

A JOURNEY TO QUANTUM COMPUTING

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Feynman's Vision in 1981



Feynman's Vision on Quantum Computing — May 1981 —

Conference

Held at MIT May 1981
with IBM, focusing
on physics and
computation



Problem

Classical computers
incapable due to
exponential complexity

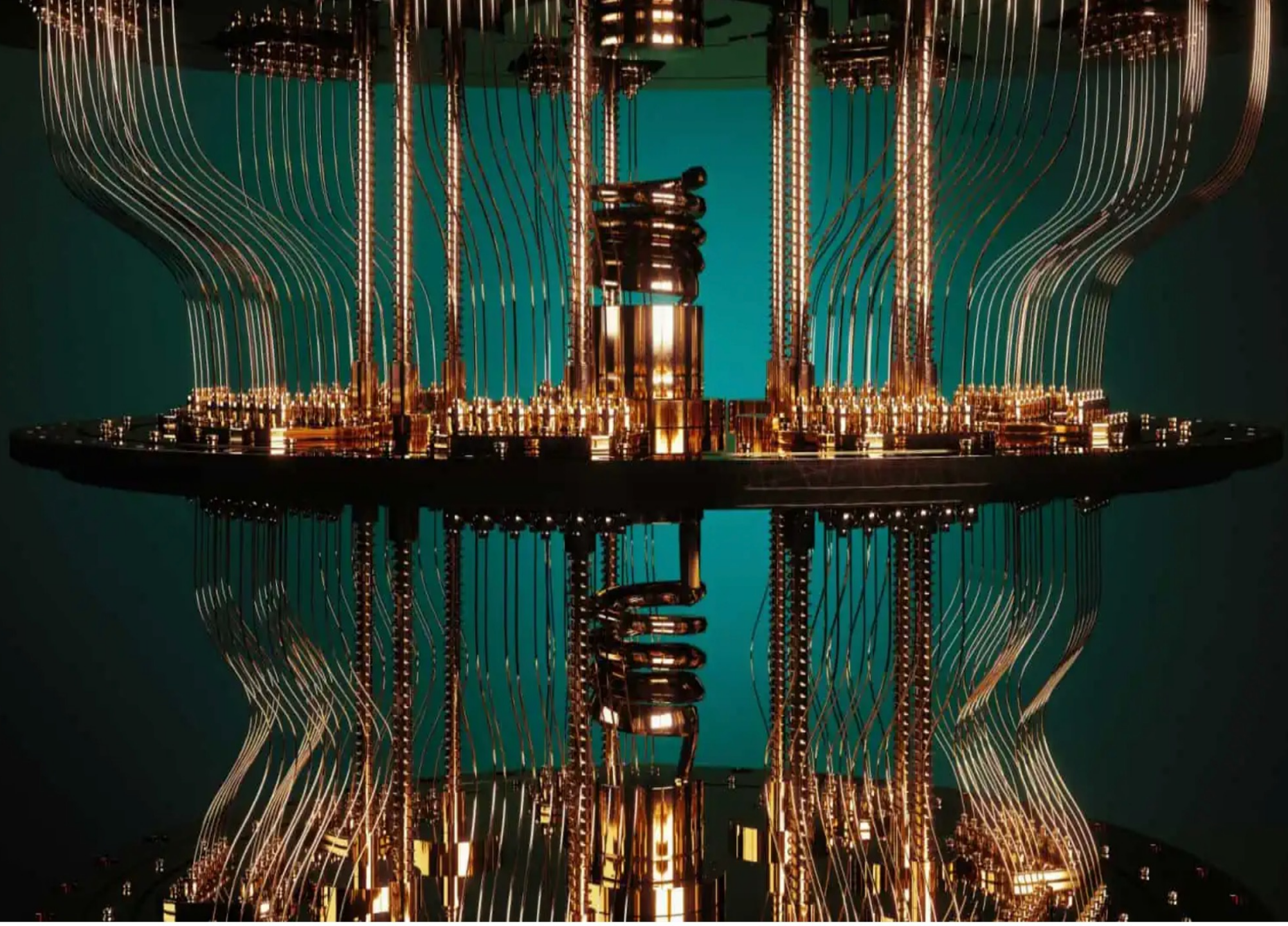


Proposition

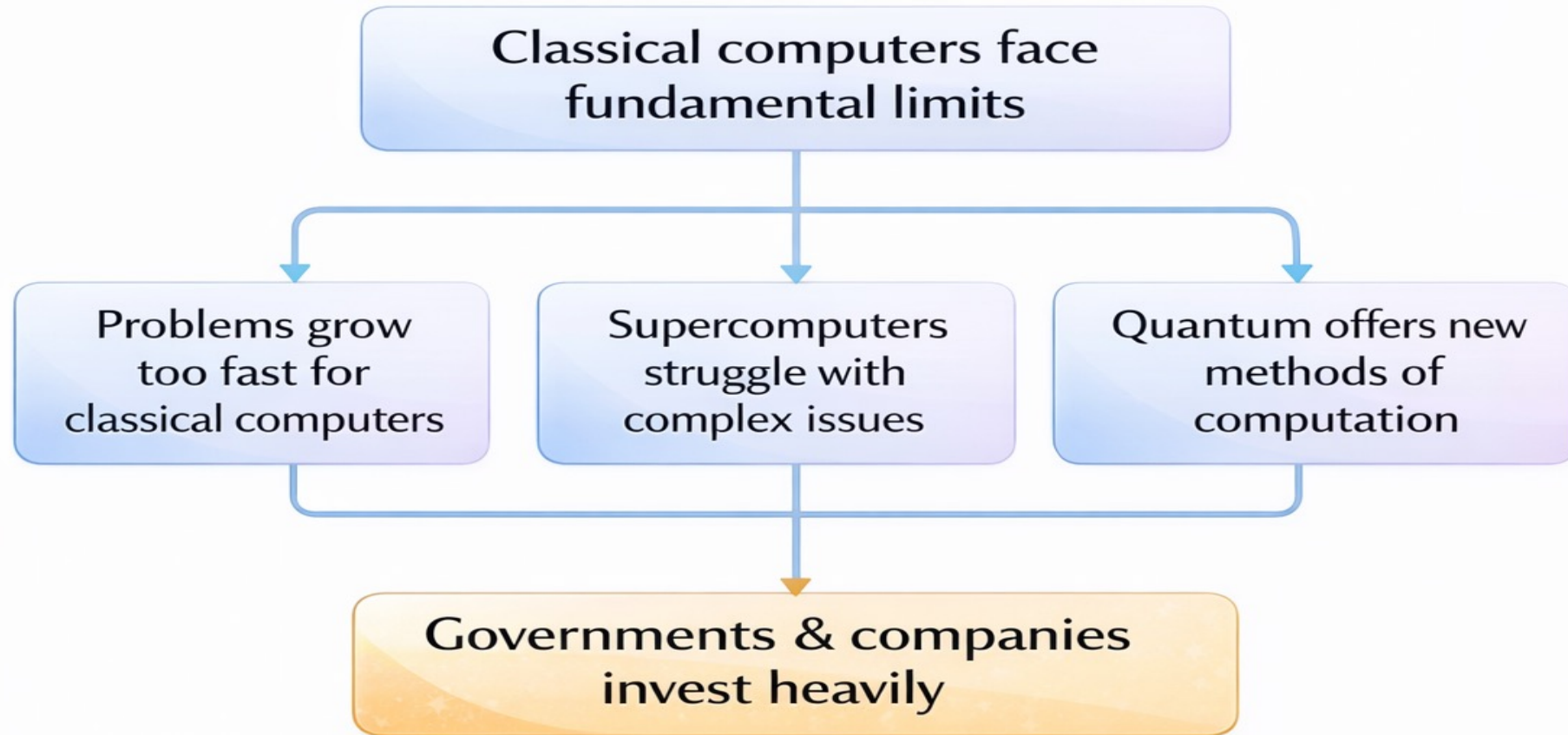
Proposed a “quantum
mechanical simulator”
to model nature



