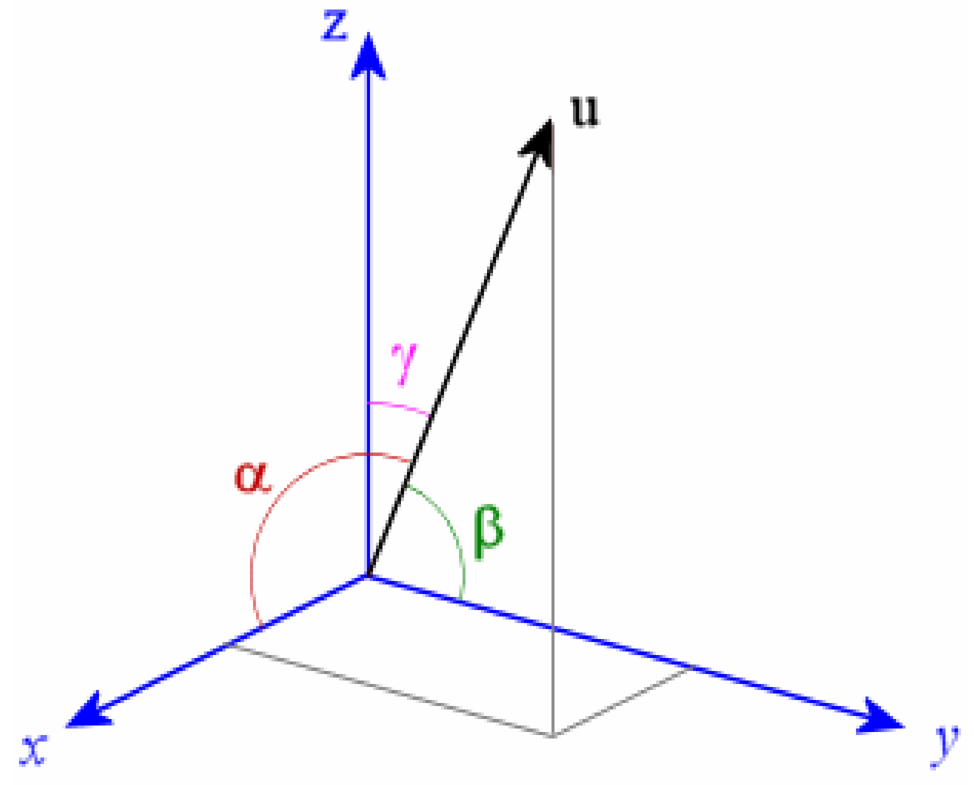
Physics:

- Modelling physical systems in multi-dimensional spaces (forces, motion, velocity, quantum systems).
- Vectors are quantities with magnitude and direction; matrices for linear transformations;.
- E.g., Operators in quantum mechanics.



Math:

- Combination of both perspectives. Includes abstract theory and rigorous study of vector spaces and set theory
- Vectors as ordered list of numbers from a set (e.g. $\mathbb{R}$ or $\mathbb{C}$), matrices for transformations.
- E.g., Study of properties like linearity, invertibility



The limit of bits

For decades we've been simplifying nature into 1s and 0s because that was the only way we could manage to create a useful and scalable system of computation.

0010011011100100100010010010011001001110010111 0
0111110010100100011100010001001010001001001010 1
0100101010111001001101110010010001001001001100 1
0011100101110011111001010010001110001000100101 0
001001001010101001010101110111001110010101111 0

The limit of bits

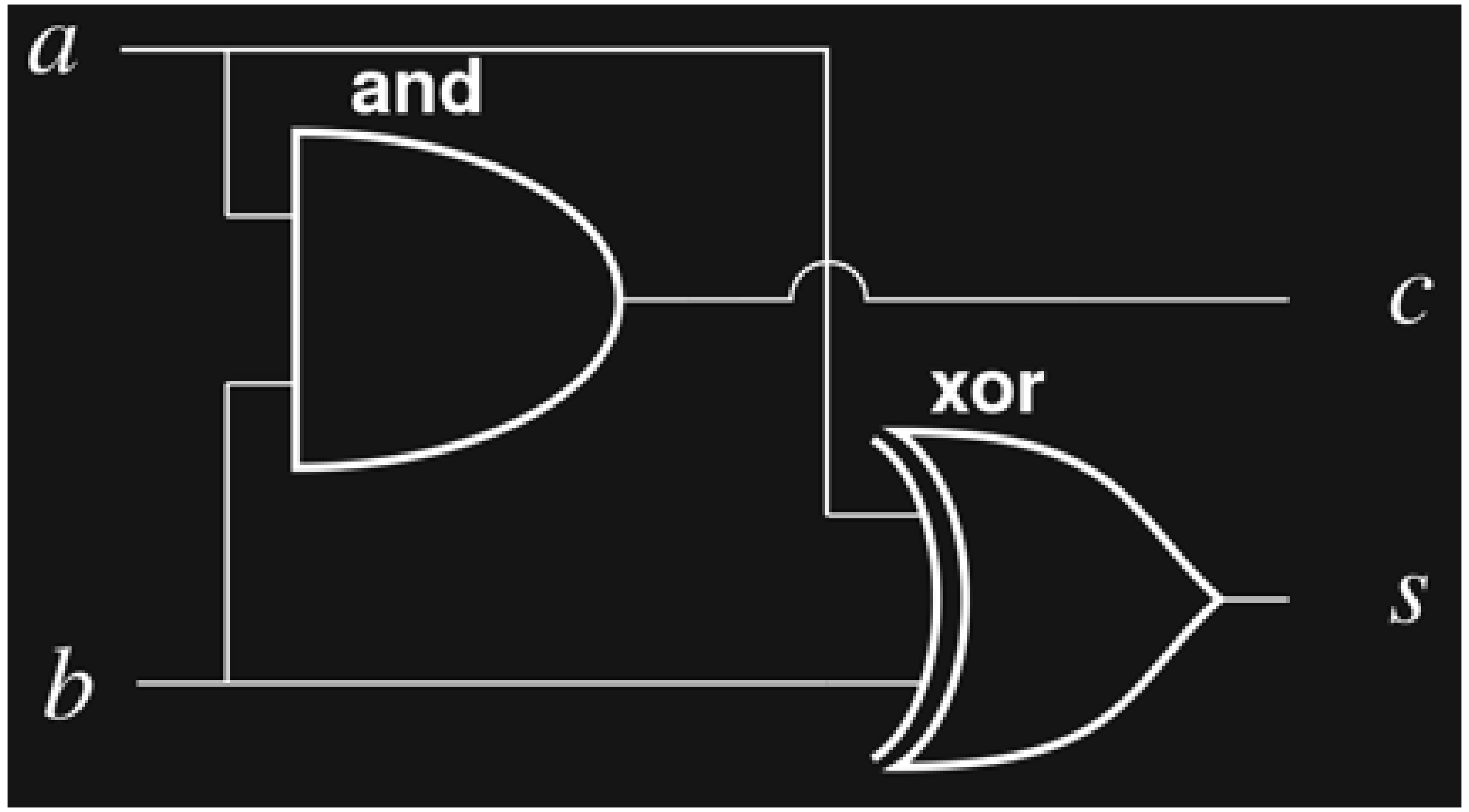
For decades we've been simplifying nature into 1s and 0s because that was the only way we could **manage** to create a useful and scalable system of computation.

00100110111001001000100100100110010011100101110
01111100101001000111000100010010100010010010101
01001010101110010011011100100100010010010011001
00111001011100111110010100100011100010001001010
0010010010101010010101011101110011100101011110

Bits and classical logic circuits

IBM **Quantum**

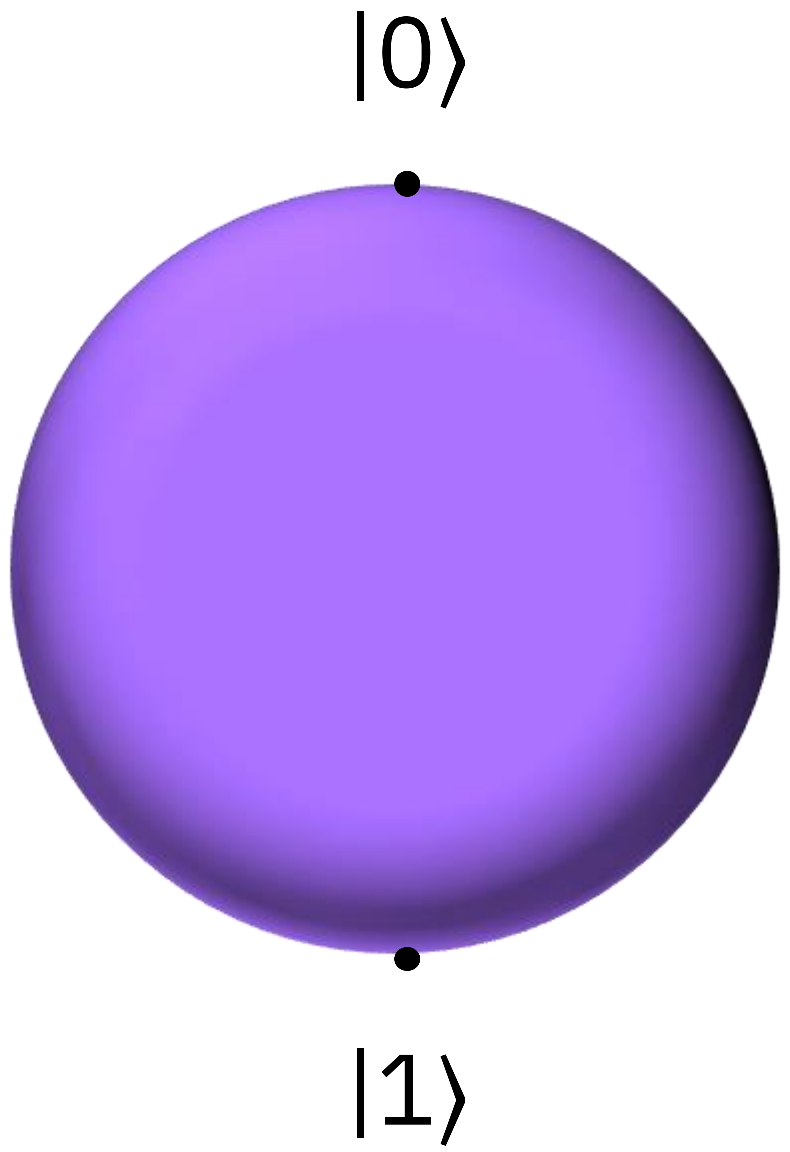
A bit is a controllable classical object that is the unit of information



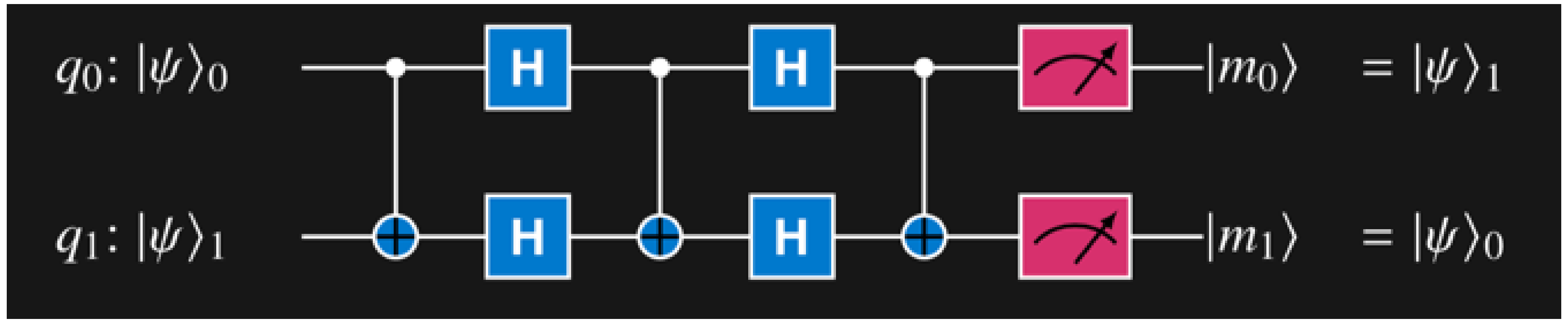
A classical logic circuit is a set of gate operations on bits and is the unit of computation

Quantum bits (qubits) and quantum circuits

IBM **Quantum**



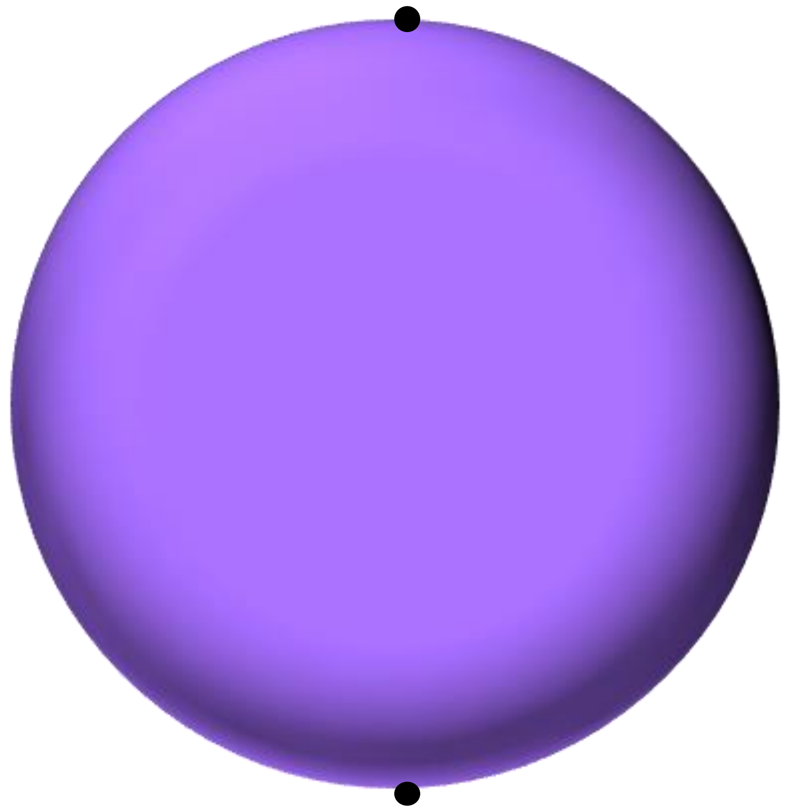
A quantum bit or qubit is a controllable quantum object that is the unit of information



A quantum circuit is a set of quantum gate operations on qubits and is the unit of computation

Quantum bits (qubits) and quantum circuits

$|0\rangle$

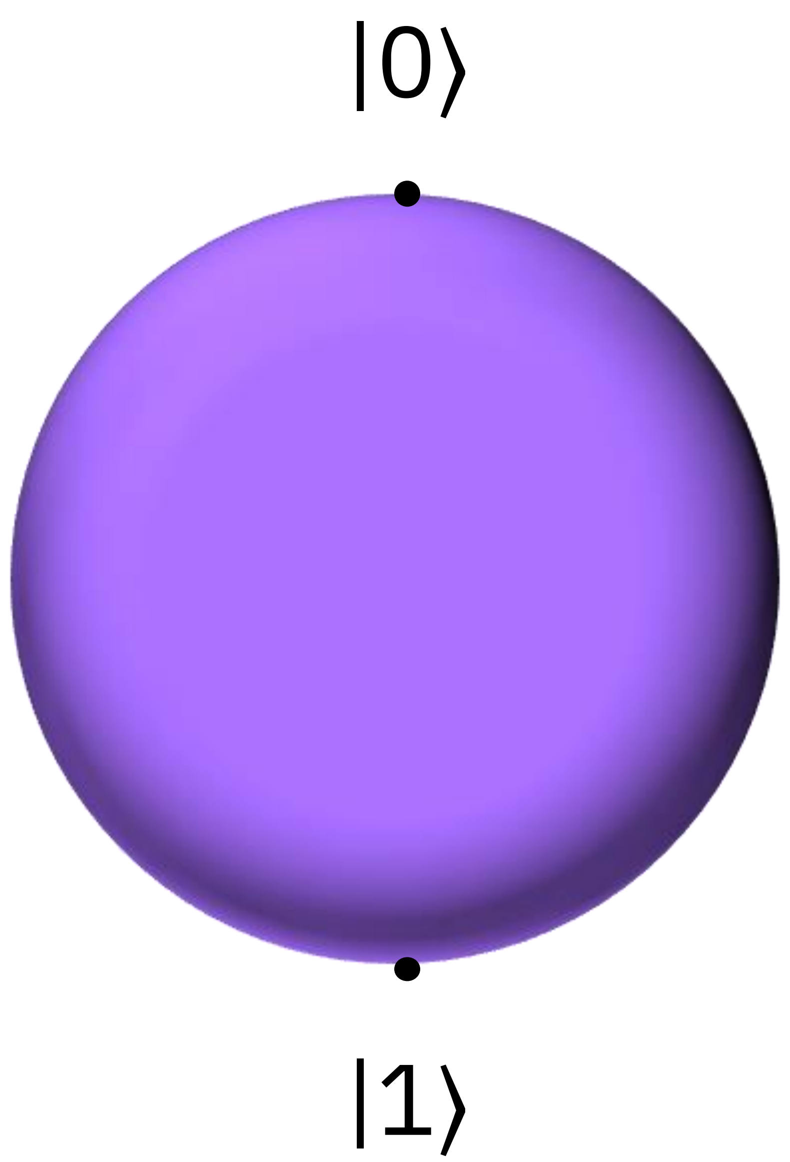


$|1\rangle$

A quantum bit or qubit is a controllable quantum object that is the unit of information

Operator	Gate(s)		Matrix
Pauli-X (X)	$\boxed{\mathbf{X}}$	$\oplus$	$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
Pauli-Y (Y)	$\boxed{\mathbf{Y}}$		$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$
Pauli-Z (Z)	$\boxed{\mathbf{Z}}$		$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$
Hadamard (H)	$\boxed{\mathbf{H}}$		$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
Phase (S, P)	$\boxed{\mathbf{S}}$		$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$
$\pi/8$ (T)	$\boxed{\mathbf{T}}$		$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{bmatrix}$
Controlled Not (CNOT, CX)			$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$
Controlled Z (CZ)	$\boxed{\mathbf{Z}}$		$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$
SWAP			$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$
Toffoli (CCNOT, CCX, TOFF)			$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$

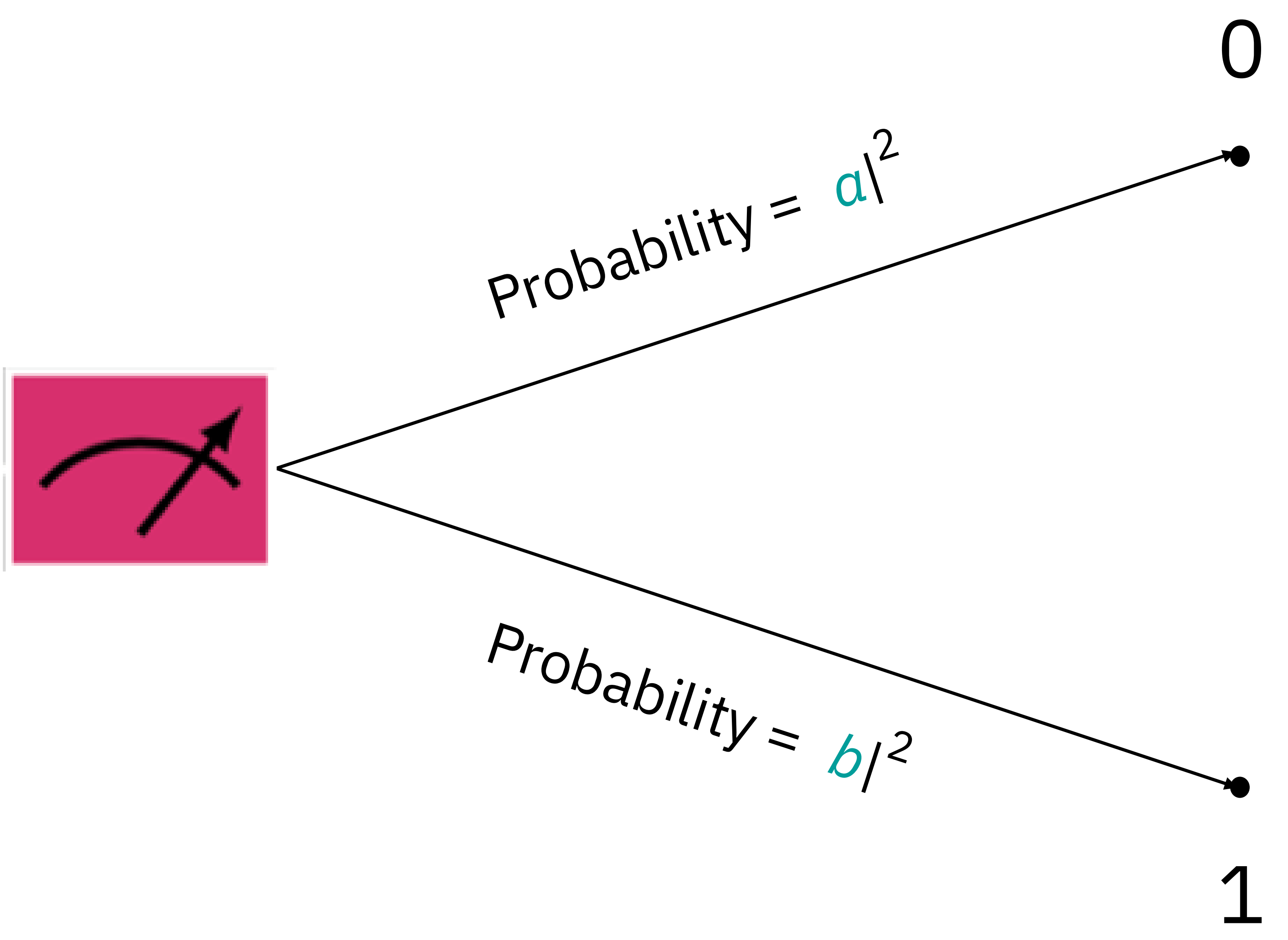
Bits and qubits



A qubit's state is a combination of |0⟩ and |1⟩:

$a\,|0\rangle + b\,|1\rangle$

This means that a single qubit contains two pieces of information.