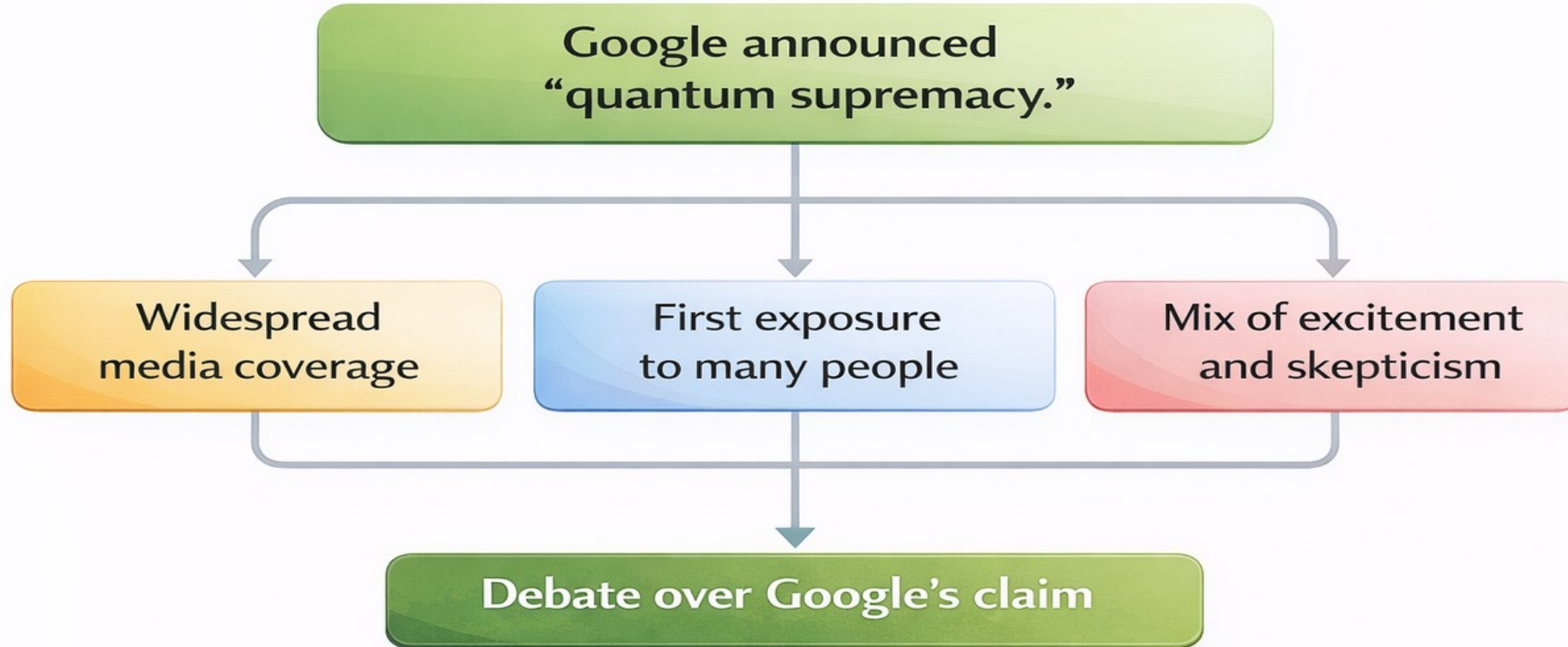
HOW DOES A QUANTUM
COMPUTER LOOK LIKE?



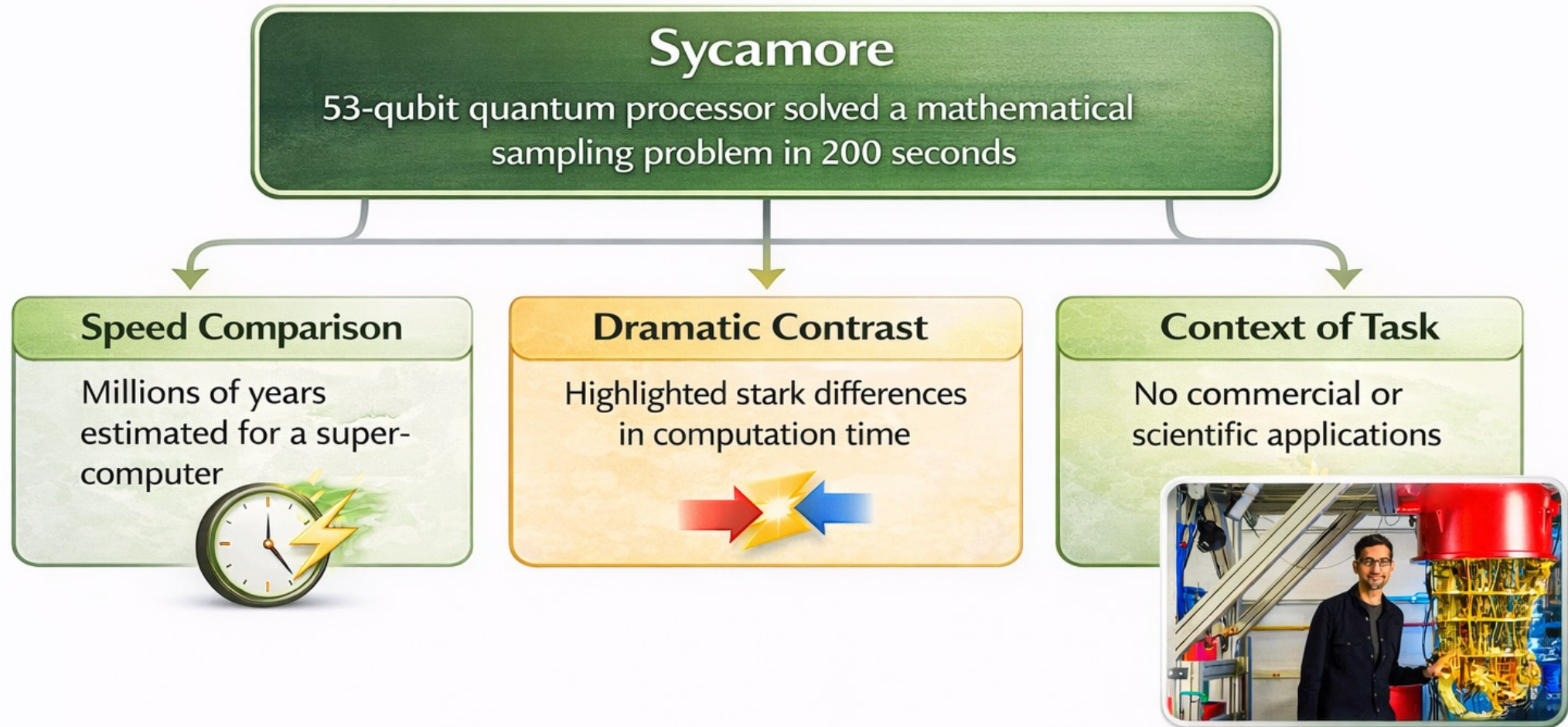
WHY THIS TOPIC MATTERS



THE 2019 HEADLINE



GOOGLE'S CLAIM



China's 2020 Announcement

Significant Advancements



Larger speedups
in optical and
superconducting
systems

Global Expansion



Quantum computing
was no longer
confined to one country

Exploring Approaches



Multiple lines of
research pursued
simultaneously

Global Recognition



Confirmed China's
prominence
in the field

Google's Willow Chip

105-qubit superconducting processor



First scaling of error rates
as the system expands



Calculations in **minutes**
instead of trillions of years



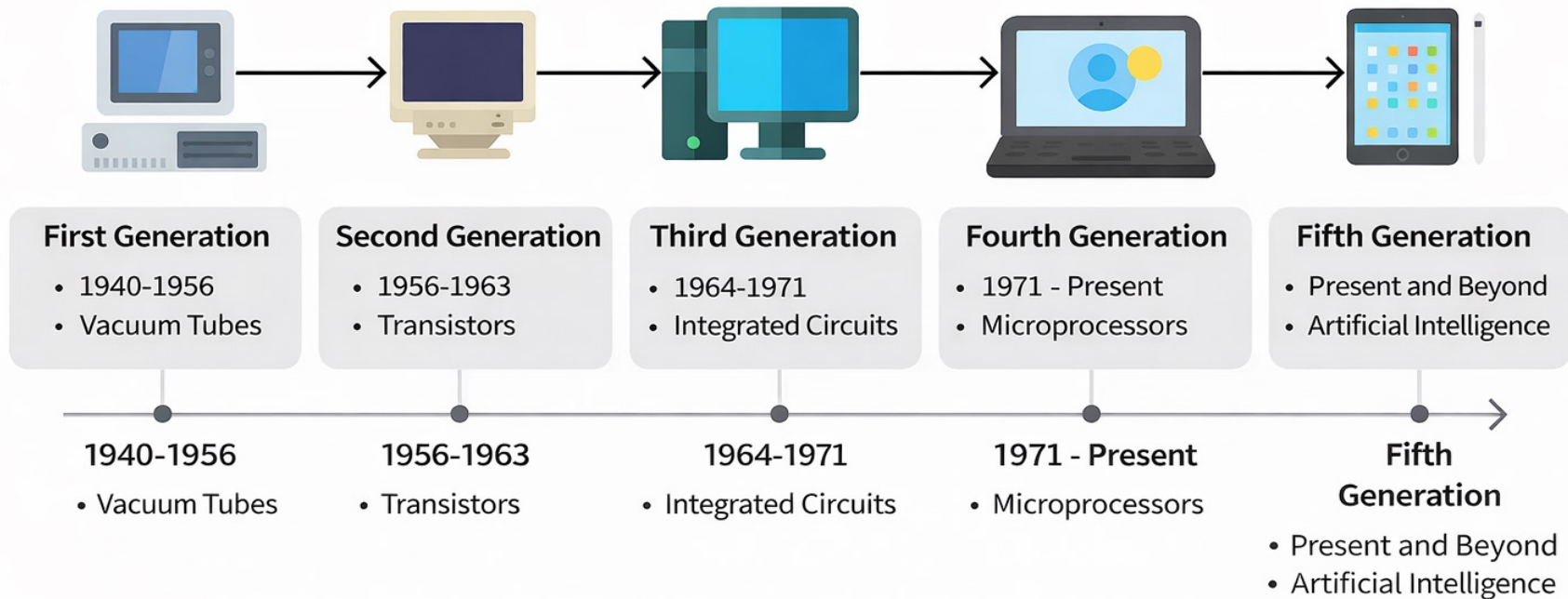
99.97% Achieved **99.97%**
single-qubit fidelity

Major leap in quantum computing, solving
complex problems classical supercomputers can't handle

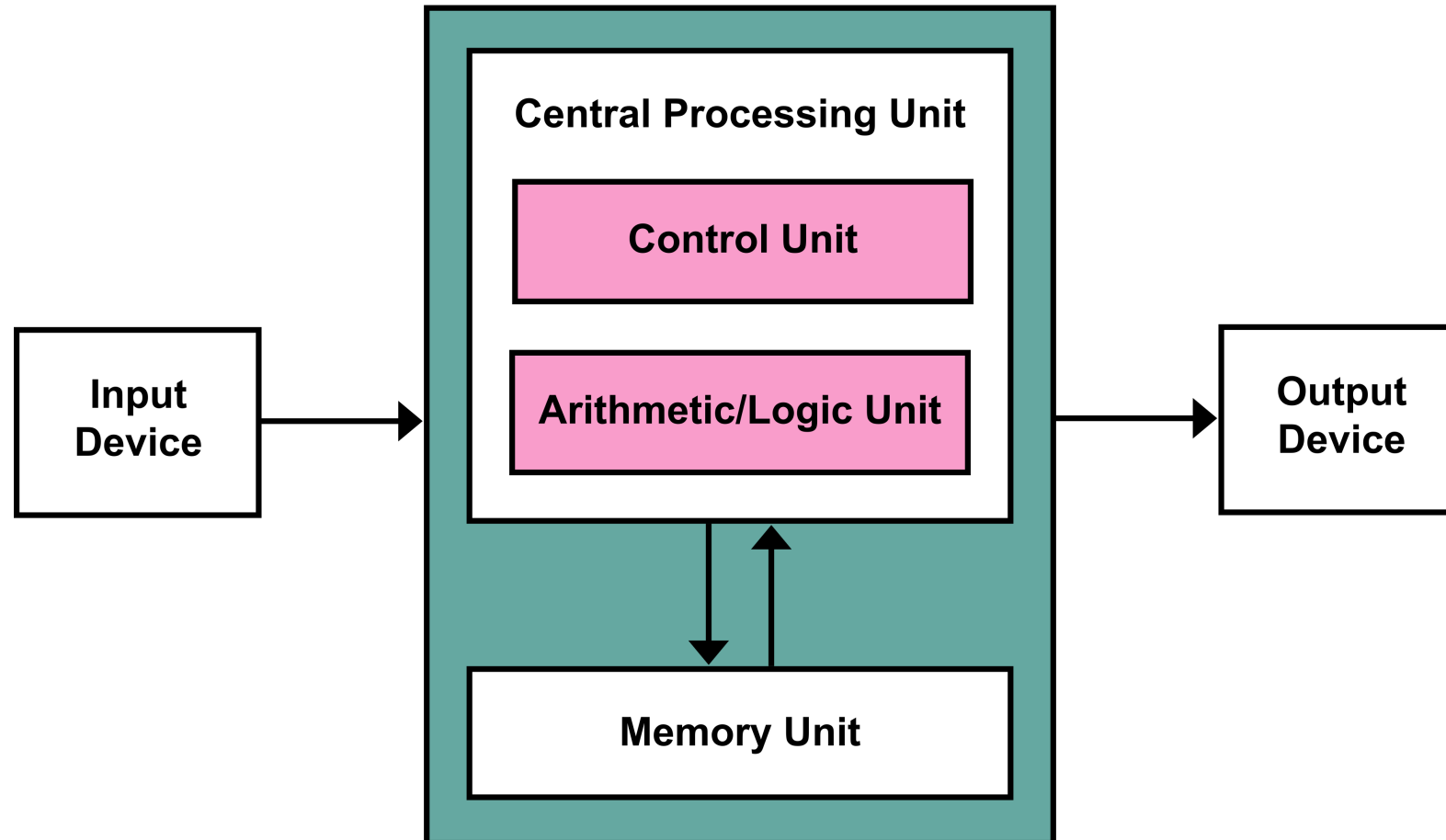
Classical Computers Vs Quantum Computers



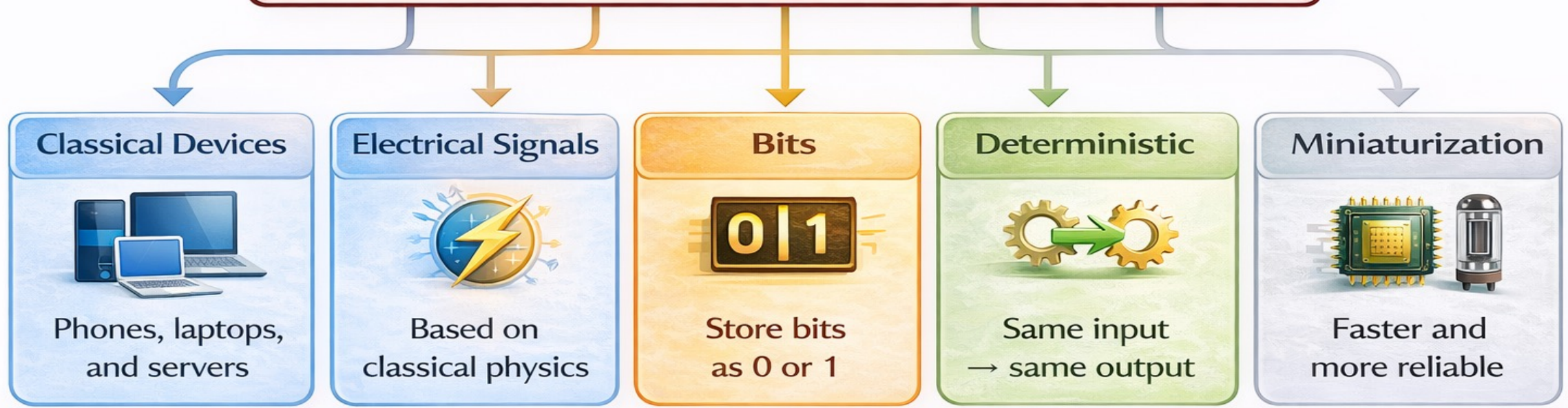
JOURNEY OF CLASSICAL COMPUTERS



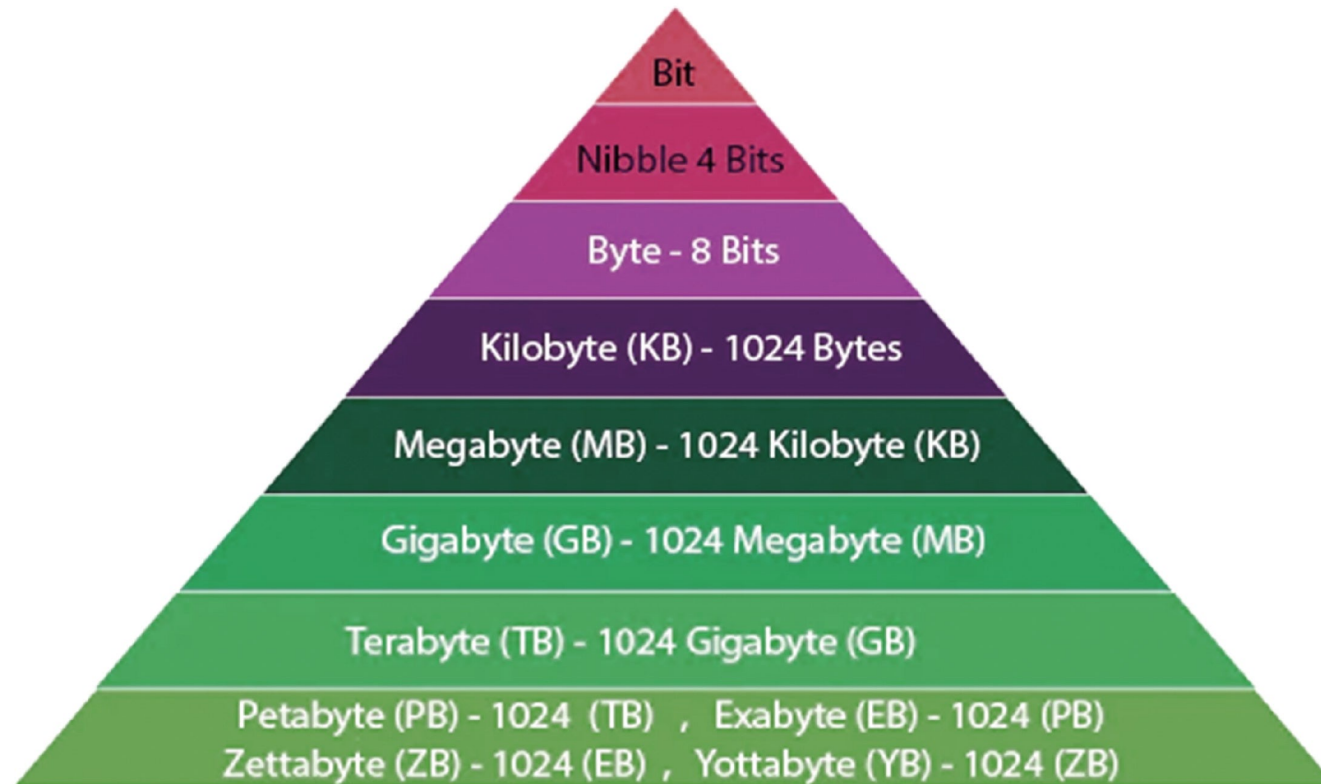
CLASSIC COMPUTERS ARCHITECTURE



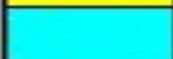
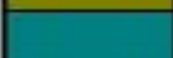
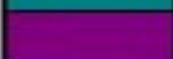
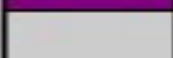
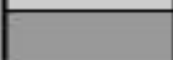
Classical Computers Today