When we measure a qubit, it becomes **0** or **1** based on probability.

Quantum computing uses essential ideas from quantum mechanics

Superposition

$|0\rangle$ and $|1\rangle$ are vectors in the two-dimensional complex vector space $\mathbf{C}^2$:

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad \text{and} \quad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

So, we can write any vector in $\mathbf{C}^2$ as

$$a\,|0\rangle + b\,|1\rangle$$

We pronounce $|0\rangle$ and $|1\rangle$ as “ket zero” and “ket one.” These are called the *computational basis*.

Quantum computing uses essential ideas from quantum mechanics

Superposition

Superposition is creating a quantum state that is a combination of $|0\rangle$ and $|1\rangle$

$$a\,|0\rangle + b\,|1\rangle$$

where

a and b are complex numbers

$|a|^2 + |b|^2 = 1$

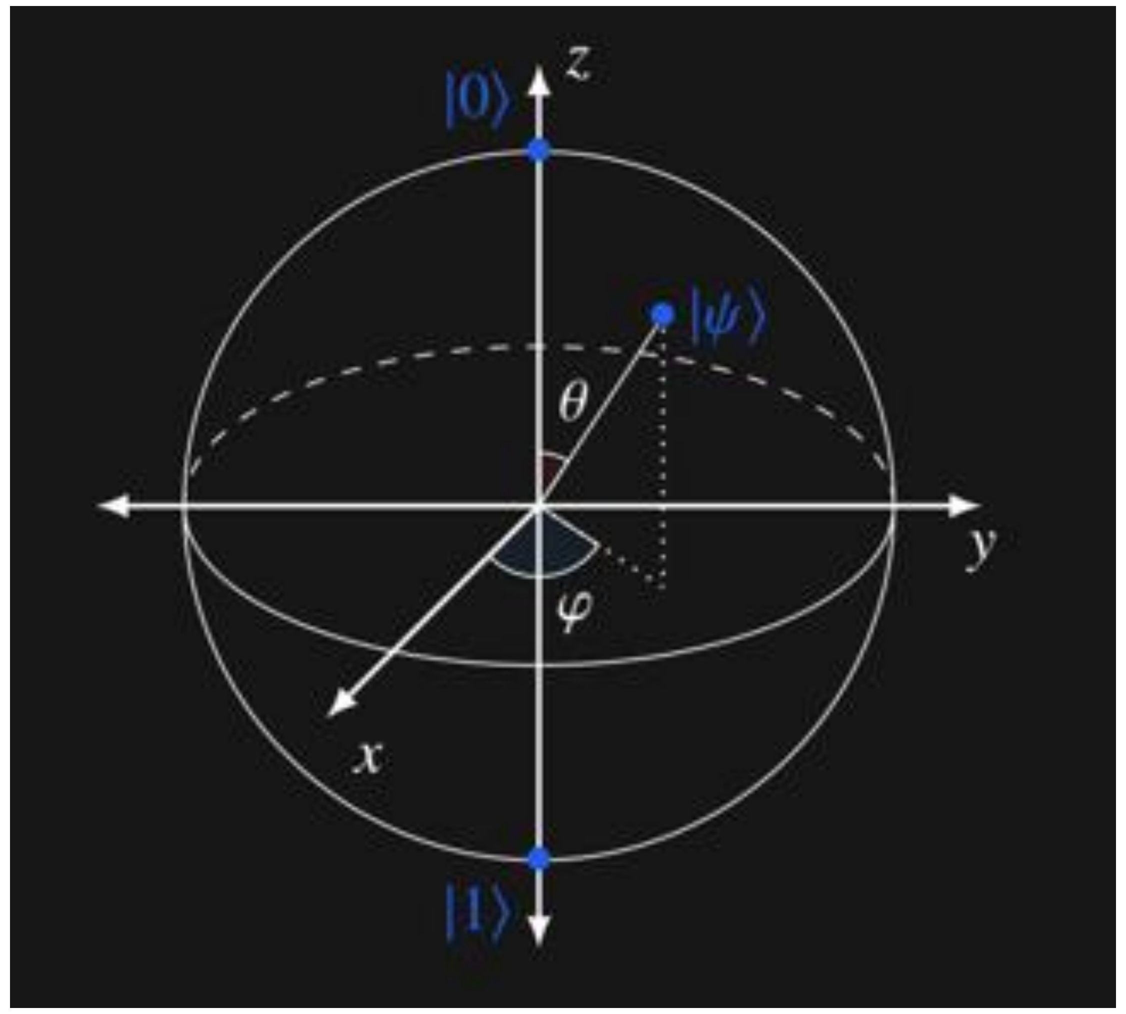
Two quantum states are equivalent if they differ only by a constant multiple u where $|u| = 1$.

This is because

$$|a|^2 + |b|^2 = |au|^2 + |bu|^2 = 1$$

Quantum computing uses essential ideas from quantum mechanics

Superposition



Superposition is creating a quantum state that is a combination of $|0\rangle$ and $|1\rangle$

$$a\,|0\rangle + b\,|1\rangle$$

These conditions allow us to map the qubit onto the *Bloch Sphere*.

Note that if a and b are non-zero, then the qubit's state contains both $|0\rangle$ and $|1\rangle$.

This is what people mean when they say that a qubit can be "0 and 1 at the same time."

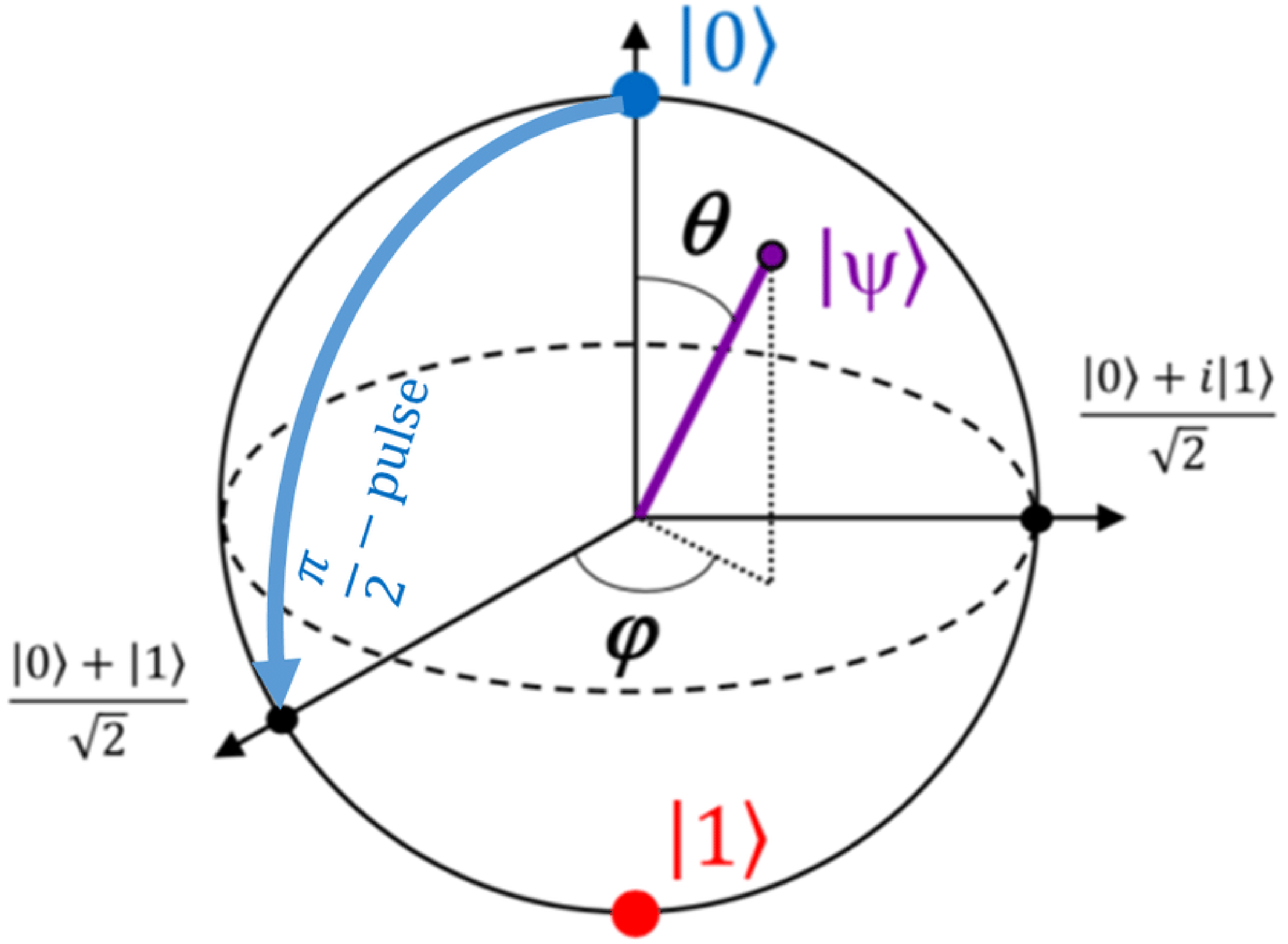
Bits and qubits

A qubit is a unit vector in a 2D complex vector space (a Hilbert space) expressed as:

$$|\,\psi\rangle \;=\; \alpha|0\rangle \;+\; \beta|1\rangle$$

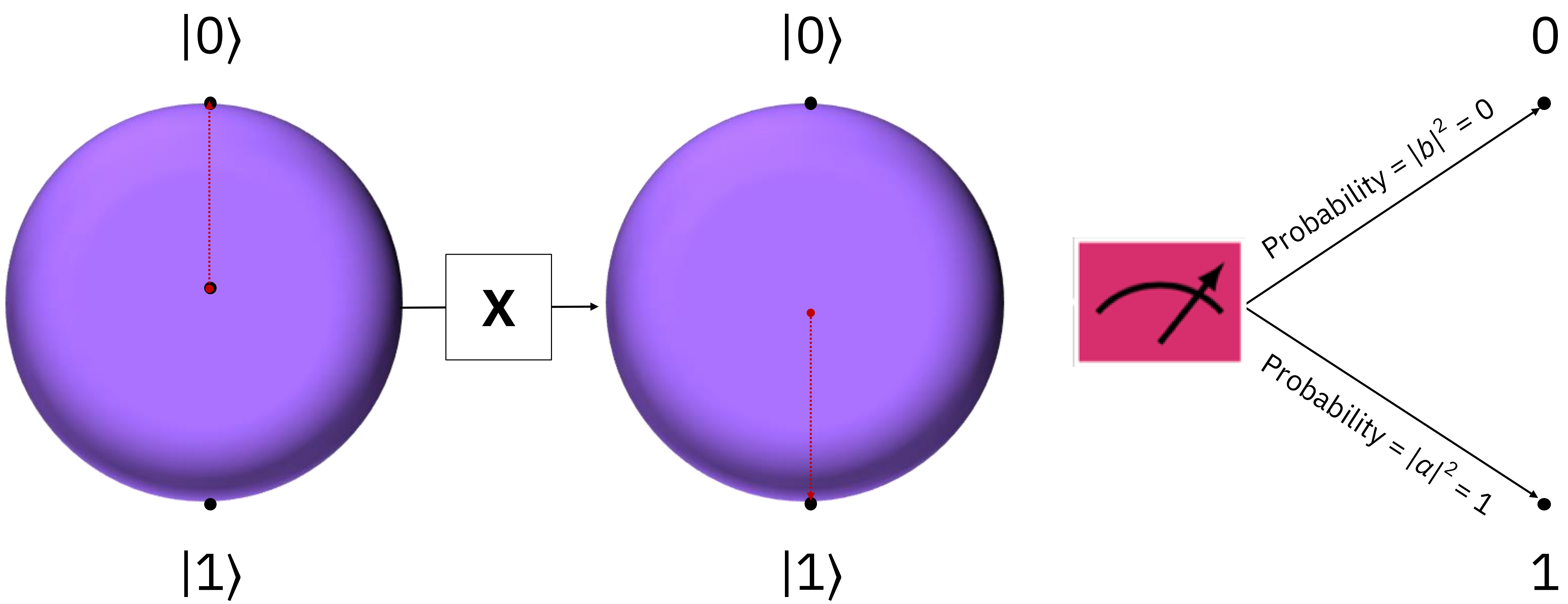
Where:

- $\alpha, \beta \;\in\; \mathbb{C}$, and describe the probability in unit vector state $\rightarrow \binom{1}{0}\; for\ |0\rangle\ and\ \binom{0}{1}\; for\ |1\rangle$
- $|\alpha|^2 + |\beta|^2 = 1$, complex magnitude/distance to origin $= \; 1$
- $|\Psi\rangle$ is a wave function/density probability matrix



$$|\psi\rangle = cos\frac{\theta}{2}|0\rangle + e^{i\varphi}sin\frac{\theta}{2}|1\rangle$$

Bits and qubits: the effect of the X gate on $|0\rangle$



The **X** gate reverses $|0\rangle$ and $|1\rangle$:

$a\,|0\rangle + b\,|1\rangle \;\mapsto\; b\,|0\rangle + a\,|1\rangle$

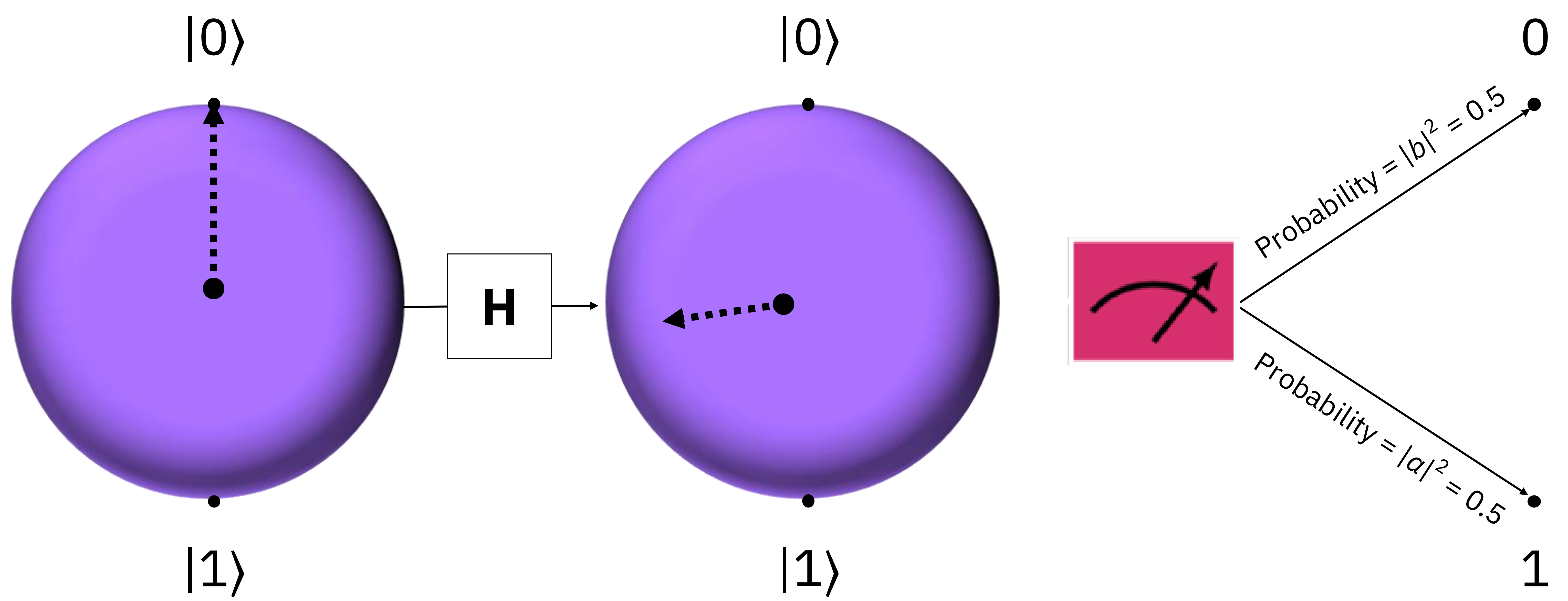
$a = 1$ and $b = 0$,

so $|0\rangle$ is mapped to $|1\rangle$.

When measured, the result is **1** with 100% probability.