Hierarchy of Data Storage



RGB COLOUR BINARY CODE

	Color	RGB Binary Code
	BLACK	00000000000000000000000000000000
	WHITE	11111111111111111111111111111111
	RED	11111111100000000000000000000000
	LIME	00000000011111111110000000000000
	BLU	00000000000000000000001111111111
	YELLOW	11111111111111111111100000000000
	CYAN	00000000011111111111111111111111
	MAGENTA	11111111100000000000011111111111
	MAROON	10000000000000000000000000000000
	GREEN	00000000010000000000000000000000
	NAVY	00000000000000000000010000000000
	OLIVE	10000000010000000000000000000000
	TEAL	00000000010000000010000000000000
	PURPLE	10000000000000000000010000000000
	SILVER	11000000011000000011000000000000
	GRAY	10000000010000000010000000000000

Alphabets Binary Codes

Character	Binary Code	Character	Binary Code	Character	Binary Code	Character	Binary Code	Character	Binary Code
A	01000001	Q	01010001	g	01100111	w	01110111	-	00101101
B	01000010	R	01010010	h	01101000	x	01111000	.	00101110
C	01000011	S	01010011	i	01101001	y	01111001	/	00101111
D	01000100	T	01010100	j	01101010	z	01111010	0	00110000
E	01000101	U	01010101	k	01101011	!	00100001	1	00110001
F	01000110	V	01010110	l	01101100	"	00100010	2	00110010
G	01000111	W	01010111	m	01101101	#	00100011	3	00110011
H	01001000	X	01011000	n	01101110	\$	00100100	4	00110100
I	01001001	Y	01011001	o	01101111	%	00100101	5	00110101
J	01001010	Z	01011010	p	01110000	&	00100110	6	00110110
K	01001011	a	01100001	q	01110001	'	00100111	7	00110111
L	01001100	b	01100010	r	01110010	(	00101000	8	00111000
M	01001101	c	01100011	s	01110011	)	00101001	9	00111001
N	01001110	d	01100100	t	01110100	*	00101010	?	00111111
O	01001111	e	01100101	u	01110101	+	00101011	@	01000000
P	01010000	f	01100110	v	01110110	,	00101100	_	01011111

Classical Computing: **Strengths** and **Limitations**



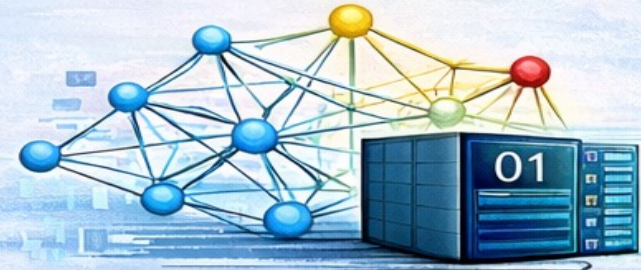
Strengths

- ✓ Reliable & consistent
- ✓ Repeatable results
- ✓ Resistant to small errors
- ✓ Powers modern apps

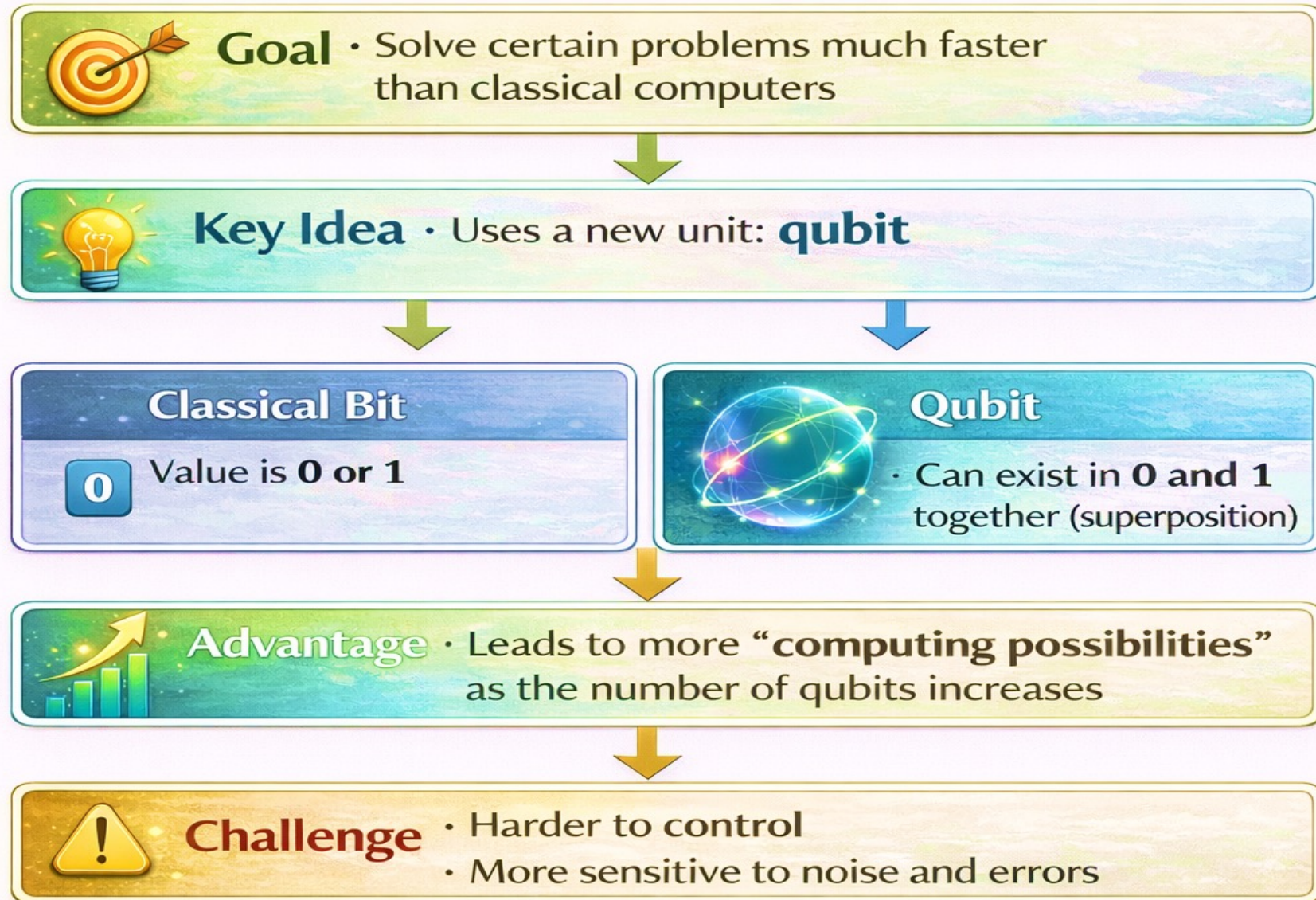


Limitations

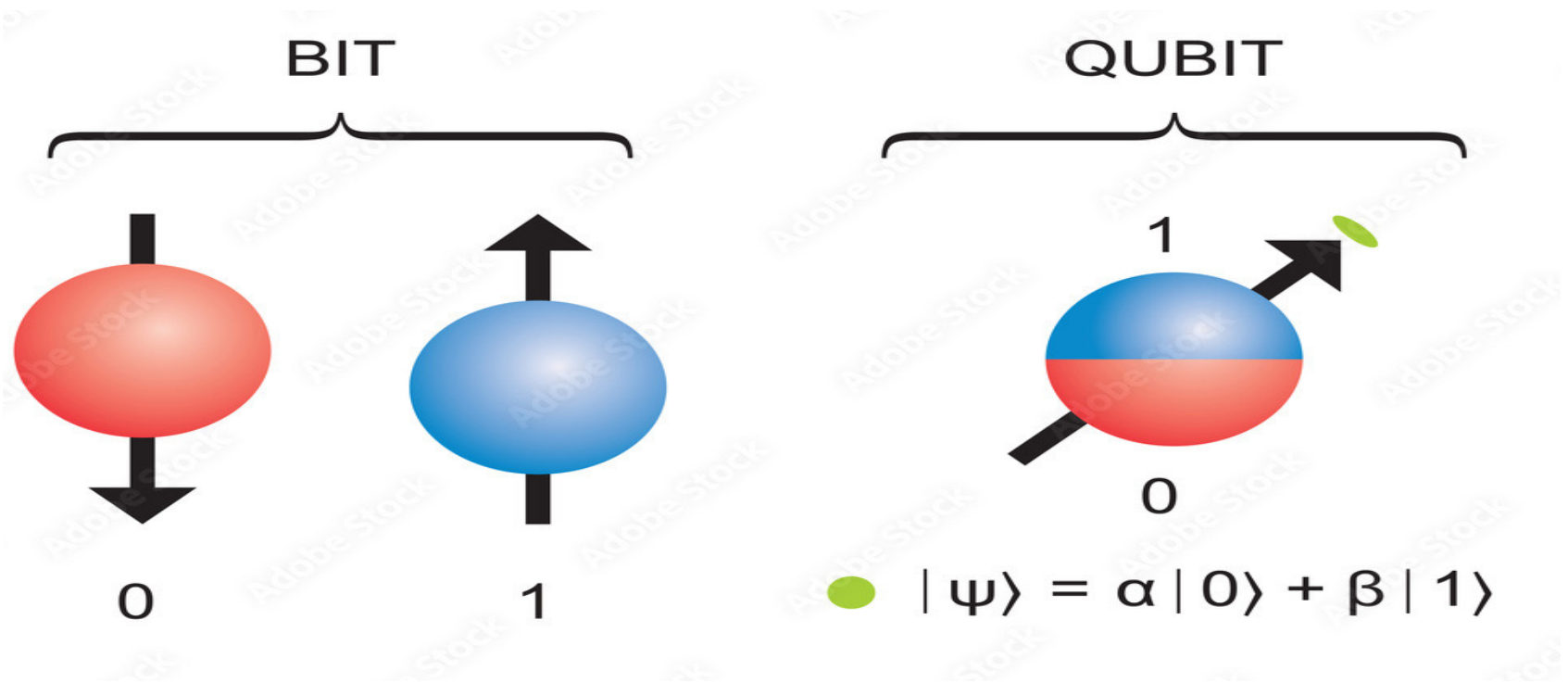
- ! Solving certain problems, where the time or resources required grow astronomically with input size
- ! Slow on large-scale tasks
- ! Even supercomputers face these limits