Bits and qubits: the effect of the **H** gate on $|0\rangle$

IBM **Quantum**



The **H** gate maps $|0\rangle$ via

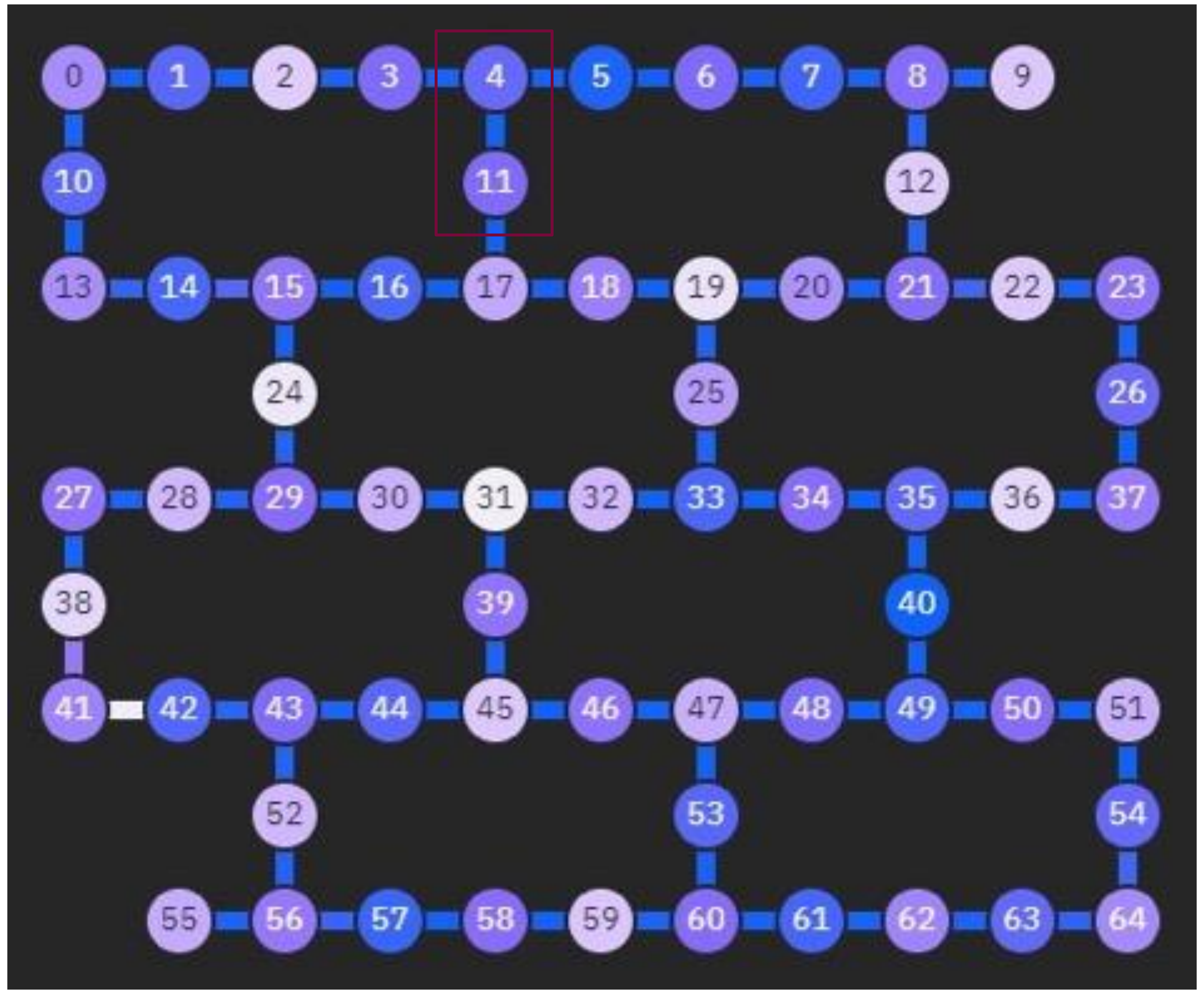
$$|0\rangle \mapsto (1/\sqrt{2})\,|0\rangle + (1/\sqrt{2})\,|1\rangle = a\,|0\rangle + b\,|1\rangle$$

Since $a = b = 1/\sqrt{2}$, $|a|^2 = |b|^2 = ½$.

When measured, the probability of getting **0** or **1** is the same, 0.5.
Quantum randomness!

Quantum computing uses essential ideas from quantum mechanics

Entanglement



With two qubits we get combinations like

$$a\,|00\rangle + b\,|01\rangle + c\,|10\rangle + d\,|11\rangle$$

where

$|01\rangle$ means the first qubit is $|0\rangle$ and the second is $|1\rangle$

a, b, c, and d are complex numbers and

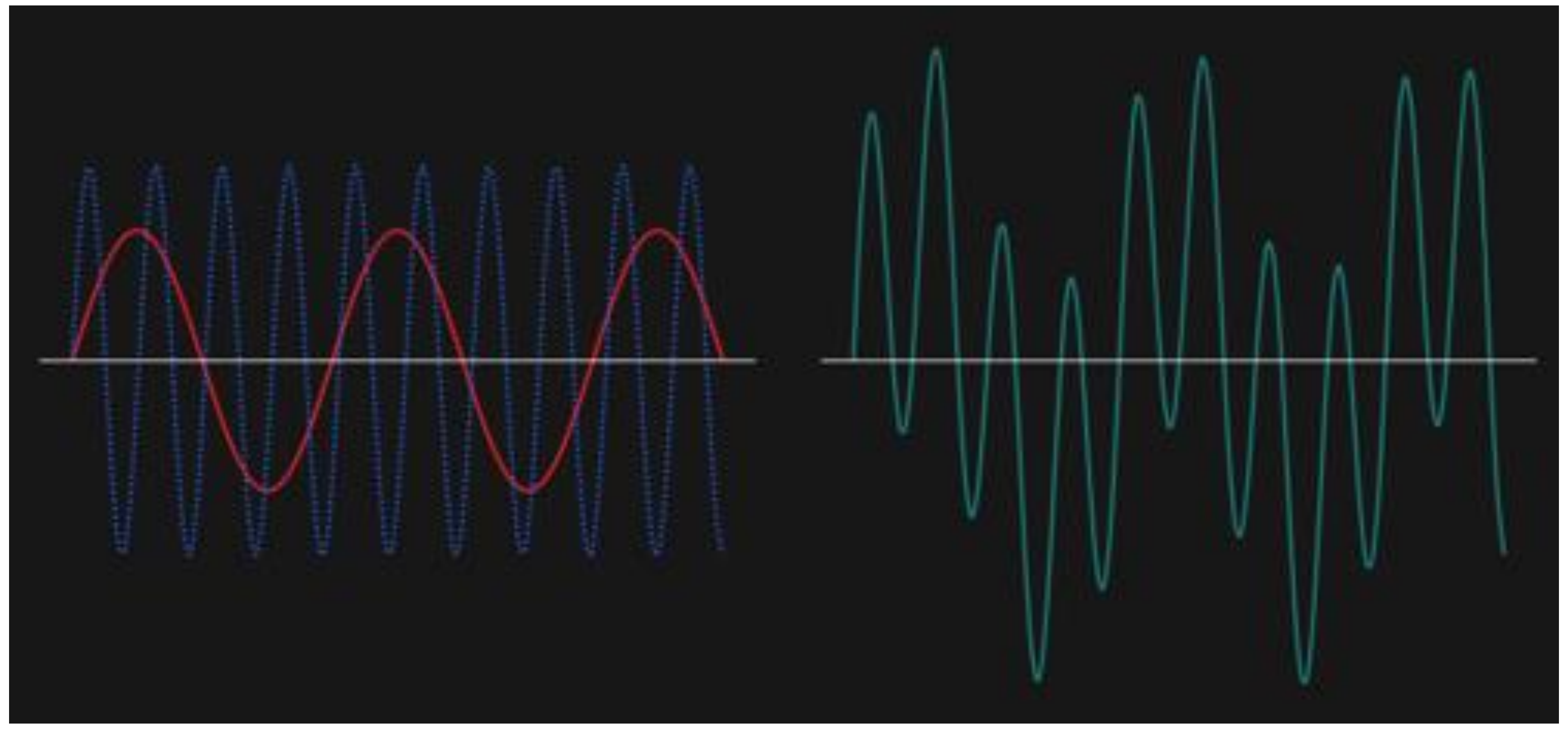
$$|a|^2 + |b|^2 + |c|^2 + |d|^2 = 1$$

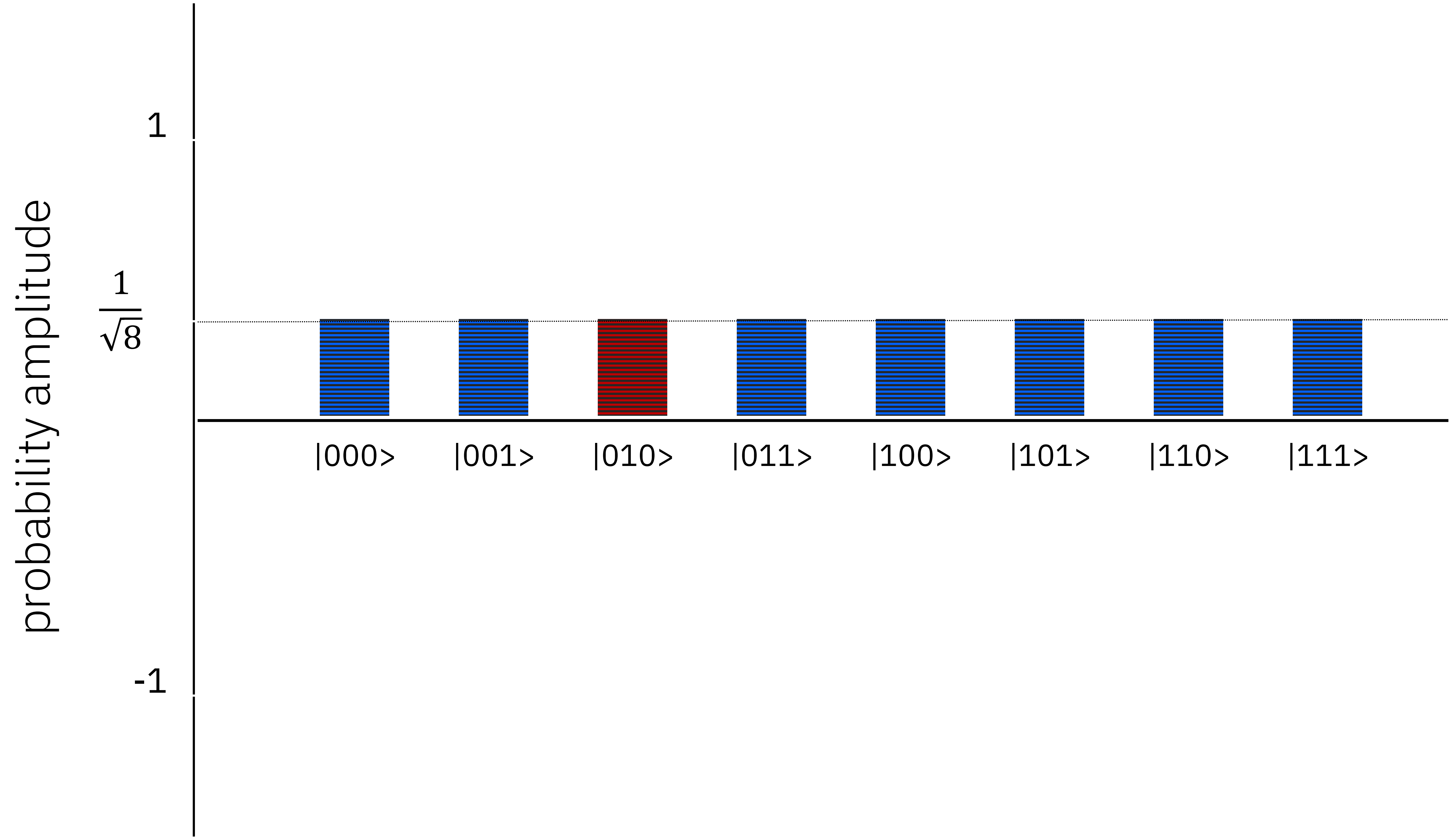
If two or more of the a, b, c, and d are non-zero, and we cannot separate the qubits, they are entangled with perfect correlation and are no longer independent.

Quantum computing uses essential ideas from quantum mechanics

Interference allows us to increase the probability of getting the right answer and decrease the chance of getting the wrong one.

Interference





Quantum computing uses essential ideas from quantum mechanics

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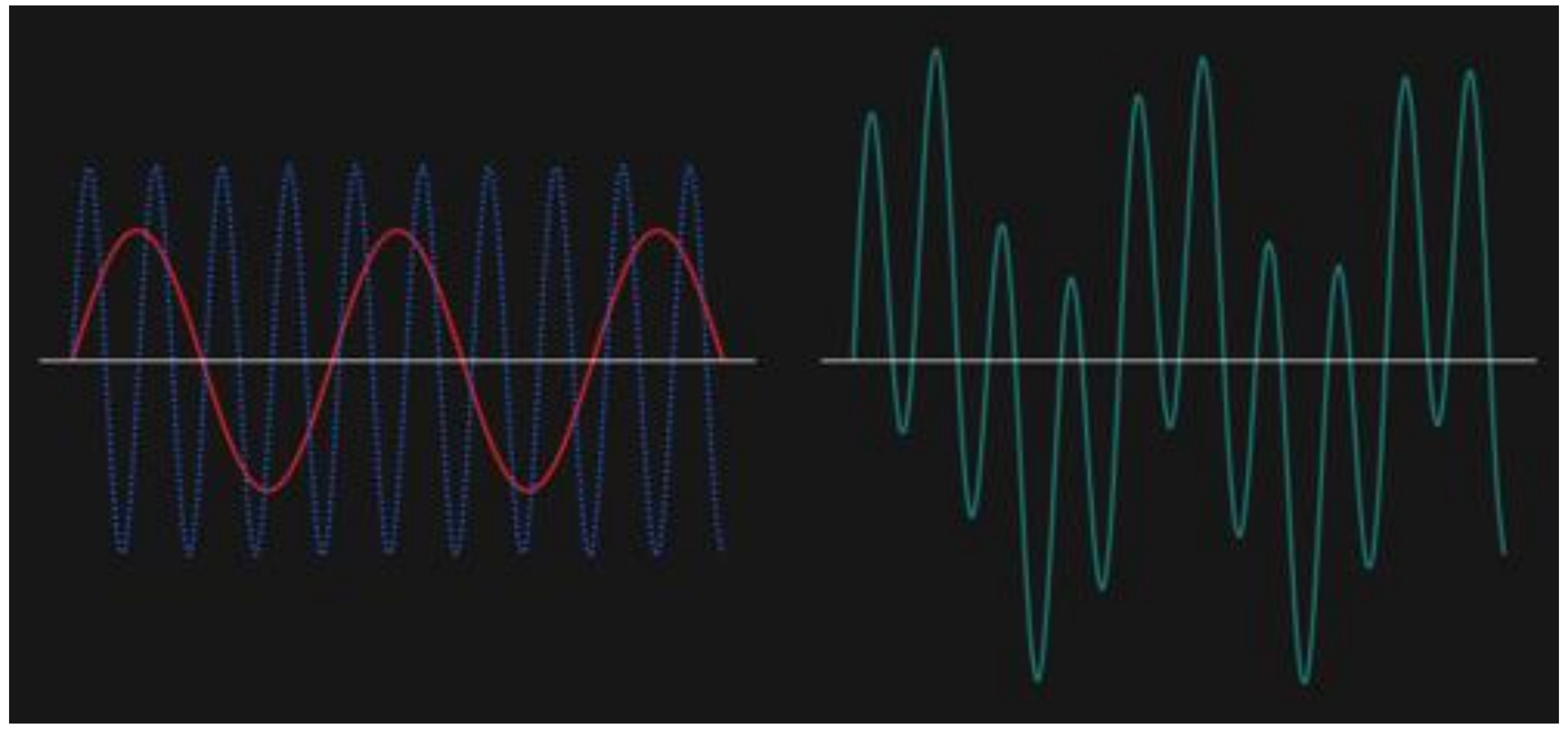

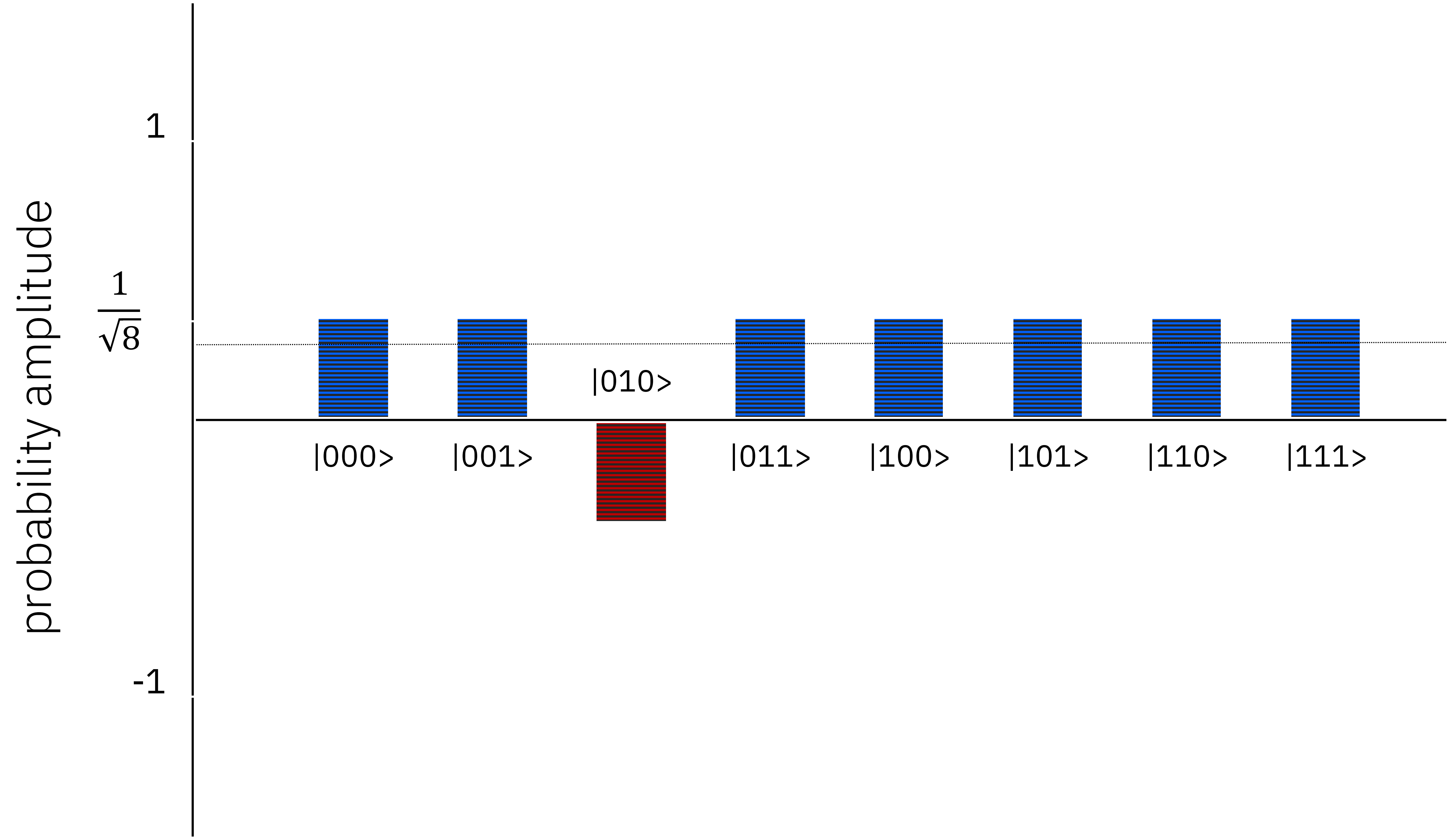

Quantum computing uses essential ideas from quantum mechanics

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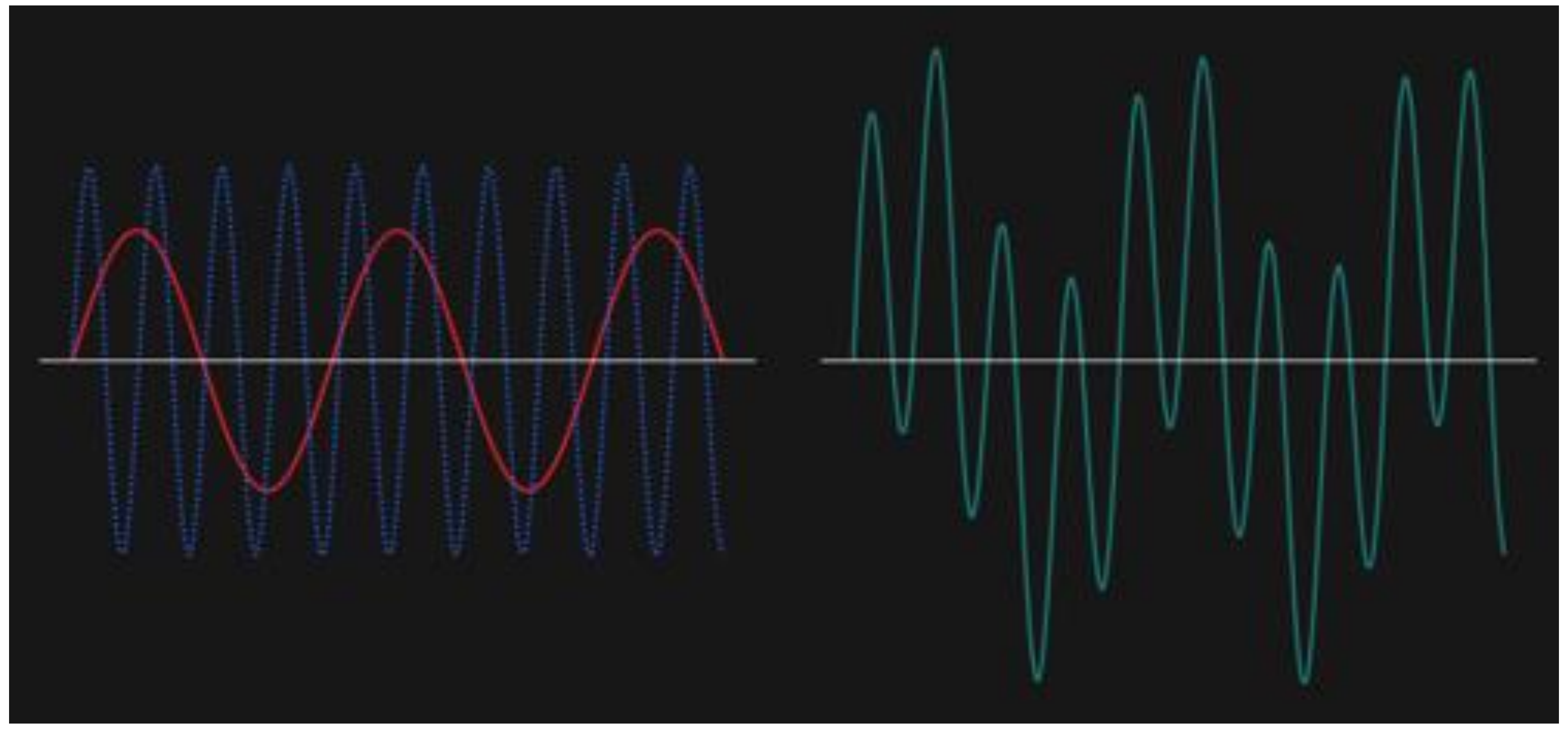
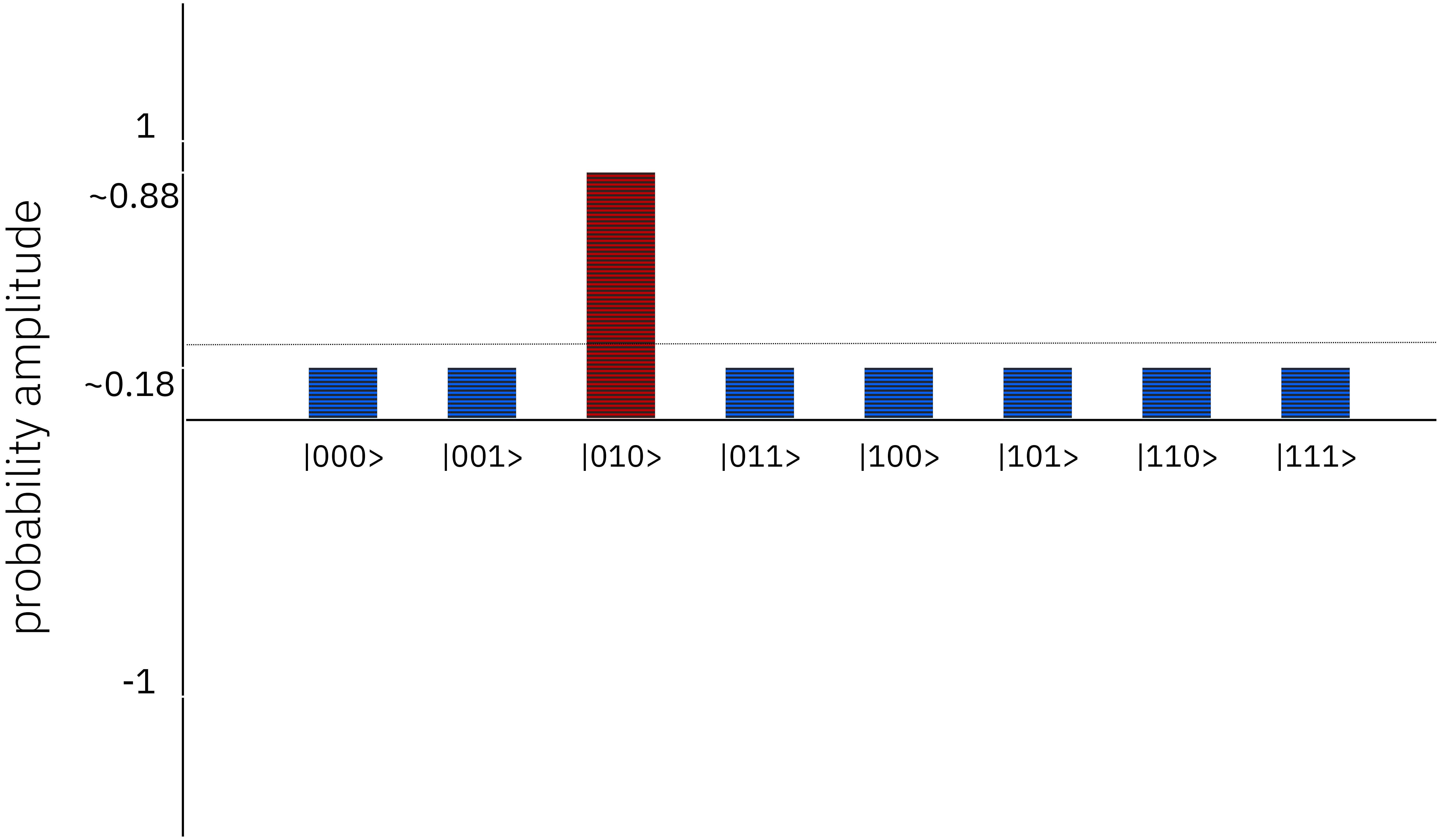
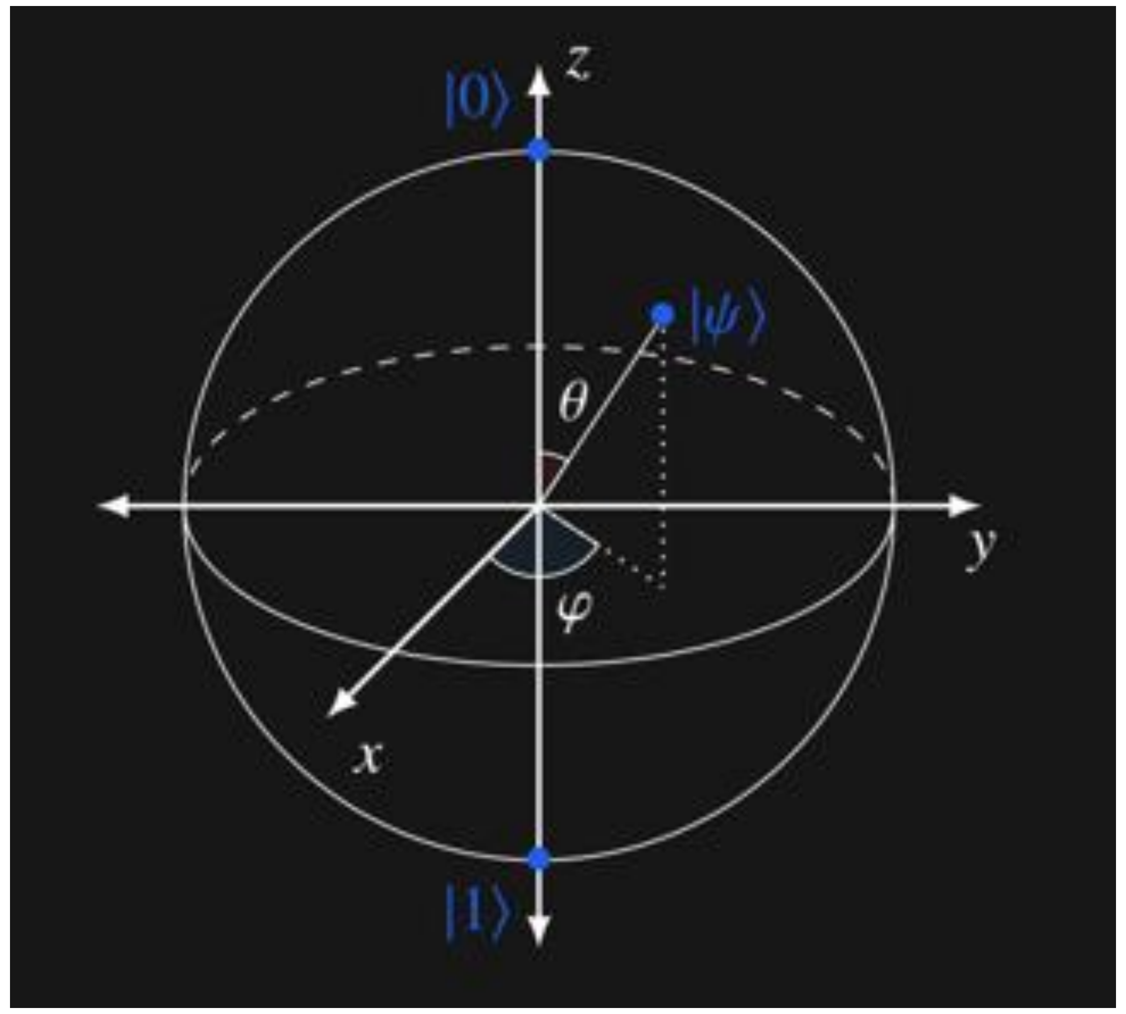




Quantum computing uses essential ideas from quantum mechanics

Measurement



Measurement is forcing the qubit's state

$$a\,|0\rangle + b\,|1\rangle$$

to $|0\rangle$ or $|1\rangle$ by observing it, where

$|a|^2$ is the probability we will get $|0\rangle$ when we measure

$|b|^2$ is the probability we will get $|1\rangle$ when we measure

For example,

$$\frac{\sqrt{2}}{2}\,|0\rangle + \frac{\sqrt{2}}{2}\,|1\rangle$$

has an equal probability of becoming $|0\rangle$ or $|1\rangle$, and

$$\frac{\sqrt{3}}{2}\,|0\rangle - \frac{1}{2}\,i\,|1\rangle$$

has a 75% chance of becoming $|0\rangle$.

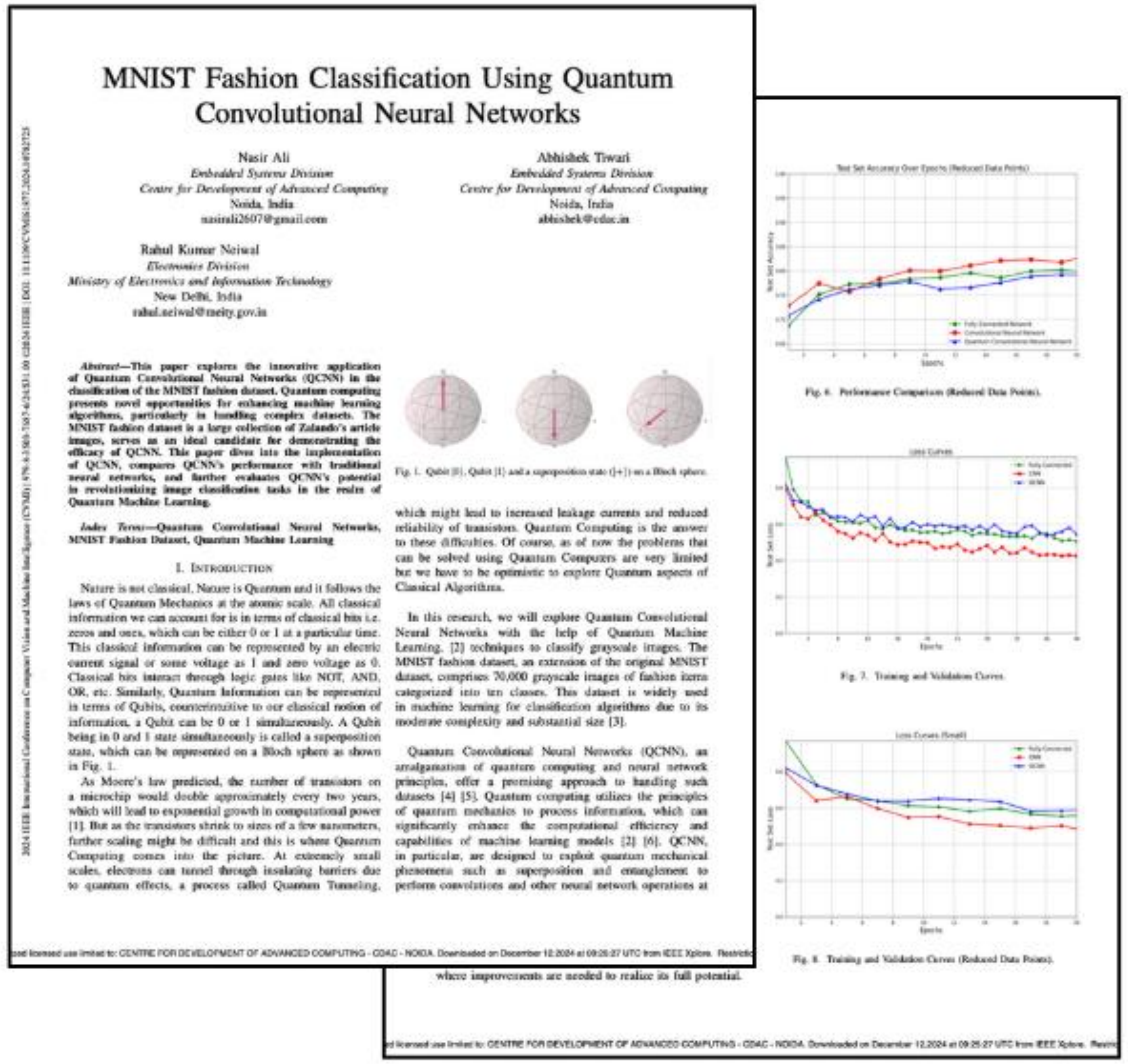
Yousra Farhani

Quantum Computing Researcher & Founder of Quantum Africa

- Founder of Quantum Africa
- Quantum Computing Researcher at INSA Lyon
- Engineering Degree in Information Technology, Ecole Nationale d'Informatique, ESI Algiers
- MSc in Research Focused on Quantum Computing, Institute of Applied Science, INSA Lyon
- Winner of the Arab Young Pioneers Award in Quantum Computing 2024

Join Quantum Africa

Explosive Growth in Quantum Algorithms Research (2024–2025)


MNIST Fashion Classification Using Quantum Convolutional Neural Networks

Nasir Ali
Embedded Systems Division
Centre for Development of Advanced Computing
Noida, India

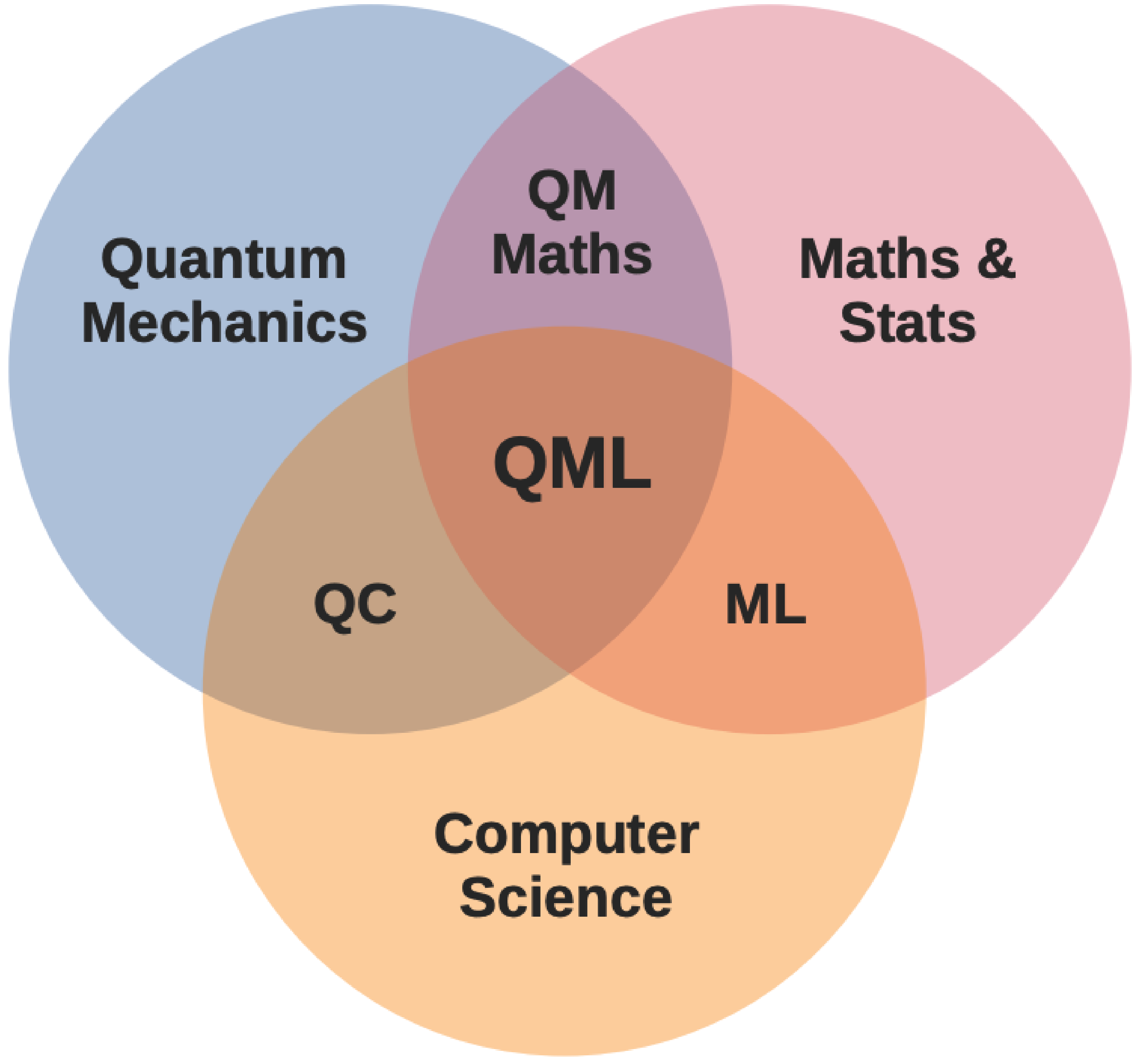
Abhishek Tiwari
Embedded Systems Division
Centre for Development of Advanced Computing
Noida, India

Rahul Kumar Neiwal
Electronics Division
Ministry of Electronics and Information Technology
New Delhi, India

Around 6,647 Published paper on Quantum Machine Learning in ArXiv (2024 - 2025)

Around 35–40% of QML ArXiv preprints from 2024 were later published in peer-reviewed journals or conference proceedings (e.g., *PRX Quantum*, *Nature Quantum Information*, *QIP*, *NeurIPS*, *ICLR*).

What is Quantum Machine Learning (QML)?



Quantum Machine Learning is the study of algorithms that run on quantum computers and are designed to learn patterns from data leveraging quantum phenomenas like superposition, entanglement, and interference to gain computational advantage.