BEYOND BITS: THE PROMISE OF QUANTUM COMPUTING



FROM BITS TO QUBITS



Qubit and Bloch Sphere

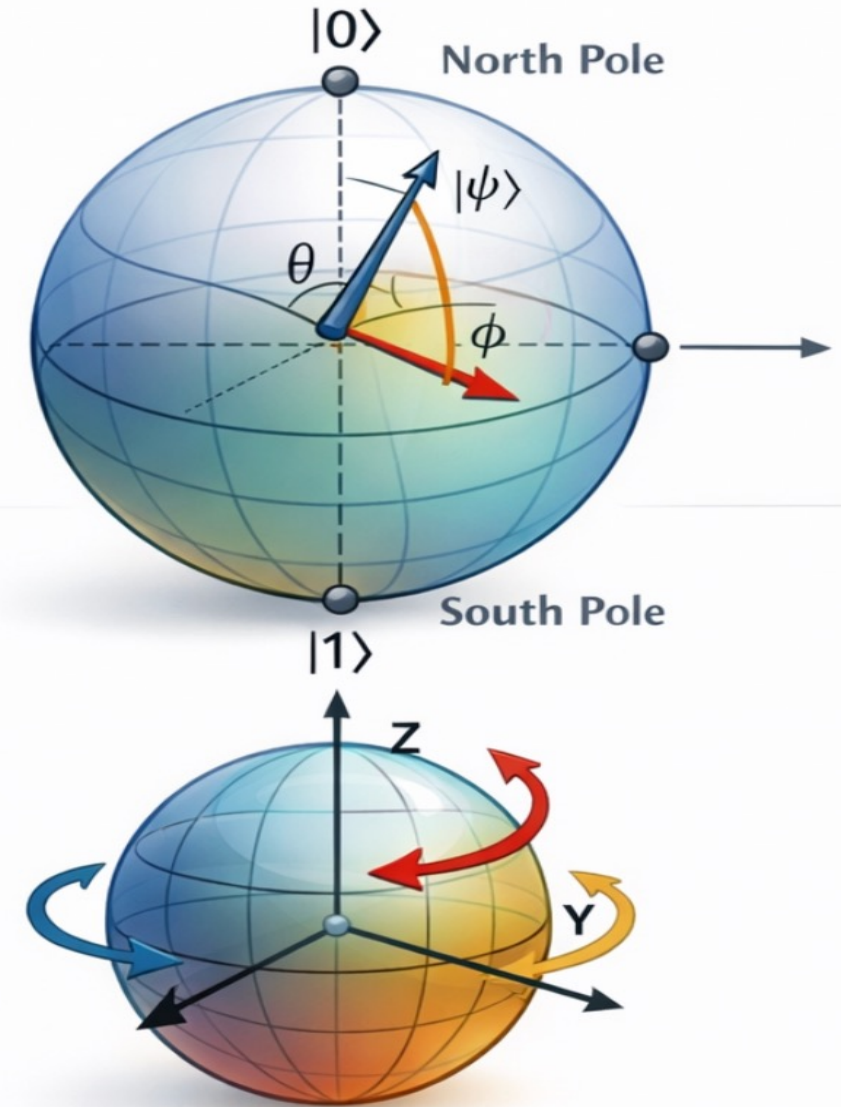
◆ Qubit (Quantum Bit)

- A qubit can exist in $|0\rangle$, $|1\rangle$, or a **superposition** of both
- General state: $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$
- $|\alpha|^2 + |\beta|^2 = 1$ (total probability = 1)
- Measurement collapses the qubit to either 0 or 1

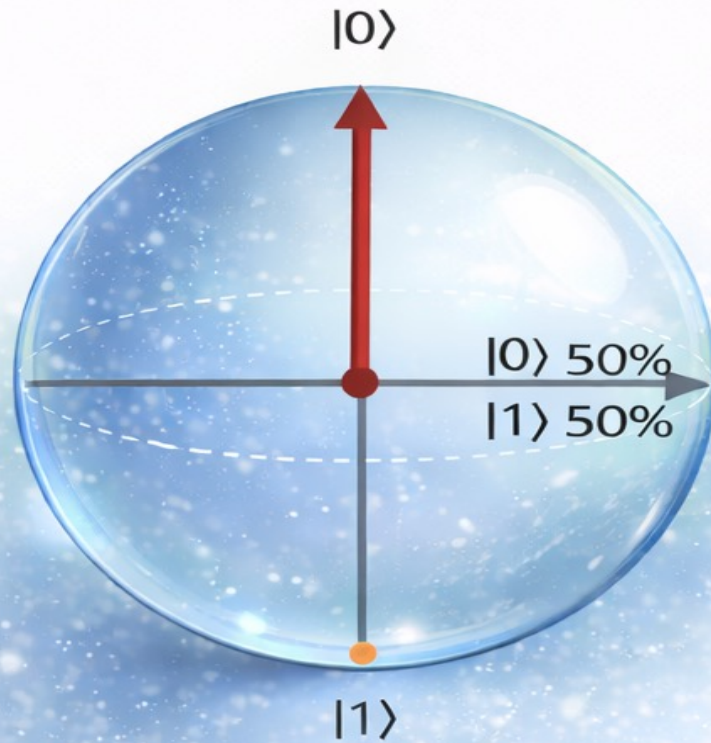
◆ Bloch Sphere (Visualization Tool)

- A geometric representation of a **single qubit state**
- North pole $\rightarrow |0\rangle$, South pole $\rightarrow |1\rangle$
- Any other point $\rightarrow$ different superposition
- Quantum gates = *rotations on the sphere*

Key Idea: A qubit is not just 0 or 1 — it is a direction in 3D space, and quantum computation works by rotating this direction before measurement.



How the Bloch Sphere Represents a Qubit



When the arrow is straight up

- ▶ State = $|0\rangle$
Probability of 0 = 100%



When the arrow is straight down

- ▶ State = $|1\rangle$
Probability of 1 = 100%



When the arrow is horizontal

- ▶ Equal mixture
Probability of 0 = 50%
Probability of 1 = 50%



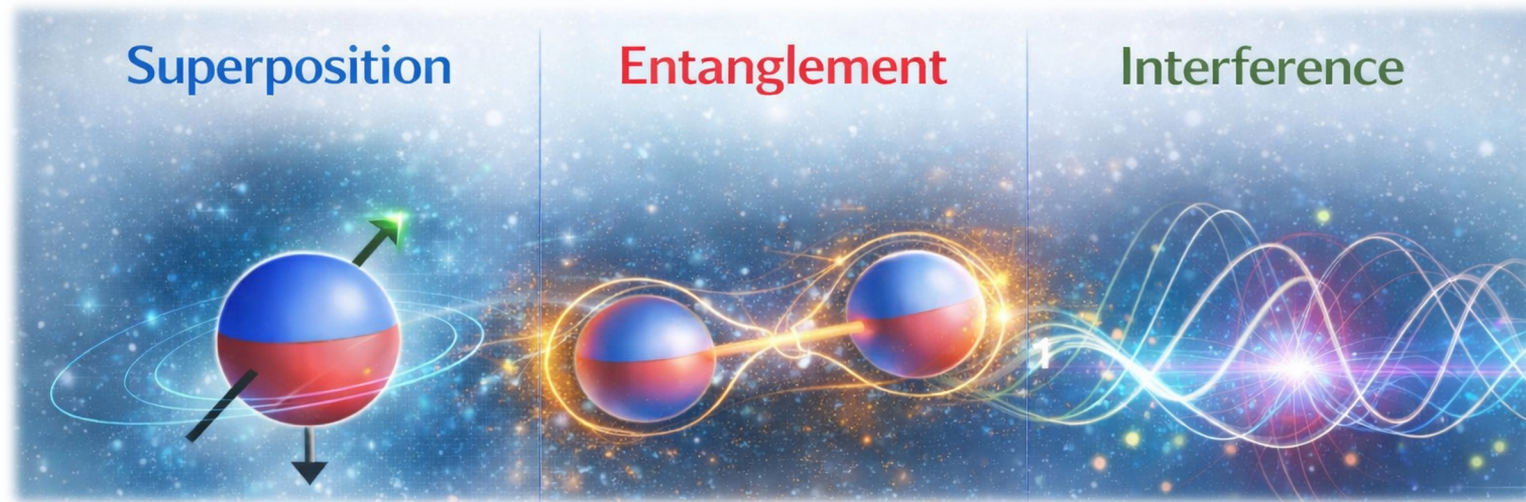
When the arrow tilts upward

- ▶ More weight toward $|0\rangle$
Example:
Probability of 0 = 75%
Probability of 1 = 25%

The direction of the arrow determines the probability of measuring 0 or 1.