– Biamonte, J., Wittek, P., Pancotti, N., Rebentrost, P., Wiebe, N., & Lloyd, S. (2017). Quantum machine learning. Nature, 549(7671), 195-202.

Quantum Machine Learning is a discipline seeking to take advantage of quantum mechanical processes to induce or enhance machine learning (ML), QML combines in novel ways the concepts and algorithms adopted from the Quantum Computing and Machine Learning research, and underpinned by the formalism of Quantum Mechanics.

- Introduction to Quantum Machine Learning Managing high complexity with the volume of data Jacob L. Cybulski Enquanted, Melbourne, Australia

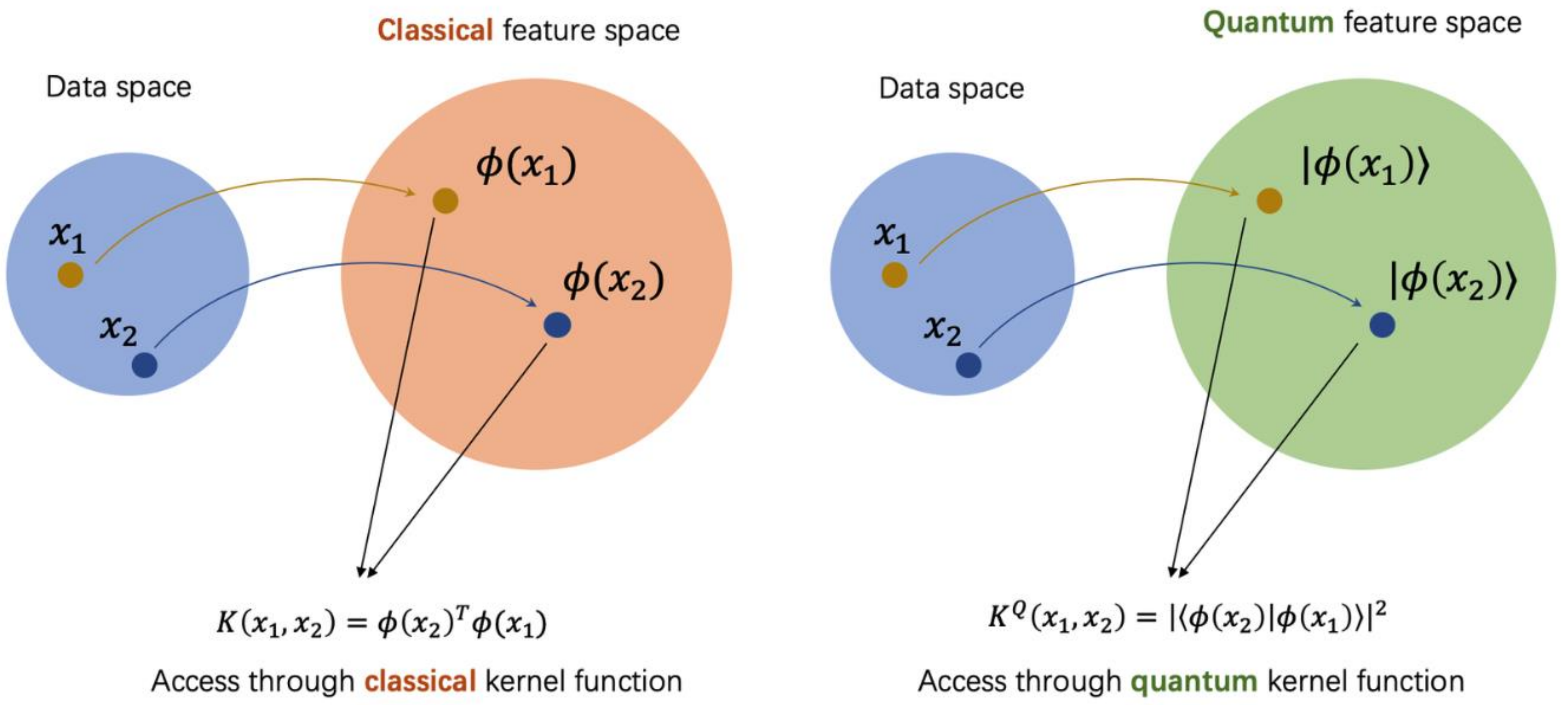
Why Quantum Machine Learning?

Classical ML Challenge

- Large feature spaces
- High-dimensional data
- Slow kernel evaluations
- Non-convex optimization

Quantum Potential Advantage

- Superposition: explore all at once
- Hilbert space embedding
- Quantum kernel methods (Faster, Secure)
- Quantum annealing, QAOA, VQE

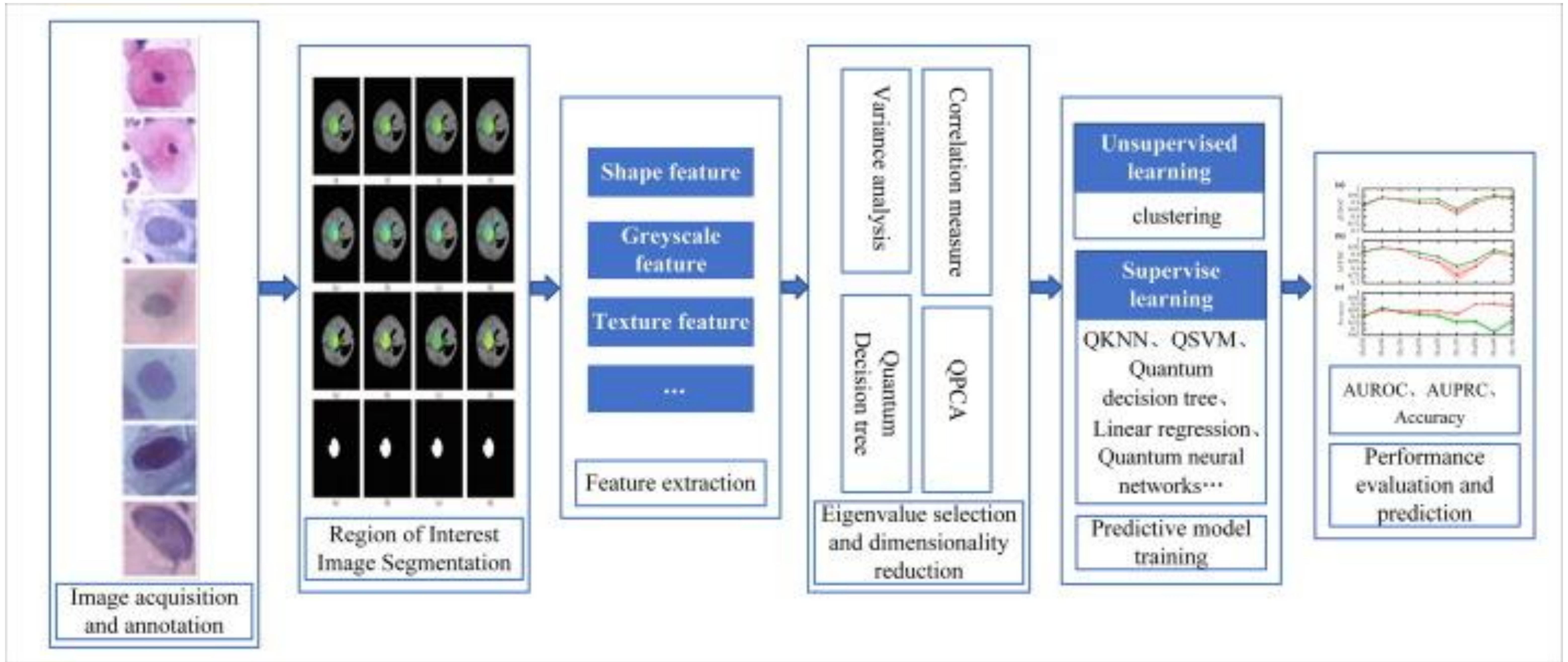


QML Use Cases

Healthcare & Medical Imaging

- QML used to enhance medical image processing (e.g., MRI, CT scans)

- Quantum Hadamard edge detection using Hadamard transforms improves contrast and boundary accuracy with O(1) Complexity

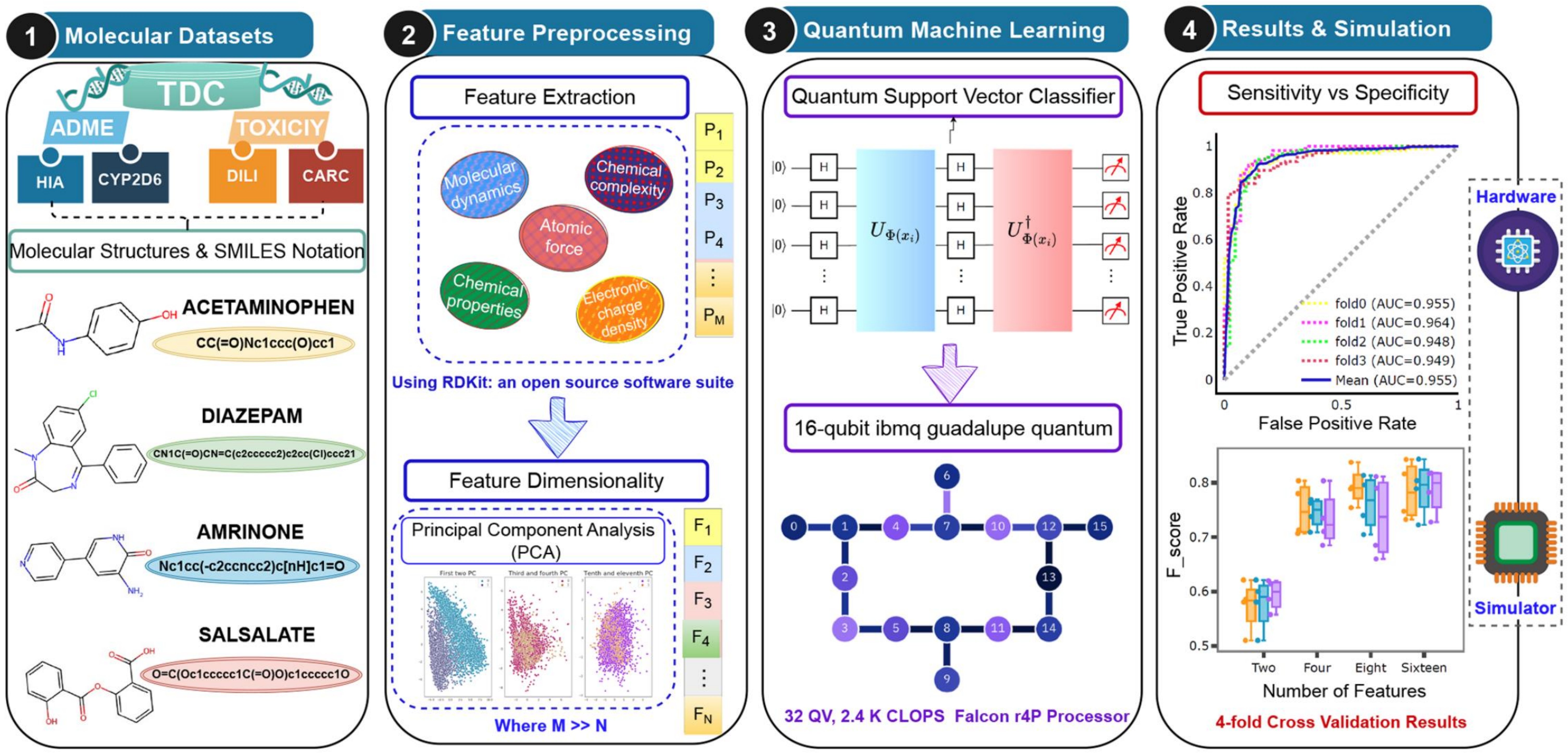


– Wei, Lin, et al. "Quantum machine learning in medical image analysis: A survey." Neurocomputing 525 (2023): 42-53.

QML Use Cases

Drug Discovery & Molecular Simulation

- QML models used to generate and classify molecular structures
- Variational quantum circuits predict molecule properties (toxicity, solubility)
- Accelerates drug design using quantum chemistry insights

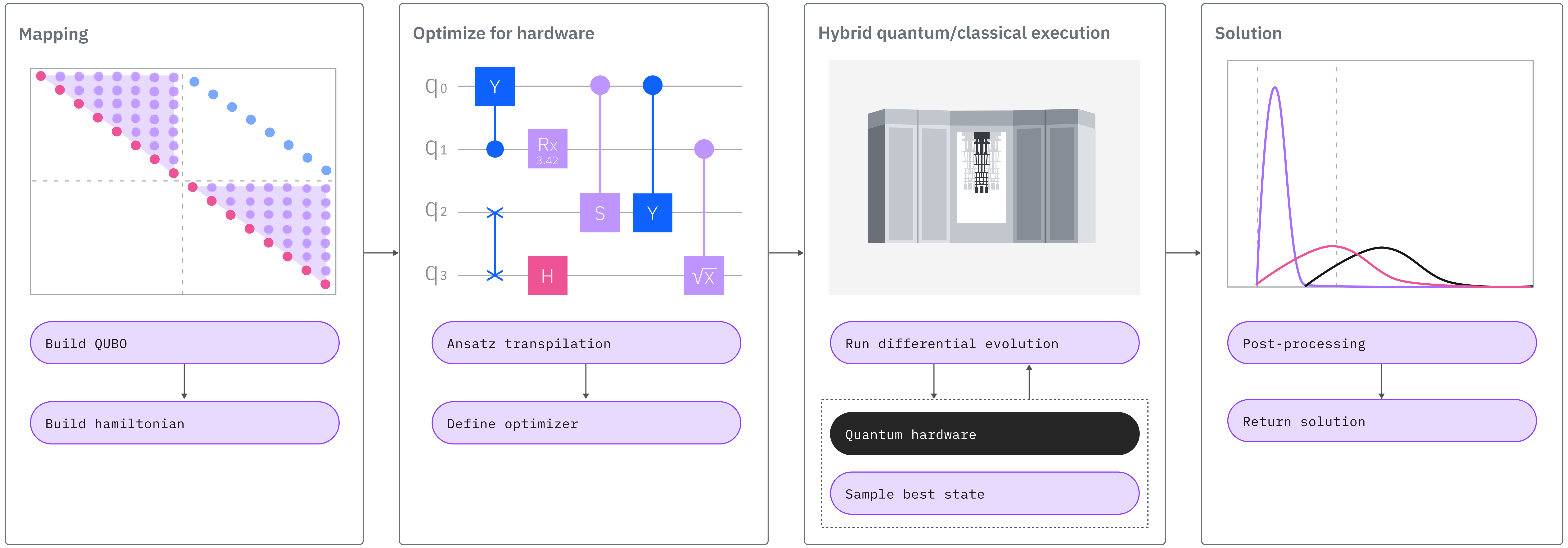


- Quantum Machine Learning Predicting ADME-Tox Properties in Drug Discovery Amandeep Singh Bhatia, Mandeep Kaur Saggi, and Sabre Kais Journal of Chemical Information and Modeling 2023, 63, 21, 6476-6486

QML Use Cases

Finance & Risk Analysis

- Portfolio optimization unde
  uncertainty
- Fraud detection using quar
  anomaly detection
- Quantum-enhanced Monte
  simulations for risk assessr



- Quantum Portfolio Optimizer: A Qiskit Function by Global Data Quantum

QML Use Cases

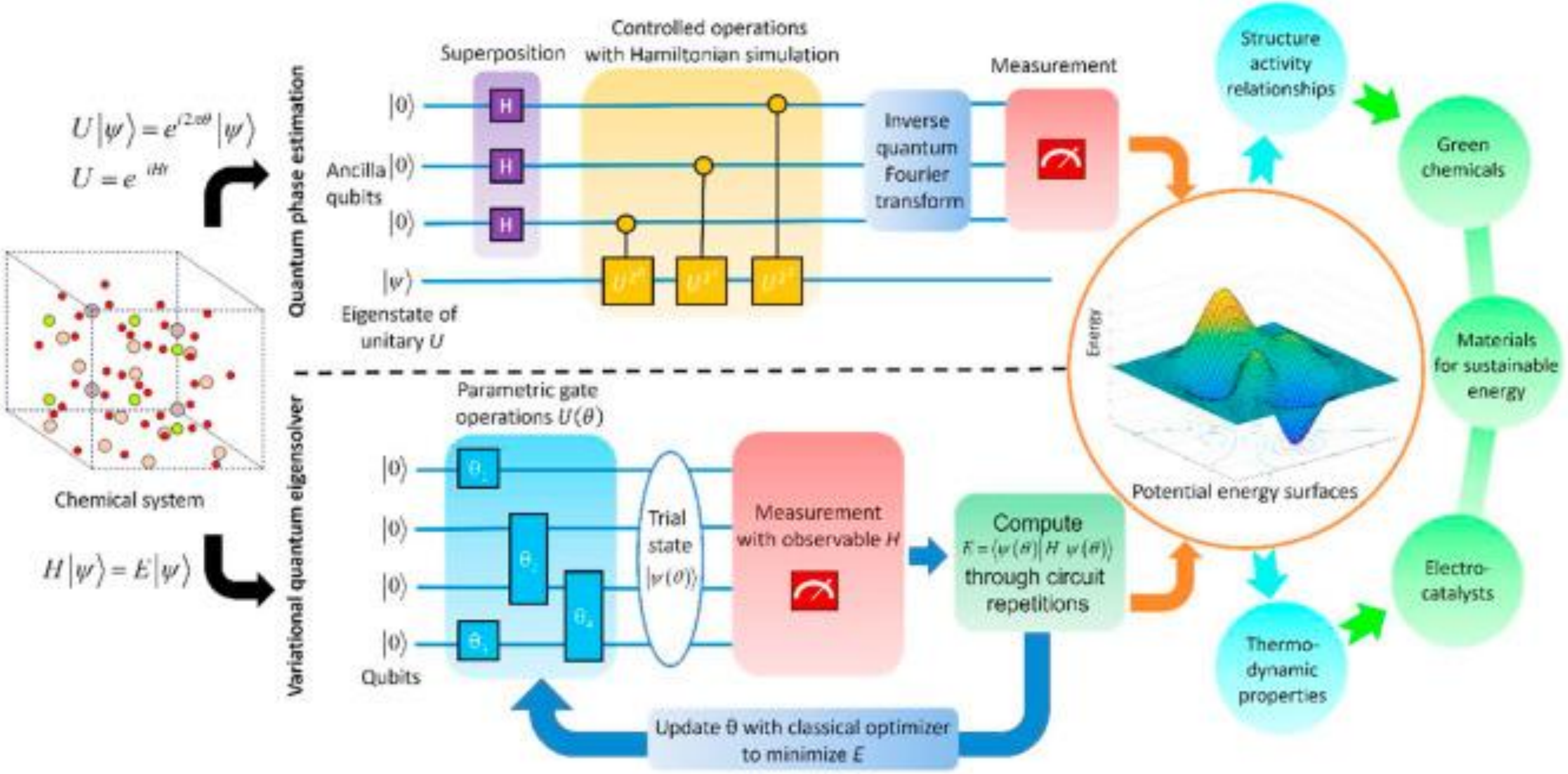
Sustainability & Climate Change

Climate Pattern Recognition

- QML models process satellite imagery and environmental data
- Detect deforestation, sea-level rise, or crop stress in real time

Energy Optimization

- Quantum optimization of energy grids for reduced carbon footprint
- Forecast renewable energy output (solar, wind) using quantum regression



- Ajagekar, Akshay, and Fengqi You. "Quantum computing and quantum artificial intelligence for renewable and sustainable energy: A emerging prospect towards climate neutrality." Renewable and Sustainable Energy Reviews 165 (2022): 112493.

Types of QML Algorithms

Quantum-enhanced ML (using quantum systems to improve ML)

- Variational Quantum Classifiers (VQC)
- Quantum Support Vector Machines (QSVM)
- Quantum Neural Networks (QNNs)
- Quantum k-means clustering
- Quantum Tensor Networks

Classical ML for Quantum Tasks

- Predicting quantum circuit outcomes
- Optimizing quantum control parameters
- Error Correction and Noise mitigation using ML models (AlphaQubit)

Hybrid Models (Classical + Quantum mix)

- Neural networks with quantum layers
- Quantum feature maps + classical optimizer

Some Research Areas in Quantum Machine Learning

Mathematical Foundations of QML

Quantum kernel theory, and the geometry of quantum learning models.

Explainability in QML

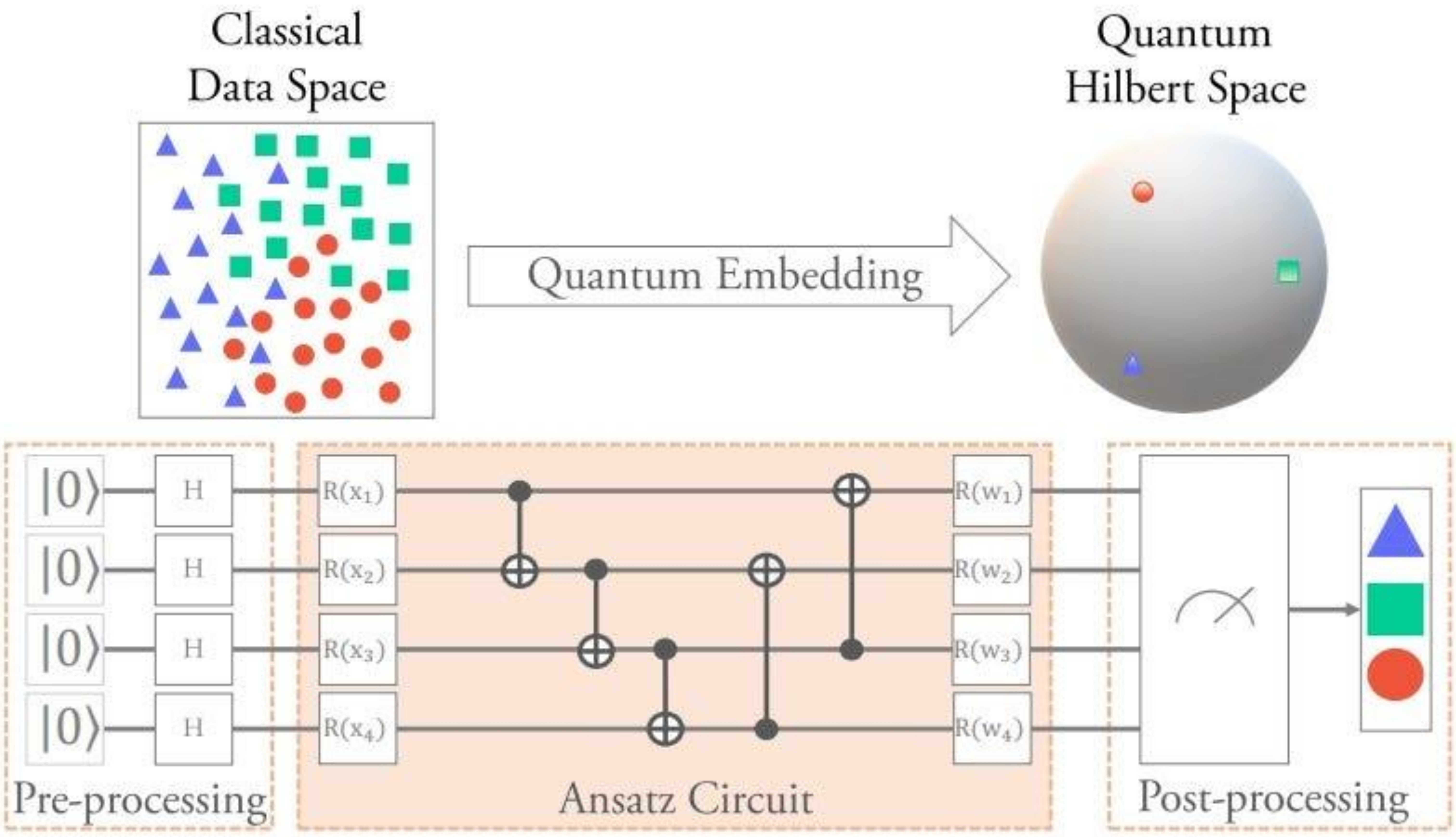
Visualizing quantum circuits, understanding learned features, and ensuring transparency in hybrid quantum-classical models.

Causality in QML

Explores how QML models can infer causal relationships, leveraging quantum advantage in interventions, counterfactual reasoning, and quantum causal discovery.

QML Pipeline

From Classical Data to Quantum Data



– Nguyen, N., & Chen, K. C. (2022). Quantum embedding search for quantum machine learning. *IEEE Access*, *10*, 41444-41456.

Quantum Data Encoding (Feature Maps)

Basic Encoding

represent each classical bit as a qubit state |0⟩, |1⟩.

Angular Encoding

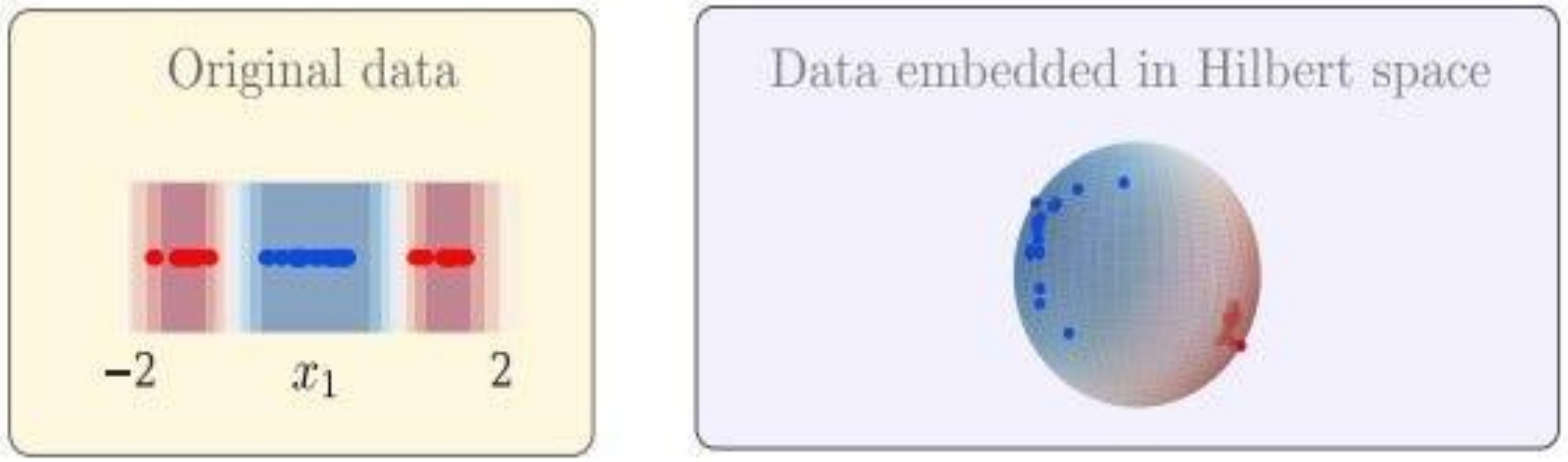
encode features into rotation angles, e.g. x--> Ry(x)

Amplitude Encoding

encode an entire normalized vector into amplitudes of a quantum state (compact but costly to prepare)

Quantum computers naturally map data into **Hilbert space**. The map that performs the embedding has been termed a **Quantum Feature Map**.

In this example, data embedding into Hilbert spaces, and can be viewed geometrical sphere, which differentiates two classes of data into 2 Hilbert spaces and ultimately stores embed data into 2-qubit system contains 4 basis states.



$x \rightarrow |\phi(x)| \rightarrow map\ transforms$

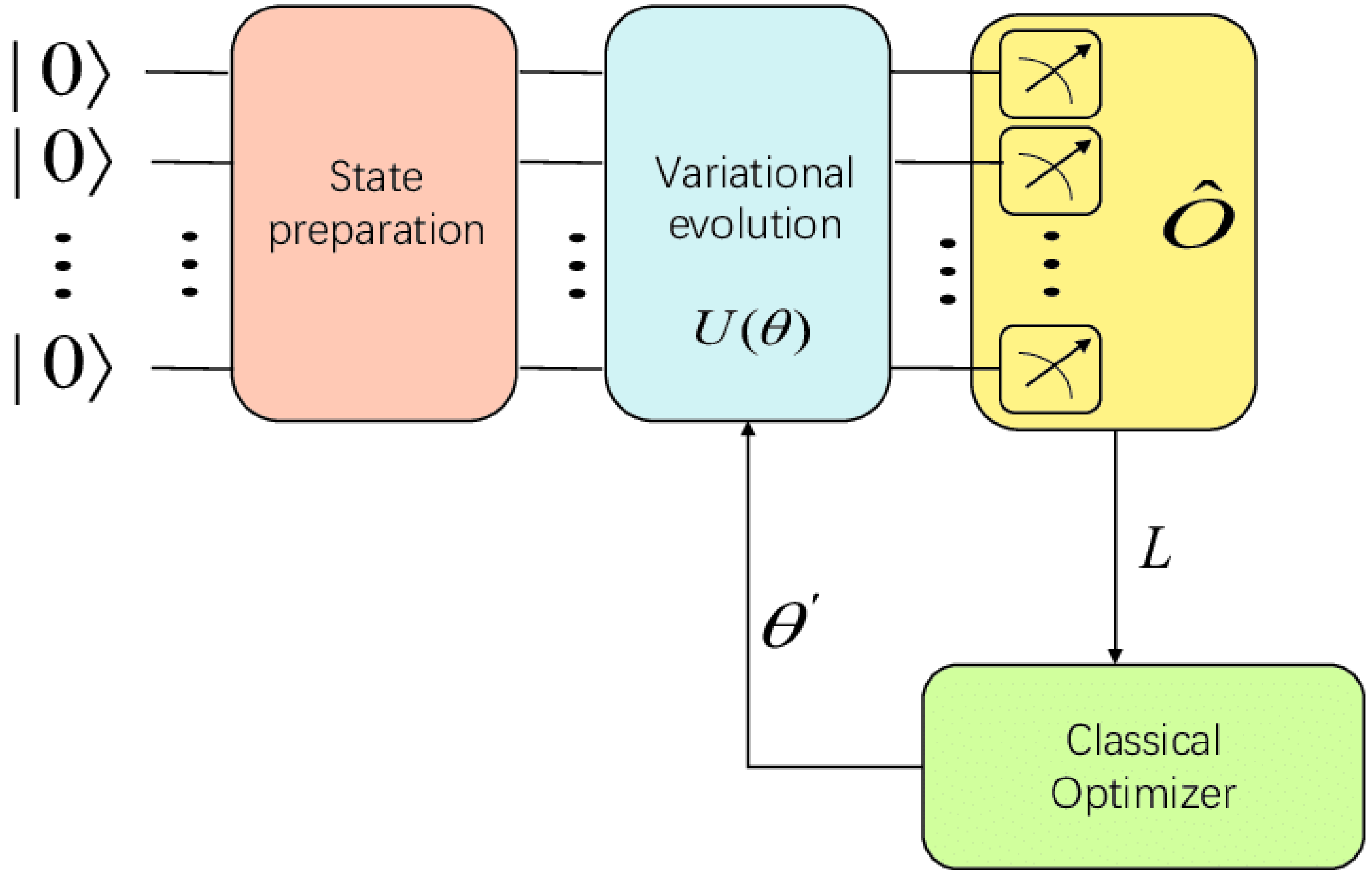
$U_\phi(x)$

Quantum Models Representation

Instead of using **neurons, weights, layers** in Classical ML

We Use Parameterized Quantum Circuits (PQCs), where unitary gates with tunable parameters play the role of weights (θ).

- Quantum circuits naturally represent high-dimensional Hilbert space functions.
- Some functions that require **exponentially large classical networks** can be compactly expressed with **shallow quantum circuits**.



Quantum Learning Process

Forward pass:

- Encode classical input into quantum state.
- Apply parameterized circuit $U(\theta)$.
- Measure expectation values → outputs a probability distribution.

Training loop:

- Define a loss function: e.g., expectation value differences from labels.
- Classical optimizer updates circuit parameters θ.
- Iterate until convergence.

Gradients:

- Measured using parameter-shift rule:

$$\frac{\partial f}{\partial \theta} = \frac{f(\theta + \pi/2) - f(\theta - \pi/2)}{2}$$

- This avoids backprop but requires more circuit evaluations.

Training in QML

Variational Quantum Circuits (VQCs)

- Most popular NISQ method. Trainable Unitaries, loss defined via measurements, optimized by classical gradient descent.
- Challenges: **barren plateaus** (vanishing gradients)

Quantum Kernels

- Quantum computers define feature maps in Hilbert space.
- Use inner products between quantum states (kernel trick). Example: **Quantum SVM**.

Quantum Generative Models

- Quantum Boltzmann Machines.
- **Quantum GANs:** quantum generator with classical discriminator (or vice versa)

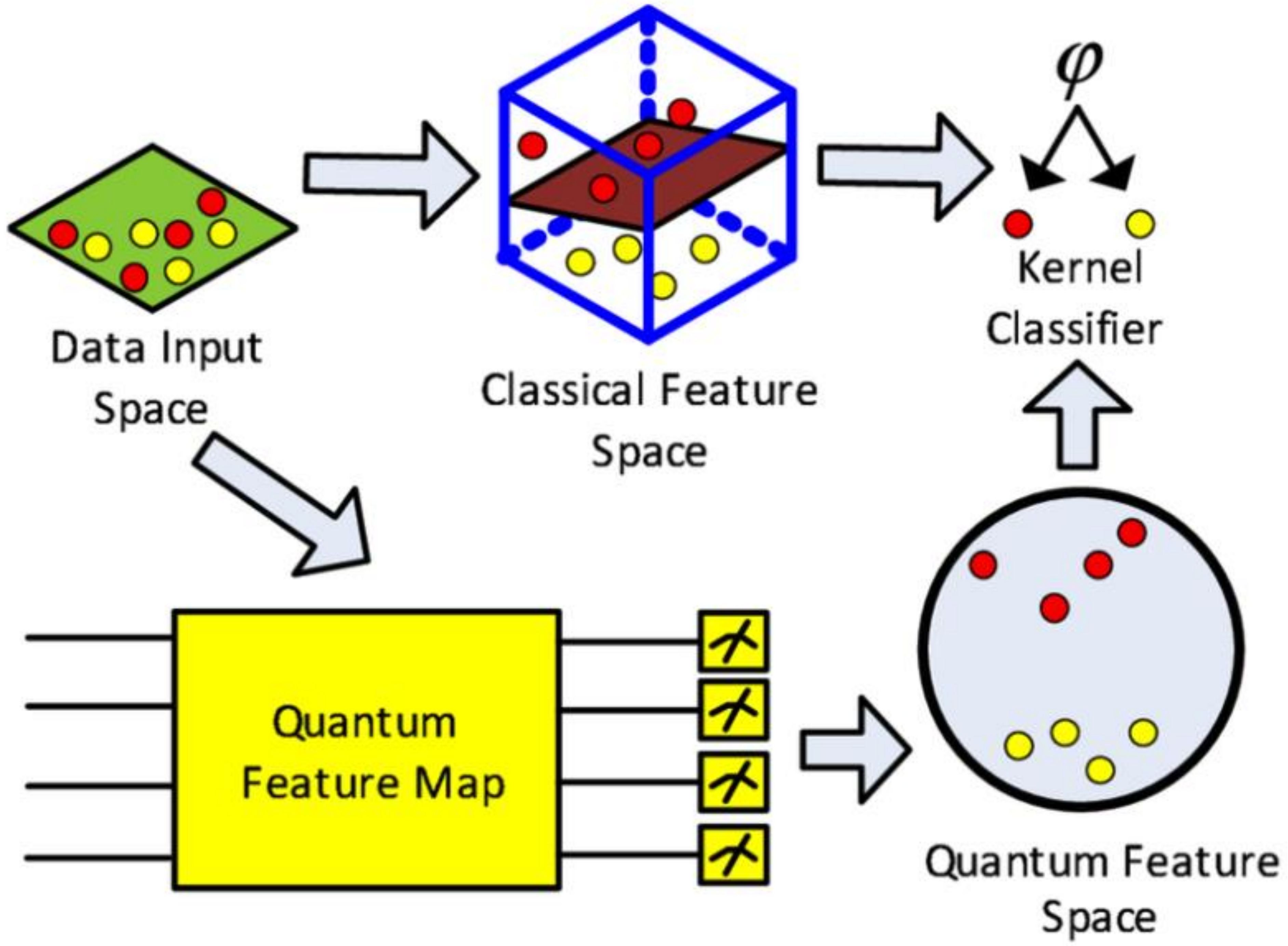
Fully Quantum Training (future)

- Algorithms like **Quantum Backpropagation** exist in theory, but current devices are too noisy.

Building a Variational Quantum Classifier from Scratch

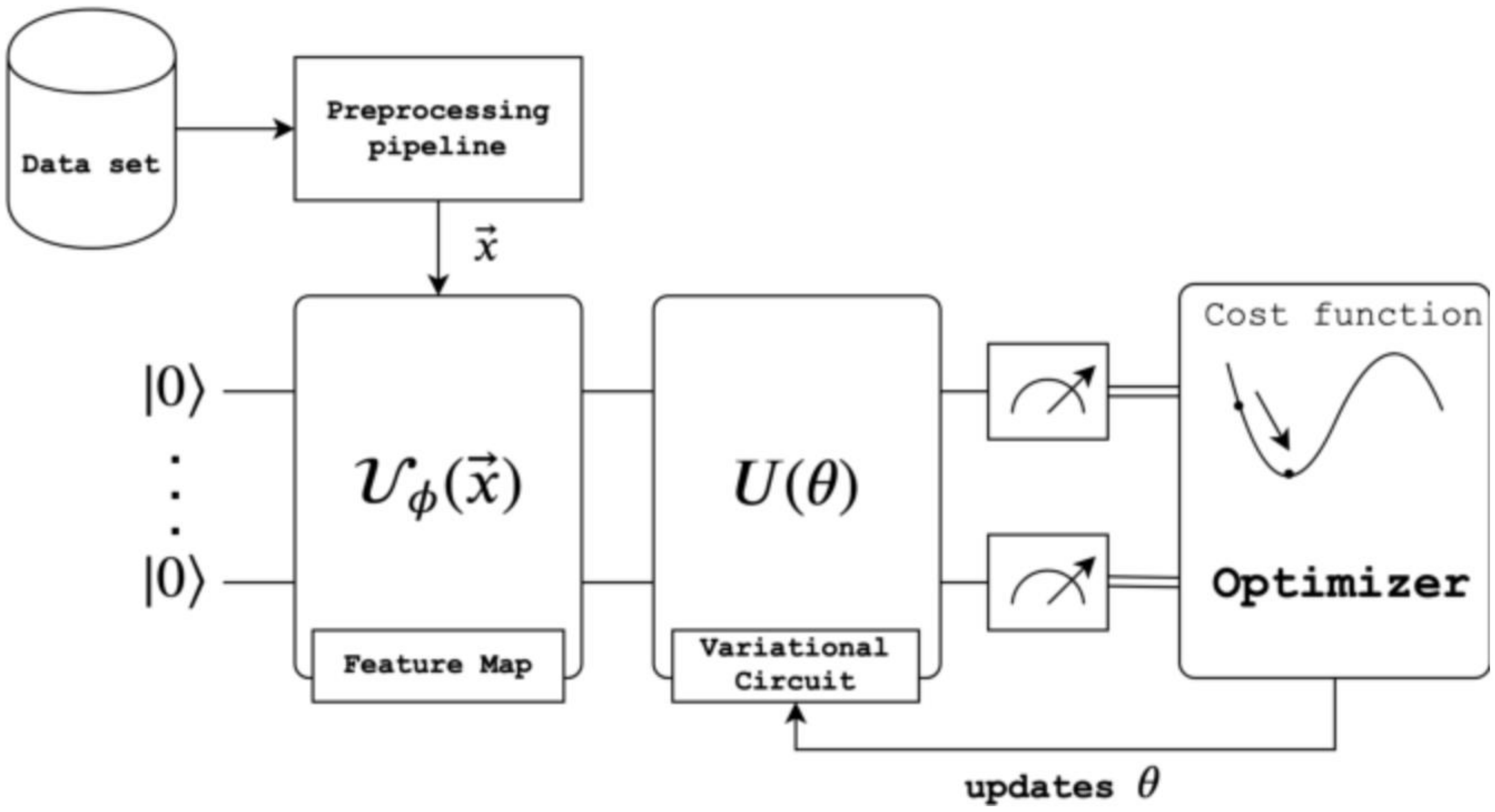
Motivation: Why Quantum Classifiers?