Quantum Computer Fundamentals

- Quantum computing uses three main concepts:
- Superposition
- Entanglement
- Interference



Superposition: Simple Analogy



Why Superposition Matters

Classical Computing

- ✓ 2 bits represent 4 states (00, 01, 10, 11).
- ✓ But only one state exists at a time.

Quantum Computing

- ✓ 2 qubits can exist in a combination of all 4 states simultaneously.
- ✓ This allows quantum systems to explore many possibilities at once.

But Measurement Changes Everything

- Superposition does not mean we instantly get all answers.
- When we measure a qubit, it collapses to one definite result.
- The challenge is to increase the probability of the correct answer.
- That is where **entanglement** and **interference** give computers their real power.



Entanglement

Interference

What is Entanglement?

- ✓ Quantum entanglement is a core phenomenon of quantum physics that is crucial in quantum computers.
- ✓ Entanglement links two or more qubits together.
- ✓ Entangled qubits cannot be described independently.
- ✓ A change to one entangled qubit will instantly affect the other, no matter the distance.

→ Entanglement ←

✓ Independent coins

Separate Outcomes



Separate Outcomes

✓ “Entangled” coins

Connected Outcomes

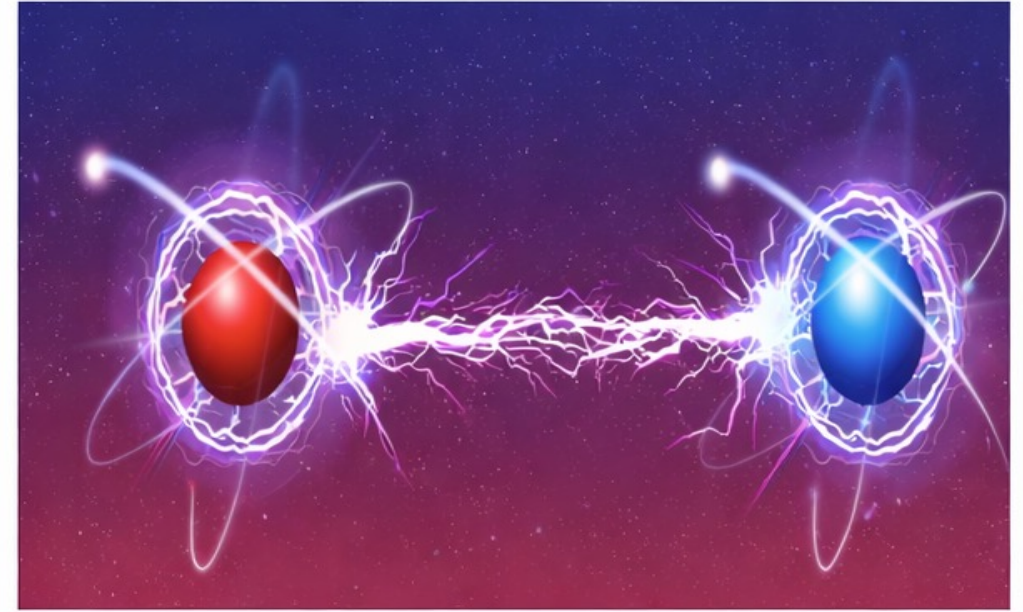
- 1 - - 0 -



Connected Outcomes

When entangled, the states are linked together

Entanglement



- ✓ Links qubits together as one system.
- ✓ The state of one instantly affects the state of the other.
- ✓ Enables complex correlations beyond classical systems.