- Classical classifiers struggle with high-dimensional data and complex entanglements.
- Quantum circuits can represent high-dimensional feature spaces more efficiently.
- VQCs combine classical optimizers with quantum circuits to solve supervised learning tasks.



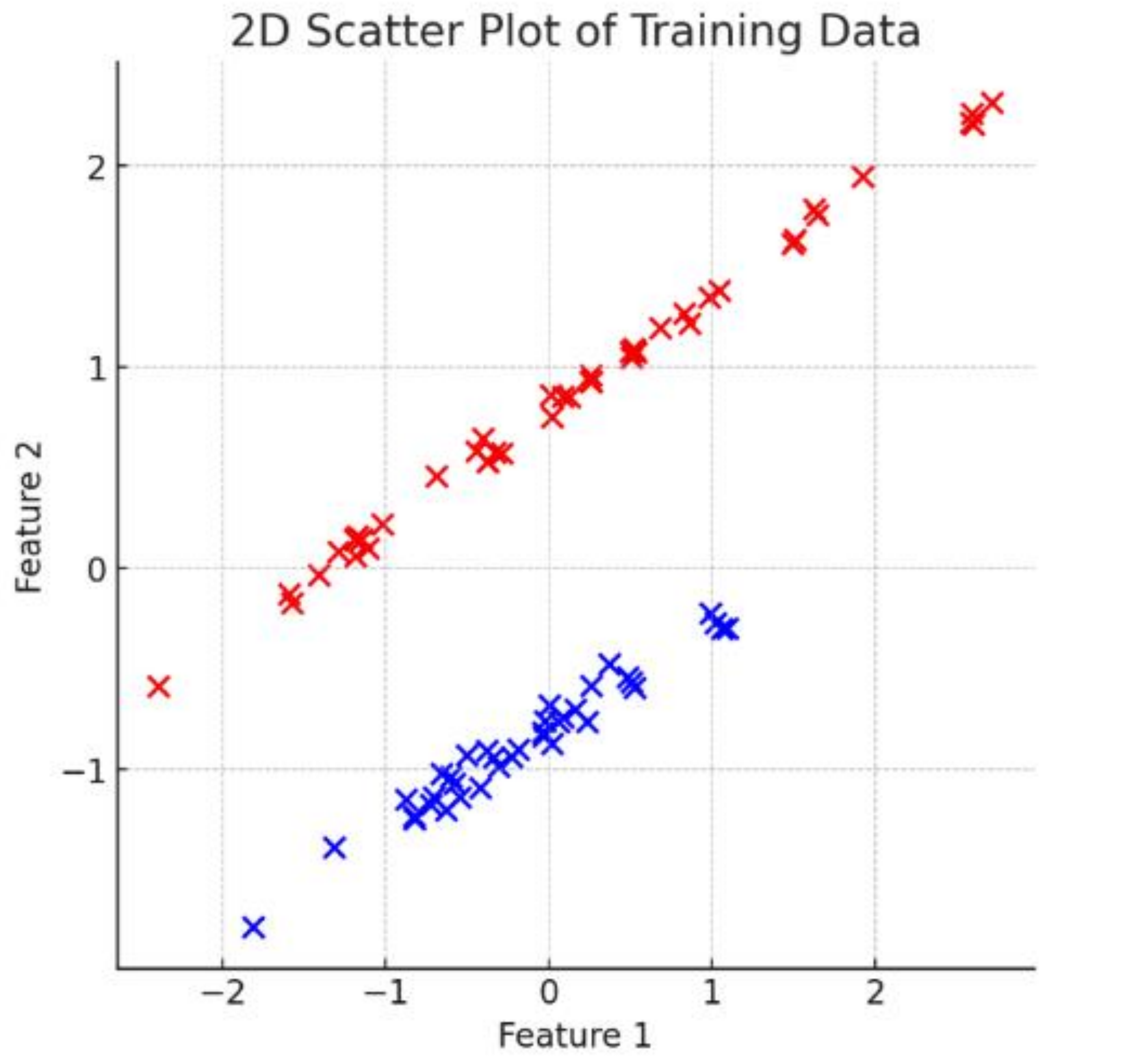
Building a Variational Quantum Classifier from Scratch

Quantum machine learning algorithm that classifies Iris dataset.



Building a Variational Quantum Classifier from Scratch

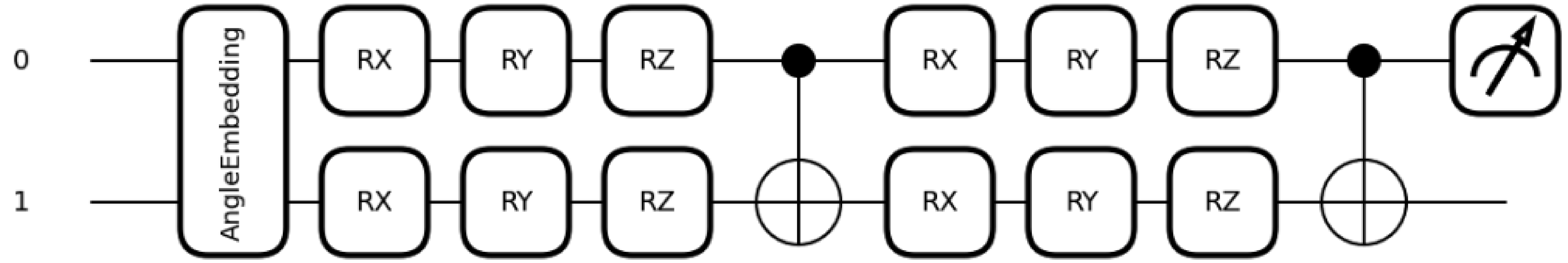
- **Task:** Binary classification on synthetic 2D dataset
  ~80 training points
- **Dataset:** make_classification from sklearn.datasets
- Normalized features
- Labels converted to {-1, +1} for compatibility with quantum output



Building a Variational Quantum Classifier from Scratch

Variational Quantum Classifier (VQC) Architecture

- Inputs: 2 classical features → angle-encoded
- Ansatz (PQCs) : Multi-layer circuit
- AngleEmbedding with rotation around Y
- 2 qubits with RX, RY, RZ layers
- Entangling gates: CNOTs between qubits
- Output: Expectation ⟨Z⟩ on qubit 0 (range: [-1, 1])



Building a Variational Quantum Classifier from Scratch

Mathematical Formulation

Let $x \in \mathbb{R}^2$, and θ be the variational parameters.

The quantum model implements:

$$f(x;\theta) = \langle 0|U^\dagger(x,\theta) Z_0 U(x,\theta)|0\rangle$$

- **Loss function**:

$$\mathcal{L}(\theta) = \frac{1}{N}\sum_{i=1}^{N}(f(x_i;\theta) - y_i)^2$$

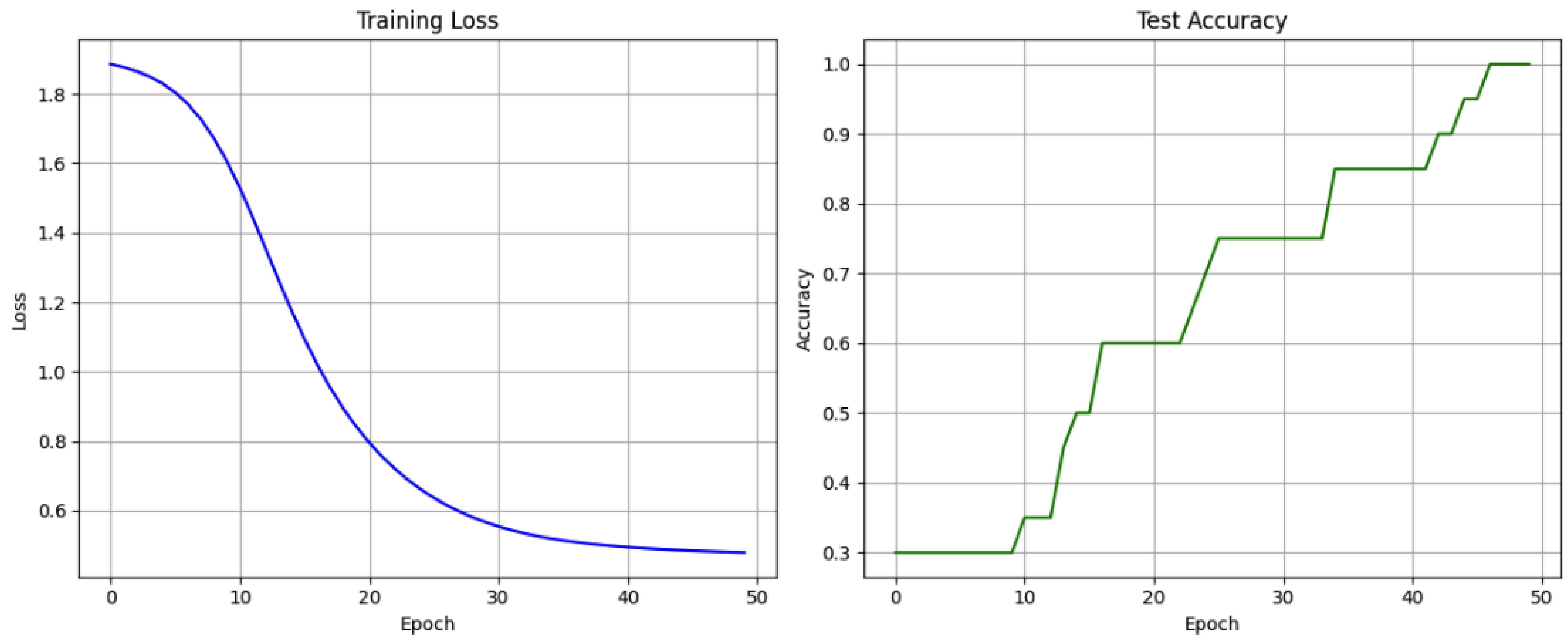
- **Training**:

  Gradient Descent using PennyLane's differentiable QNodes

Building a Variational Quantum Classifier from Scratch

Training Results

- Gradual loss decrease over epochs
- Final test accuracy: ~90% (depending on noise & circuit depth)



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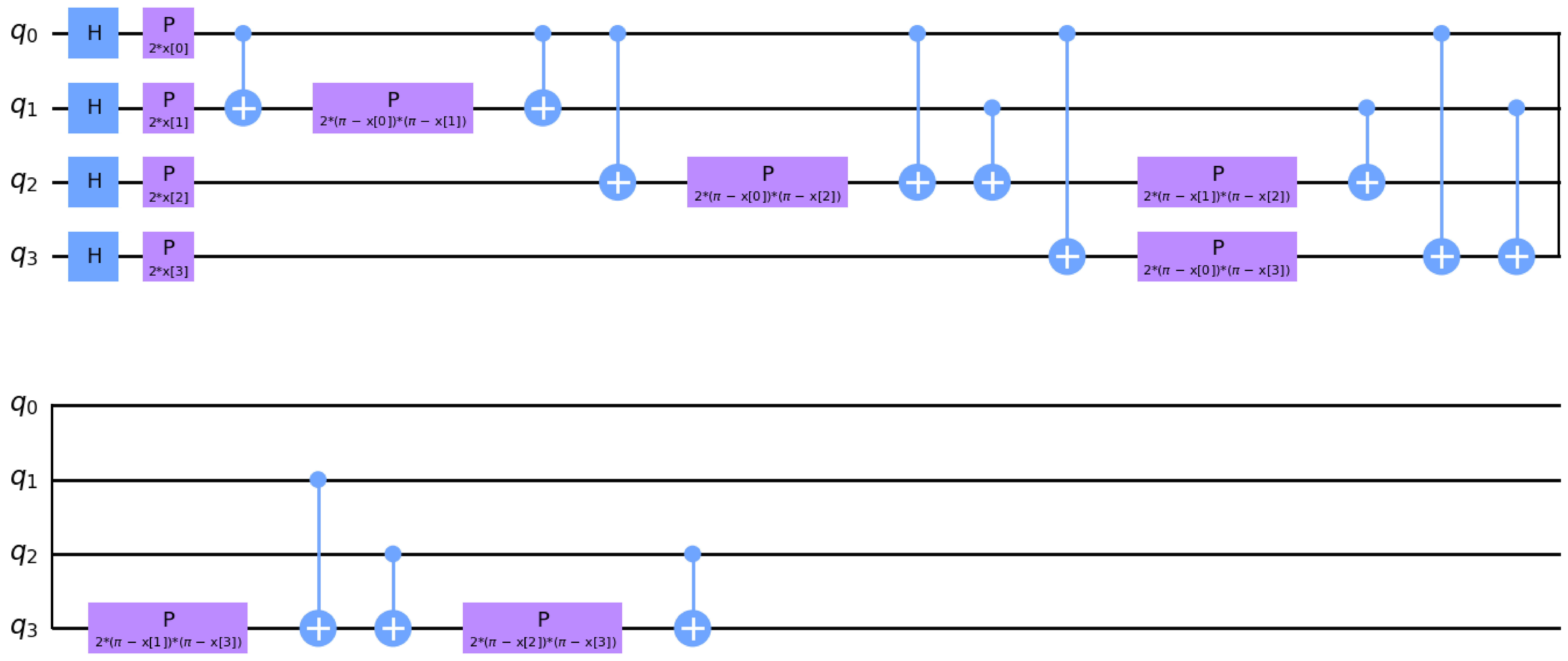
Quantum machine learning algorithm that classifies **Iris dataset.**



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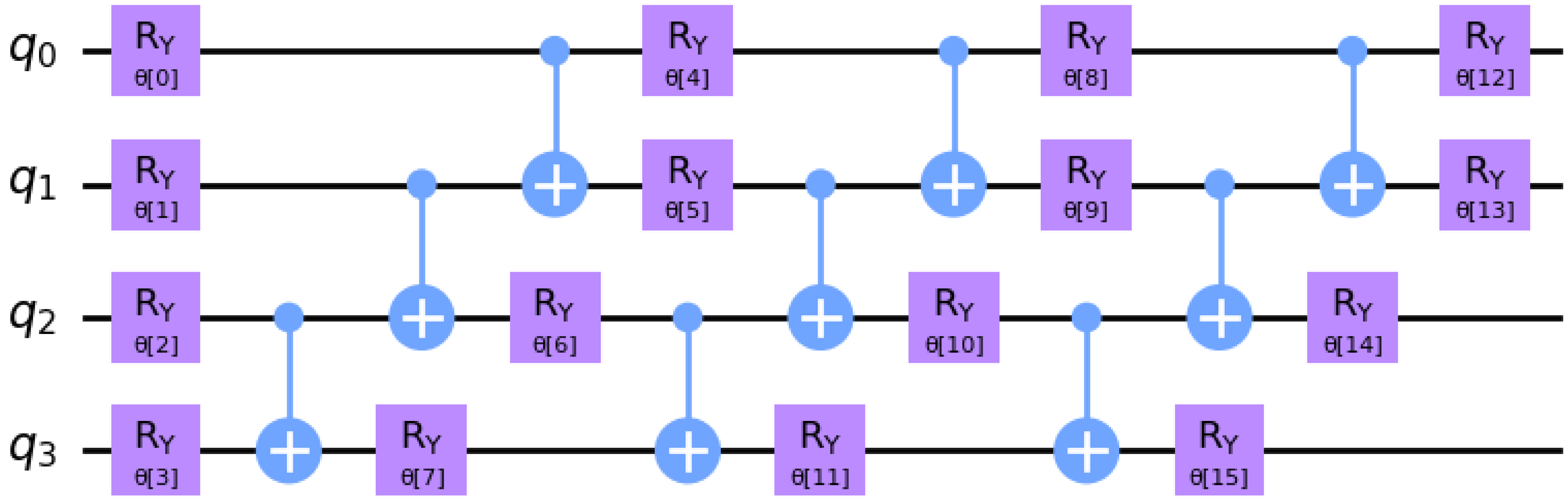
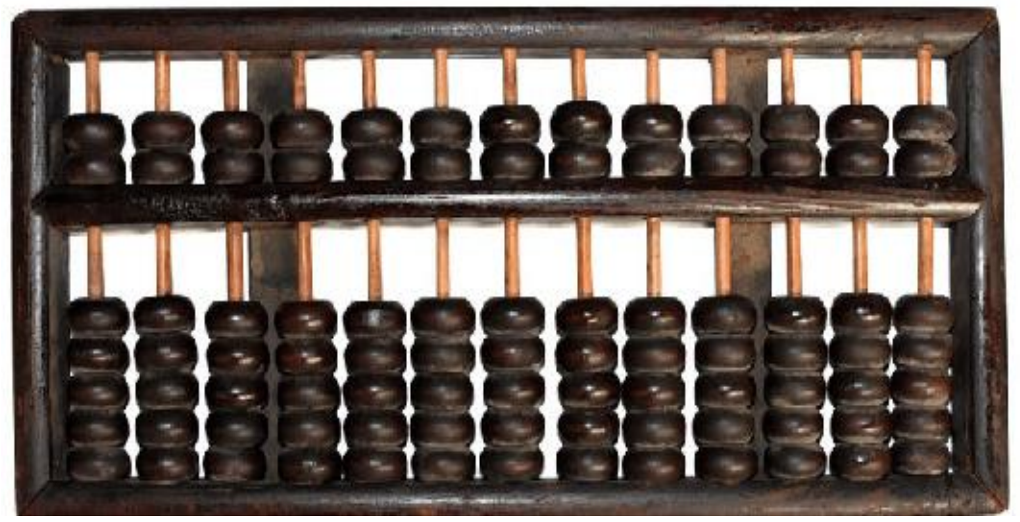
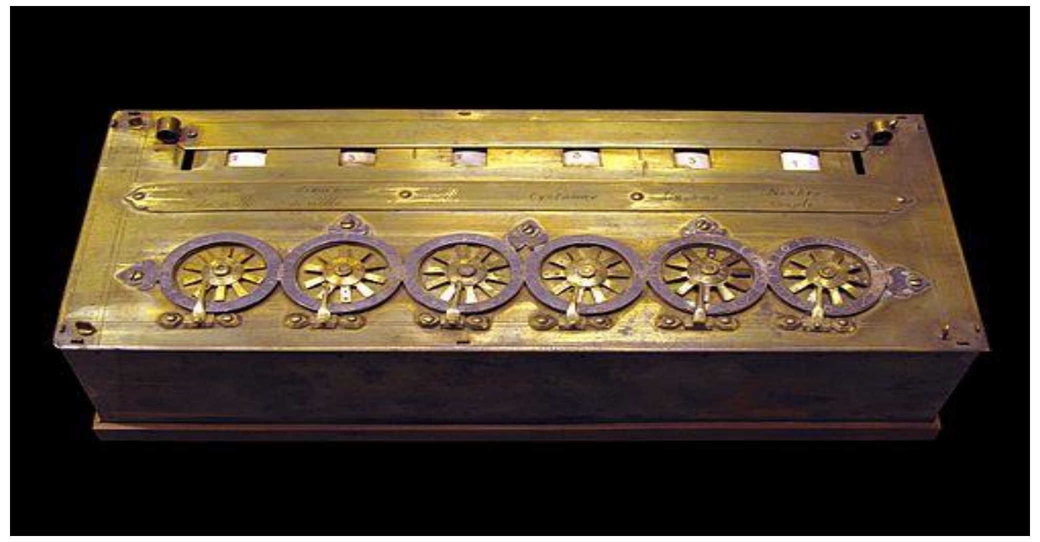


History of Computing



Early Counting Devices (Pre-Computer Era)

- Analog objects to represent bits via position.
- Physical location = numeric value; each position is a "state.”
- human interpretation simulates logic by moving beads according to rules.
- E.g., Abacus, Tally Sticks



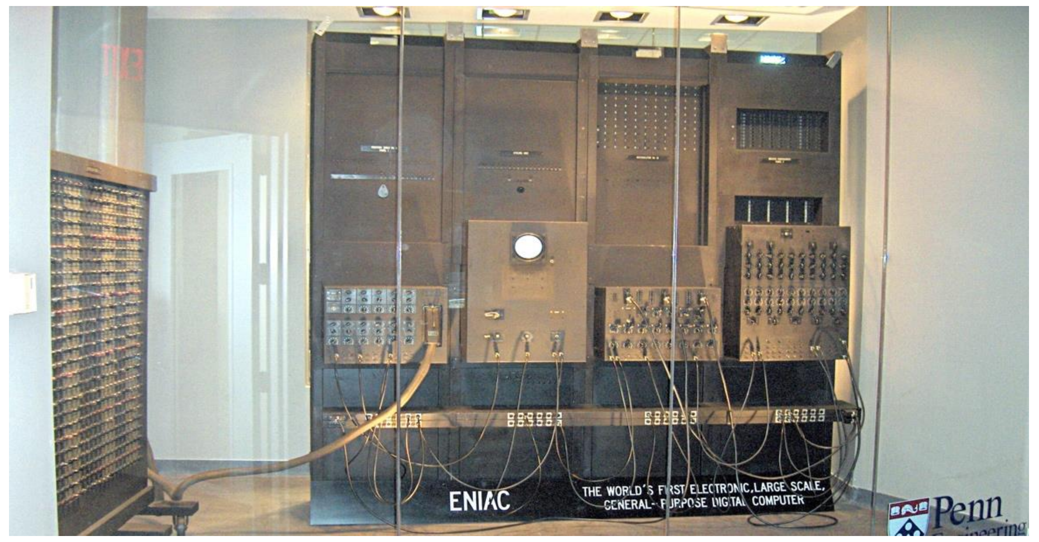
Mechanical Computers (1600s–1800s)

- Gears and Levers to represent bits of information
- Mechanical interactions mimic arithmetic operations—addition, subtraction—via mechanical "logic.”
- E.g., Pascal’s Calculator, Leibniz Wheel

Electro-mechanical Computers (1930-1940s)

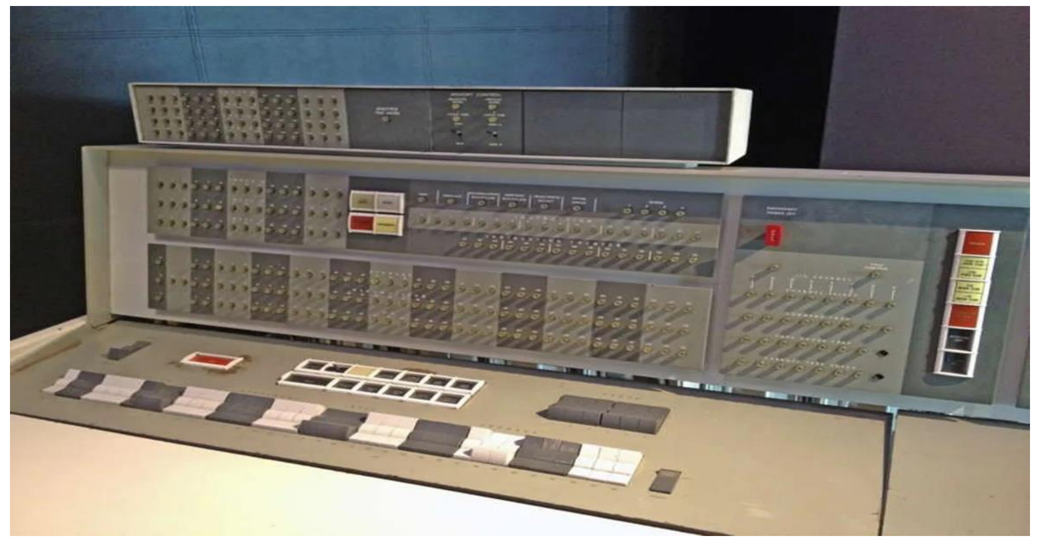
- Combines electrical components (relays, switches) with mechanical parts (gears, motors, counters) to perform computations
- Binary logic adoption.
- E.g., IBM Harvard Mark I, Konrad Zuse’s Z3

History of Computing



Electronic Digital Computers (1940s–1950s)

- Utilized vacuum tubes as switches: on/off states representing binary 1 and 0
- Performed Boolean logic—AND, OR, NOT, XOR—via vacuum-tube circuits
- First programmable, electr onic, general purpose digital computers
- E.g., ENIAC & EDVAC



Transistor Era (1950s–1970s)

- Transistors replaced vacuum tubes, switched electrical currents, enabling "on/off" binary states
- Smaller, portable, faster
- Used in flip-flops and digital registers for memory and processing.
- E.g., IBM 1401

Microchips & Microprocessors (1970s–present)

- Millions of transistors integrated on a single integrated circuit (IC)
- Foundation of modern computing: laptops, smartphones, servers
- Dramatic increases in speed, size reduction, and cost efficiency
- E.g., Intel 4004 and Apple M-series chips

Future of Computing

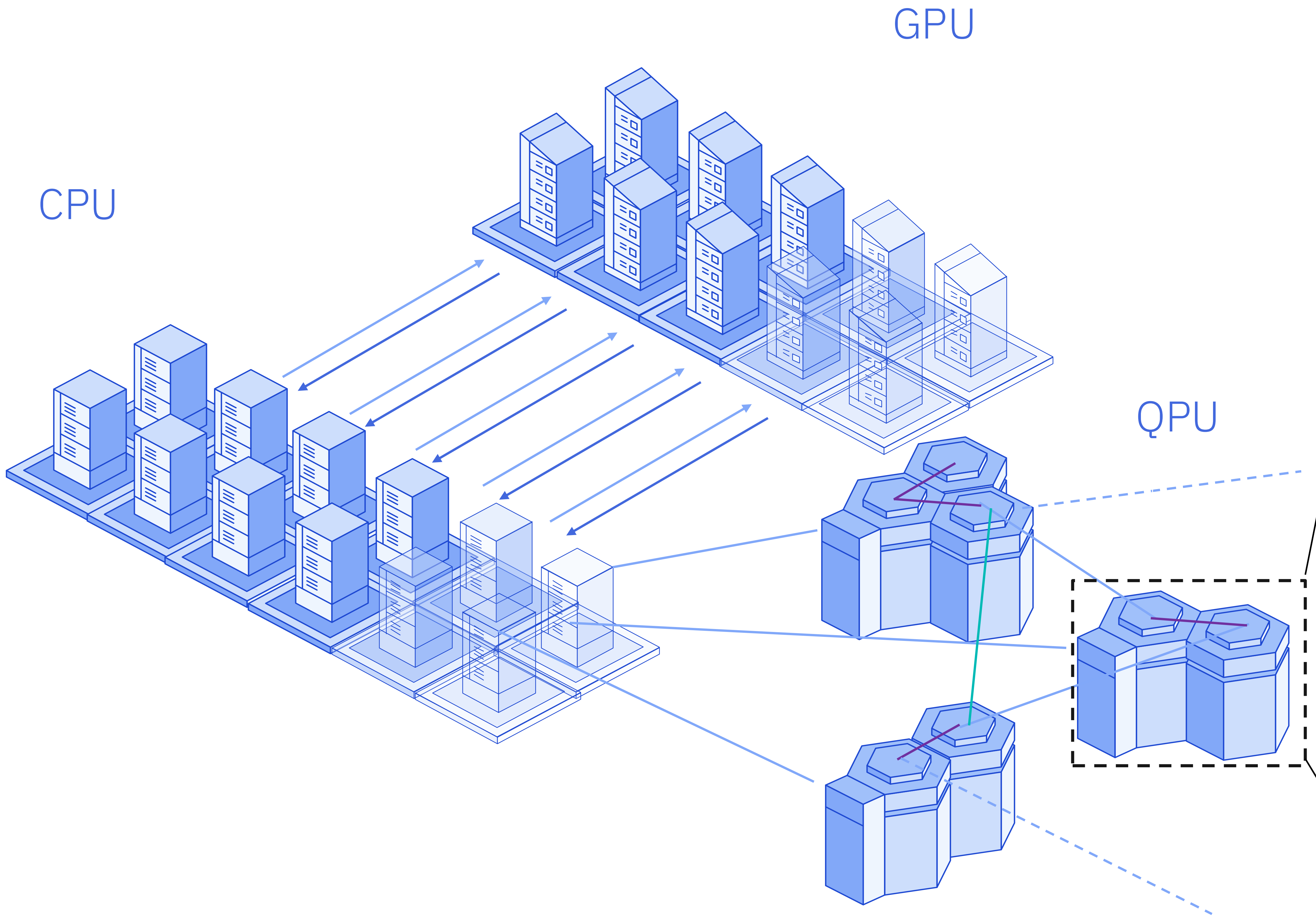
Quantum Computing (2000-Present)

- Utilize qubits (quantum vectors) encoded in quantum physical systems (e.g., spin states, superconducting currents, trapped ions) to represent information.
- Quantum logic operations are represented by unitary matrices acting on the quantum state space
- Allows simultaneous occurrence of different states through superposition.
- Potential for solving problems intractable for classical computers:

i. Cryptography (Shor's algorithm),
ii. Optimization (QAOA),
iii. Quantum chemistry (VQE)

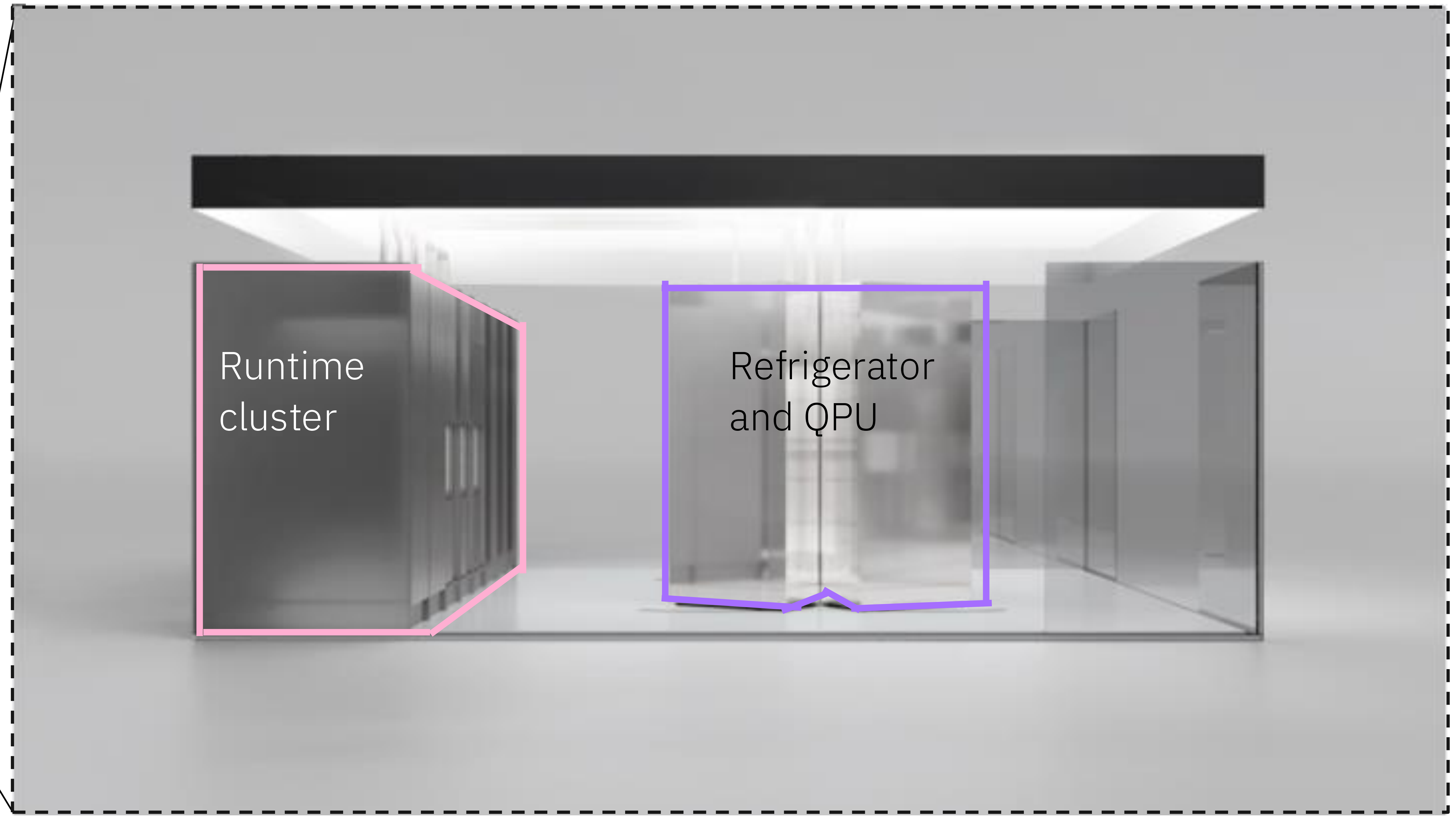
IBM

Quantum-centric supercomputing



Delivering impactful quantum computing requires the interplay of quantum and classical resources at scale

Quantum-centric supercomputing is the path toward industrial-scale applications



Qiskit Global Summer School

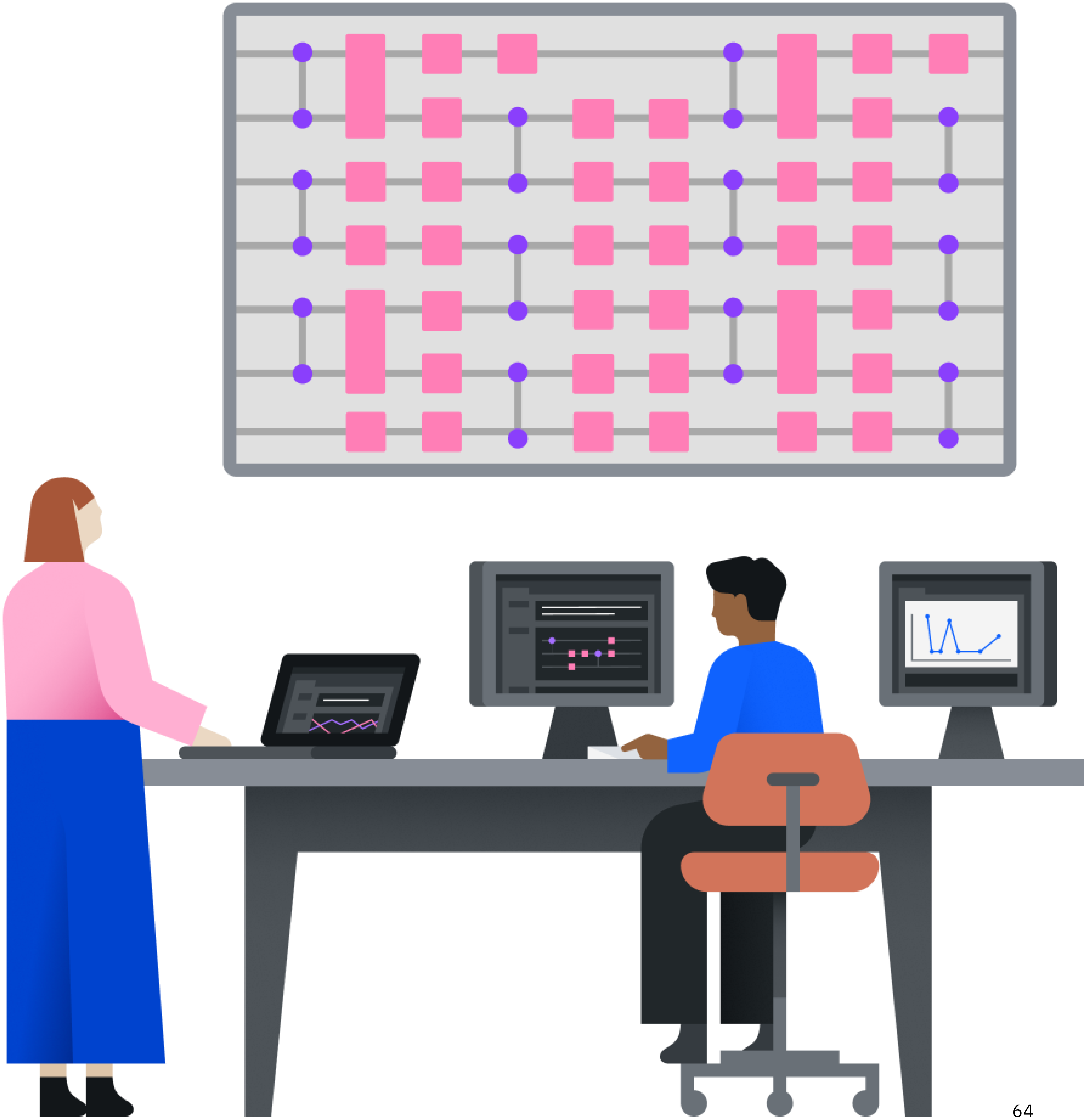
Our largest educational event every year. Two weeks of lectures, labs, Q&As, and community engagement.

Rooted in the IBM Quantum Learning courses, with new content each year.

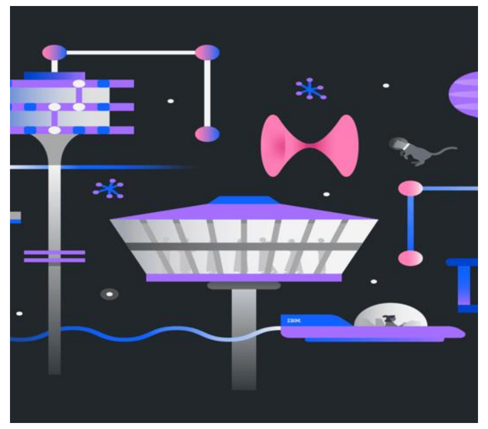
6,000+ seats sold out in 2024.

Live event featuring badges for completion, extra assignments for partners, and more.

After the event is over, the lecture material becomes available on YouTube.



Qiskit Fall Fest



Student-led quantum computing events on campus
↳ Crafted by student leaders, supported by IBM

Working with the student leaders of today to shape the industry leaders of tomorrow

Organic growth of local communities

Since 2021:

195	28k+
Events	Attendees

(Pictured: 2024 Qiskit Fall Fest event at The University of Ibadan in Nigeria)

AQC
African Quantum Consortium

QUANTUM AFRICA

DEEP LEARNING INDABA

QWORLD

<Wits|Q>
Wits Quantum Initiative

INTERNATIONAL YEAR OF
Quantum Science
and Technology

QUANTUM LEAP AFRICA

SA QuTI
South African Quantum Technology Initiative

CQTech
Constantine Quantum Technologies
cqtech.org

Century of Quantum
QISKIT
2025 2025
FALL FEST

Let's create something that changes everything.