Why Entanglement Matters

PROS



Information is **distributed** across the system



Enables powerful computations



Boosts performance



CONS



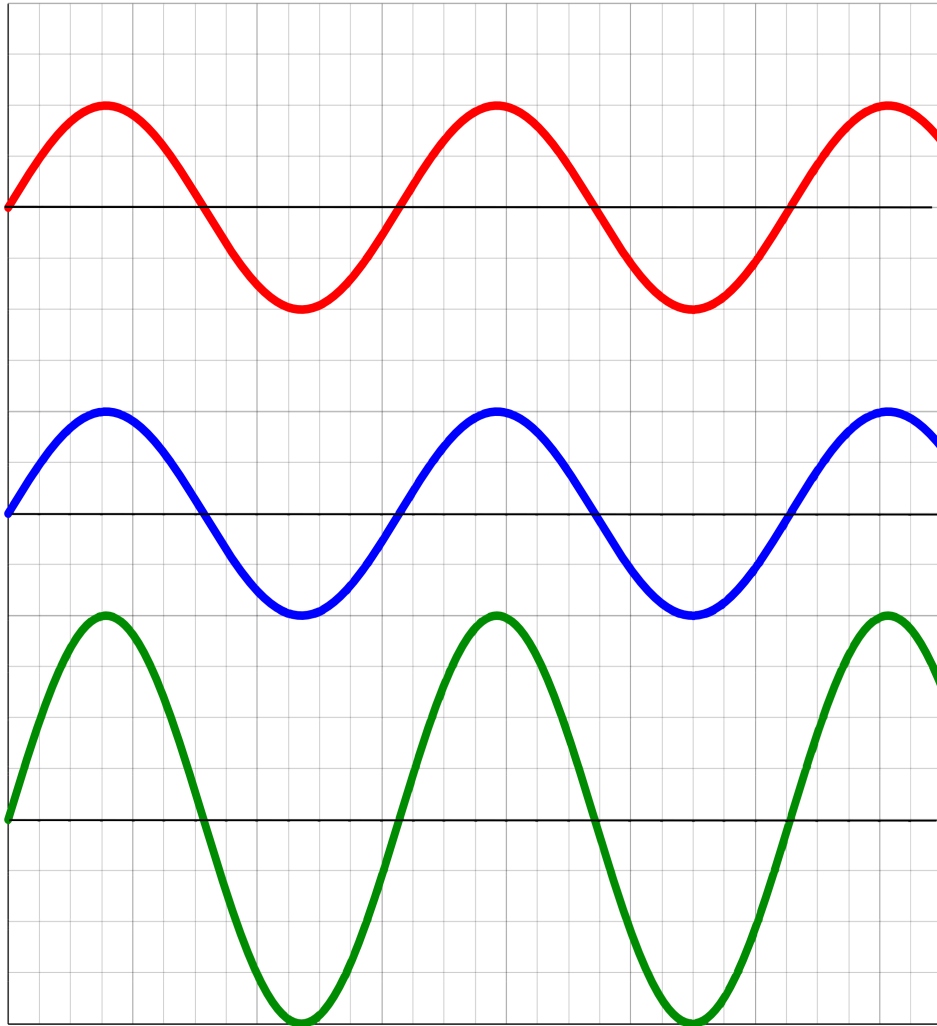
Increases fragility

Errors spread rapidly

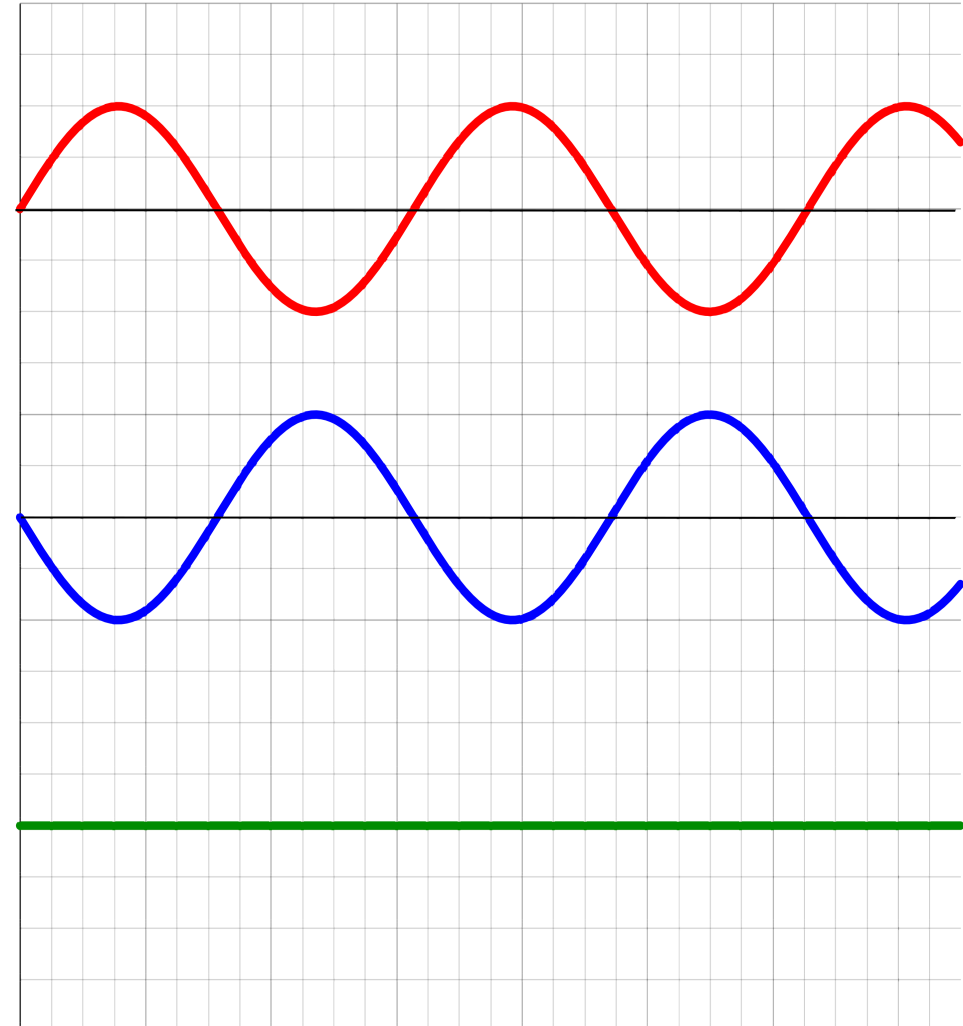
Requires careful design

Interference

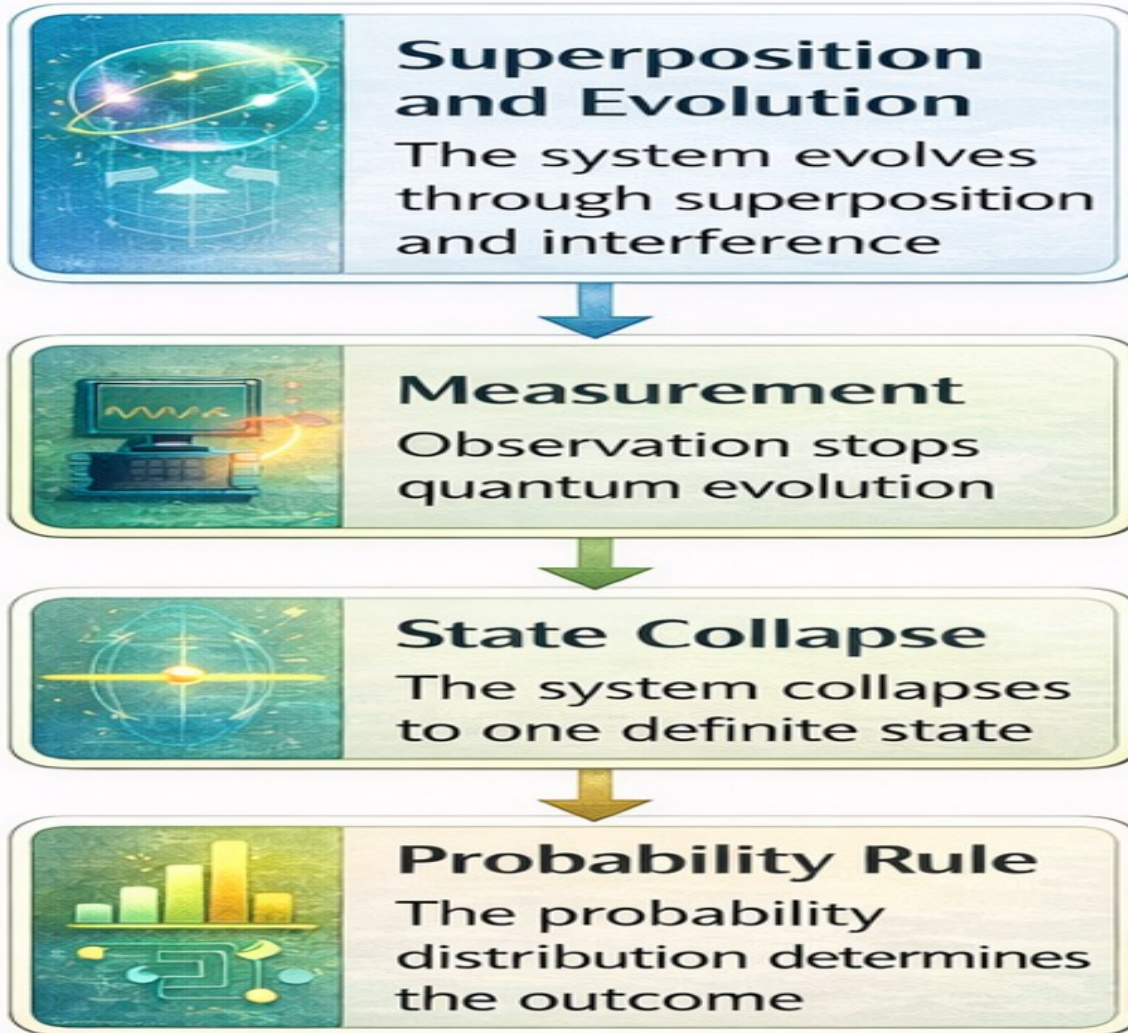
Constructive



Destructive



Measurement and Final Result

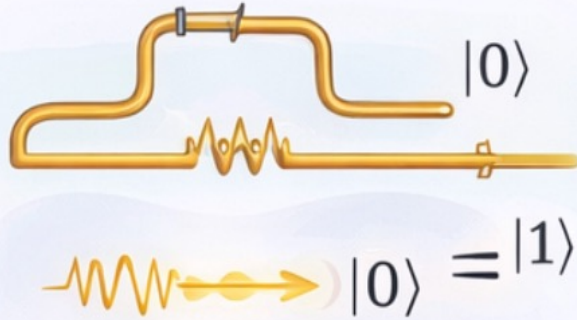


Quantum Computer Hardware

Types of Qubits and How Their Two States Are Created

1 Superconducting Qubit

- Energy levels in a quantum circuit



- Energy levels in a quantum circuit

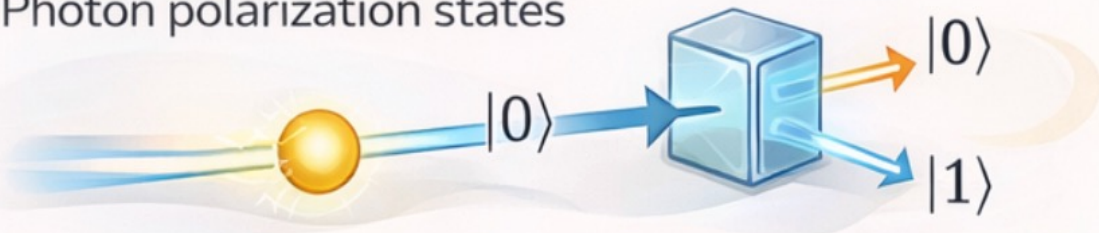
2 Trapped Ion Qubit

- Uses a single ion trapped by **electromagnetic fields**
- $|0\rangle, |1\rangle$ = two stable **electronic energy levels**
- Manipulated using **laser pulses**



3 Photonic Qubit

- Photon polarization states



4 Topological Qubit

- States of entangled particles

$|0\rangle$ $|1\rangle$

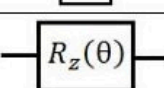
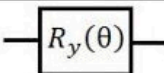
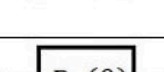
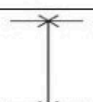


Classical Computer

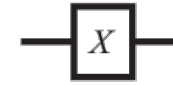
Logic Gates

Name	NOT	AND	NAND	OR	NOR	XOR	XNOR																																																																																																
Alg. Expr.	$\overline{A}$	AB	$\overline{AB}$	$A+B$	$\overline{A+B}$	$A\oplus B$	$\overline{A\oplus B}$																																																																																																
Symbol																																																																																																							
Truth Table	<table><tr><th>A</th><th>X</th></tr><tr><td>0</td><td>1</td></tr><tr><td>1</td><td>0</td></tr></table>	A	X	0	1	1	0	<table><tr><th>B</th><th>A</th><th>X</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	B	A	X	0	0	0	0	1	0	1	0	0	1	1	1	<table><tr><th>B</th><th>A</th><th>X</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	B	A	X	0	0	1	0	1	1	1	0	1	1	1	0	<table><tr><th>B</th><th>A</th><th>X</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	B	A	X	0	0	0	0	1	1	1	0	1	1	1	1	<table><tr><th>B</th><th>A</th><th>X</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	B	A	X	0	0	1	0	1	0	1	0	0	1	1	0	<table><tr><th>B</th><th>A</th><th>X</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	B	A	X	0	0	0	0	1	1	1	0	1	1	1	0	<table><tr><th>B</th><th>A</th><th>X</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	B	A	X	0	0	1	0	1	0	1	0	0	1	1	1
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Quantum Gates

Gate	Symbol	Matrix
Pauli-X (NOT)		$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$
Pauli-Y		$\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$
Pauli-Z (Phase flip)		$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$
S		$\begin{pmatrix} 1 & 0 \\ 0 & i \end{pmatrix}$
T		$\begin{pmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{pmatrix}$
Hadamard		$\frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$
Rotation Z		$\begin{pmatrix} e^{-i\theta/2} & 0 \\ 0 & e^{i\theta/2} \end{pmatrix}$
Rotation Y		$\begin{pmatrix} \cos(\frac{\theta}{2}) & -\sin(\frac{\theta}{2}) \\ \sin(\frac{\theta}{2}) & \cos(\frac{\theta}{2}) \end{pmatrix}$
Rotation X		$\begin{pmatrix} \cos(\frac{\theta}{2}) & -i\sin(\frac{\theta}{2}) \\ i\sin(\frac{\theta}{2}) & \cos(\frac{\theta}{2}) \end{pmatrix}$
CNOT		$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$
Swap		$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$

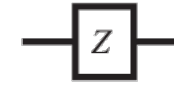
Pauli-X (NOT)



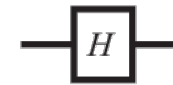
Pauli-Y



Pauli-Z (phase flip)



Hadamard



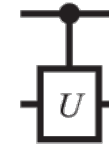
Phase



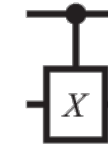
$\pi/8$



controlled-U



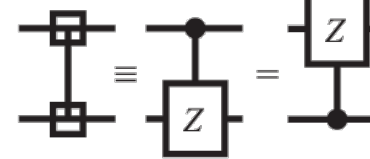
controlled-X



CNOT



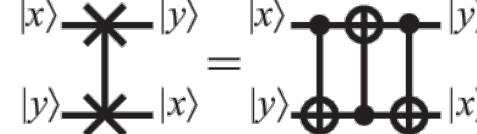
controlled-Z



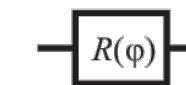
controlled-phase



SWAP



Y-rotation



Quantum Gates – Instructions for Qubits

What is a Quantum Gate?

A **command** that changes a qubit

Gate (Instruction)

“Flip”, “Rotate”, “Add Phase”

Hardware

Performs it using **signals**

Microwave

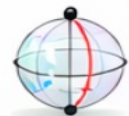
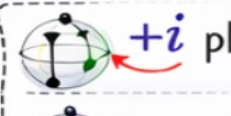
Laser/Light

Electric Pulse

Gate = **Instruction** (Software)

Signal = **Physical Action** (Hardware)

Single-Qubit Gates

I	I (identity)	does nothing	$ 0\rangle \rightarrow 0\rangle$ $ 1\rangle \rightarrow 1\rangle$	
X	X (Pauli-X)	flips $ 0\rangle \leftrightarrow 1\rangle$ (NOT)	$ 0\rangle \rightarrow 1\rangle$	
Z	Z (Pauli-Z)	keeps $ 0\rangle$ same, flips phase of $ 1\rangle$	$ 0\rangle \rightarrow 0\rangle$ $ 1\rangle \rightarrow - 1\rangle$	
Y	Y (Pauli-Y)	flip + phase (rotation around Y)	$ 0\rangle \rightarrow i 1\rangle$ $ 1\rangle \rightarrow i 0\rangle$	
H	H (Hadamard)	makes superposition	$ 0\rangle \rightarrow \frac{ 0\rangle + 1\rangle}{\sqrt{2}}$ $ 1\rangle \rightarrow \frac{ 0\rangle - 1\rangle}{\sqrt{2}}$	
S	S (Phase)		$ 1\rangle \rightarrow i 1\rangle$	
T	T (T gate)		$ 1\rangle \rightarrow e^{i\pi/4} 1\rangle$	

Rotations

$R_x(\theta)$ – rotate around X



$R_y(\theta)$ – rotate around Y

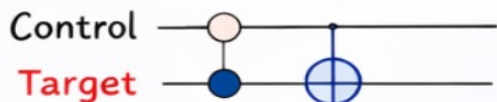


$R_z(\theta)$ – rotate around Z



2-Qubit Gates (Create Correlation / Entanglement)

CNOT



If control = $|0\rangle \rightarrow$ target unchanged

If control = $|1\rangle \rightarrow$ **Flip target**

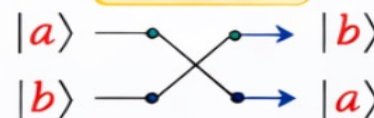
CZ



If both = $|1\rangle \rightarrow$ add - sign (phase flip)

$$\frac{1}{\sqrt{2}}(|100\rangle + |111\rangle)$$

SWAP



Swaps two qubits

Goal of 2-Qubit Gates:

Create **correlation** (entanglement)

$$\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

$\rightarrow$ Qubits become **linked!**

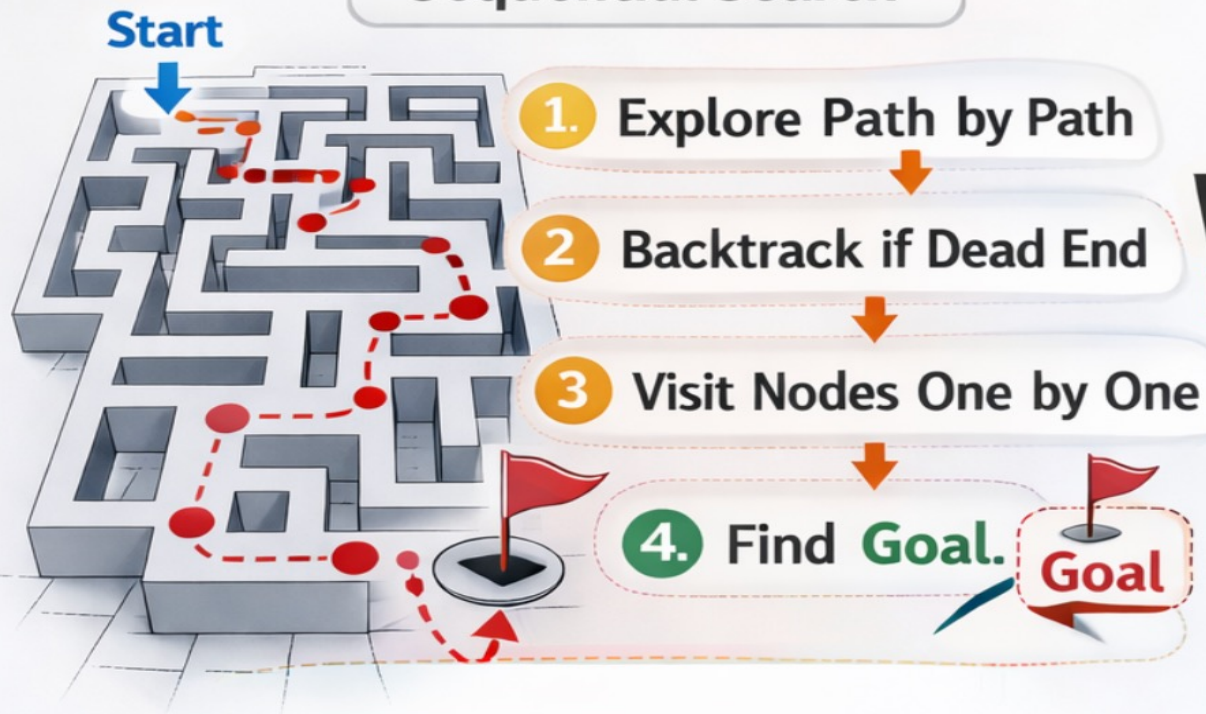
What is a Quantum Algorithm?

A quantum algorithm is a step-by-step method that solves a problem by using **qubits + quantum gates**.

A quantum algorithm is a **recipe** that tells a quantum computer which gates to apply and in **what order** to solve a problem.

CLASSICAL COMPUTING

Sequential Search



VS

QUANTUM COMPUTING

Parallel Search (Superposition)



Speed Comparison



Where Quantum Computing Can Help

Quantum computing can help in specific problems that are difficult for classical computers.



Quantum computing naturally handles problems that are difficult for classical computers.

India's National Quantum Mission

The Indian government is implementing the National Quantum Mission (NQM) with a ₹6,003.65 crore budget (2023–2031) to develop quantum computers, secure communication, and sensors.



Four 'Thematic Hubs' (T-Hubs)

Focused on quantum research



Fabrication Facilities

Set up at premier IITs and IISc



Intermediate-Scale Quantum Computers

Develop advanced quantum processors

Developing quantum computers, secure communication, and sensors with a ₹6,003.65 crore budget for 2023–2031.

Feynman's Vision To Today's Real Quantum Processors

The Foundations of Quantum computing are Deep

&

Possibilities are Extraordinary.

With every Break through we are getting closer to

A New Era of Computation.

Journey of Quantum Computing Continues.

Thank You!



Temperature Stages

Metal "floors" in dilution refrigerator at multiple stages:
50 K, 4 K, ~1 K, 100 mK, 10-20 mK
step-by-step cool, anchor wiring
limit heat leakage

Mechanical Supports & Thermal Links

Stabilize stack alignment
stepwise thermalize

- minimize downward heat conduction

Signal Wiring Harness

Orderly curved coaxial cables
bring control/readout signals
to various plate levels

- loops minimize thermal contraction and stress

- Supports & Thermal Links
- Temperature Stage
- Signal Flow
- Connectors & Feedthroughs

- Signal flow
- Connectors & Feedthroughs

Top Temperature Stage

~4 Kelvin, Moderate Cooling
& Signal Entry Anchor

- step-by-step cool (50 K, 4 K, ~1 K, 100 mK)
- step-by-step cool, wiring limit heat leak

Signal Wiring Harness

Orderly curved coaxial cables
bring control/readout signals
to various plate levels

- loops minimize thermal contraction & stress

Connectors & Feedthroughs

- Robust microwave assemblies anchor/control at each stage
- block/reduce high-frequency noise

Sample Can / Chip Package Zone

- Coldest and Most Shielded Region (~10 – 20 millikelvin)
- Where Quantum Processor Sits
- Attenuators reduce incoming noise
- Low-pass/IR filtering + Thermal Anchors
- Dissipative Filters remove Stochastic high-frequency noise

● Quantum Chip Package