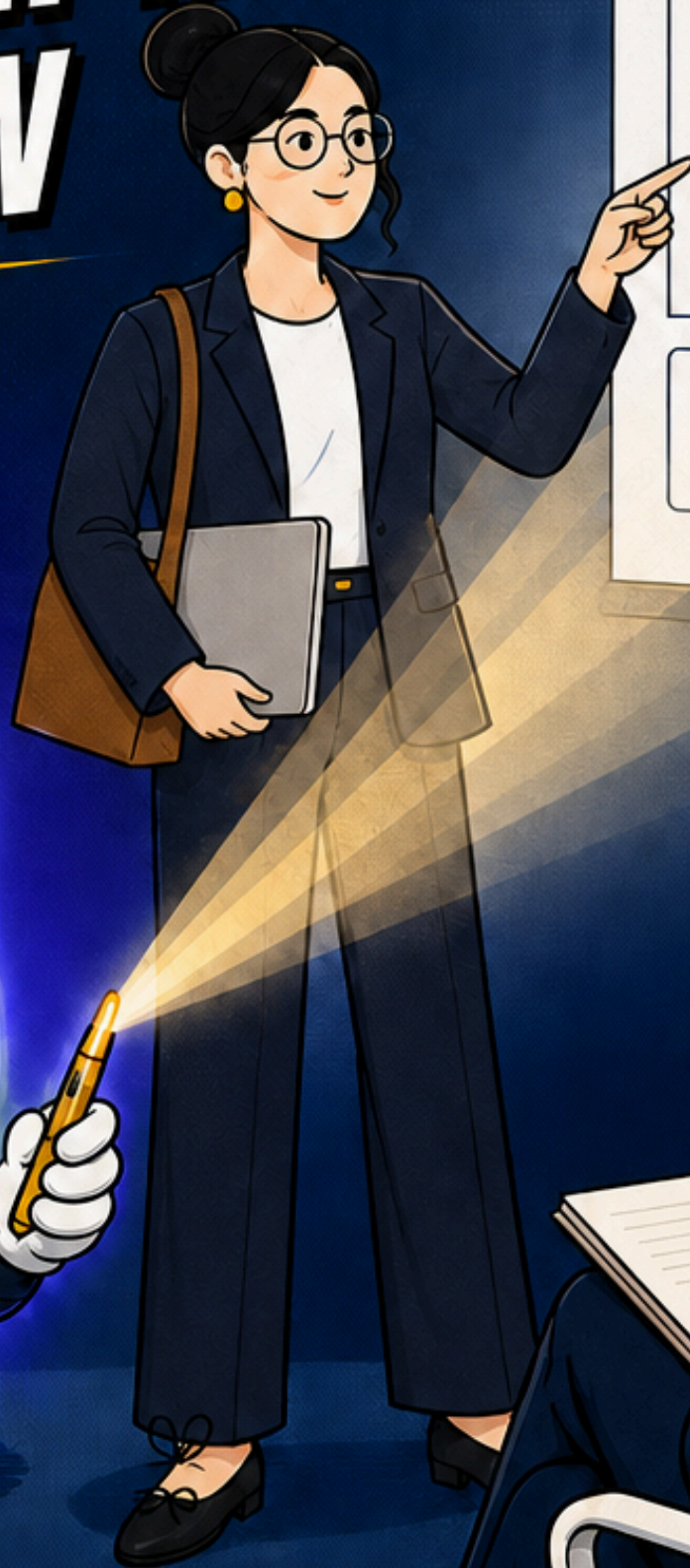
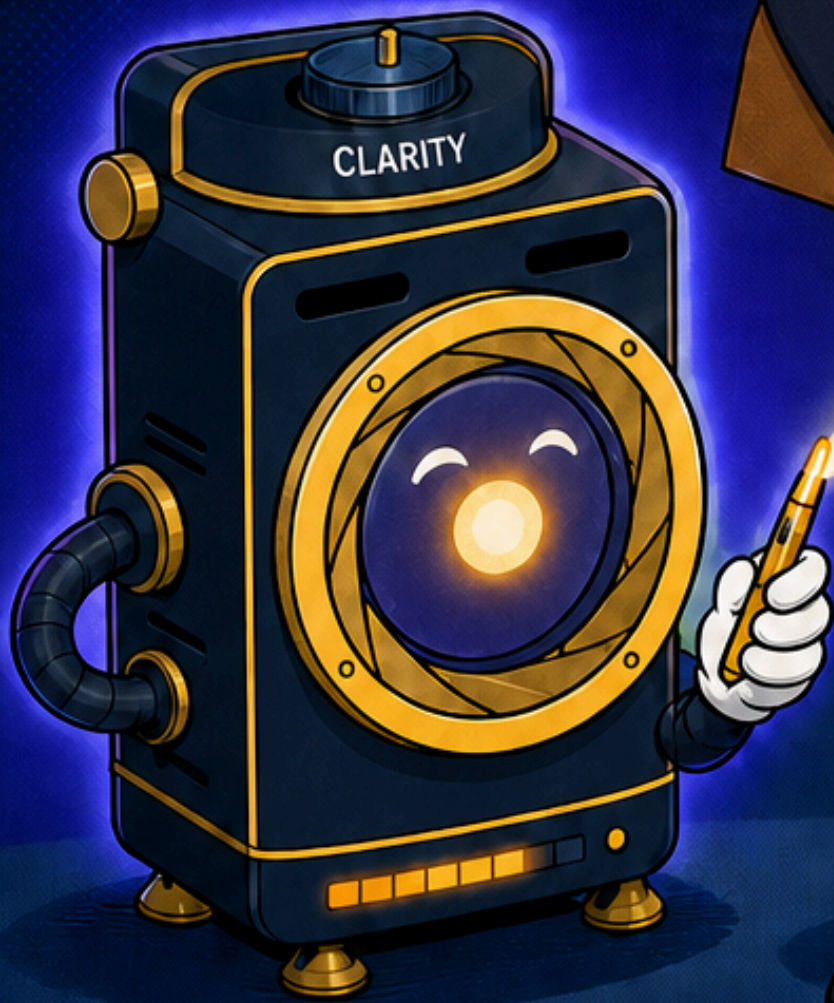
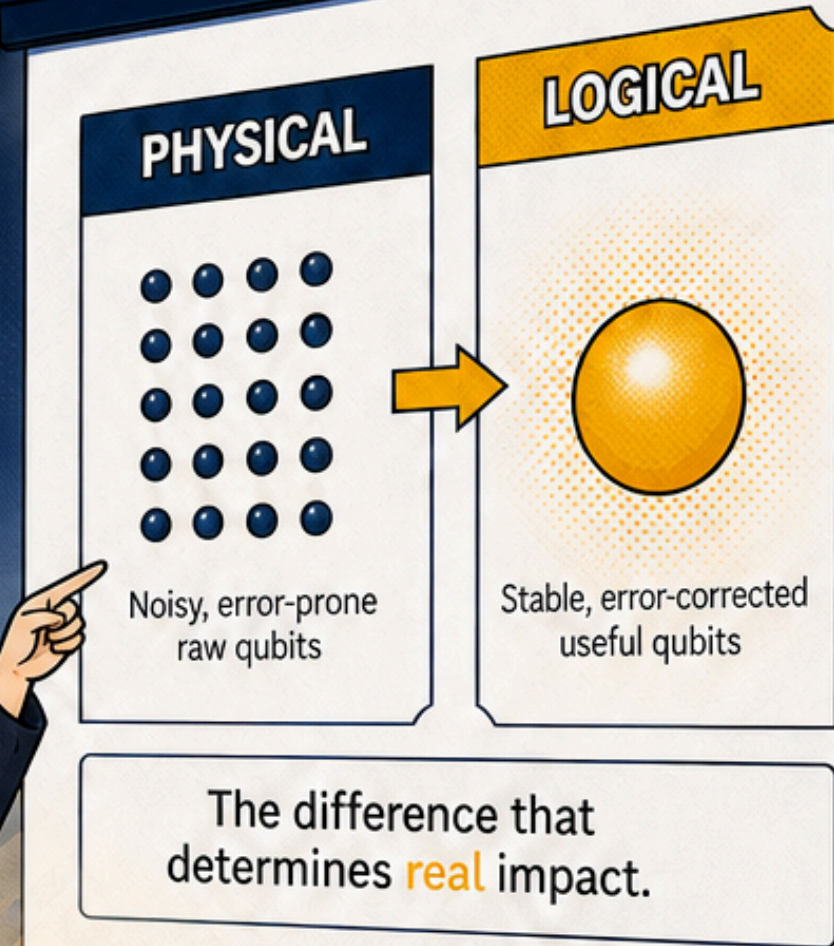


# QUANTUM COMPUTING - PHYSICAL VS LOGICAL QUBITS:

## WHAT INVESTORS ACTUALLY NEED TO KNOW



# THE RAW MATERIAL: PHYSICAL QUBITS

A physical qubit is the actual hardware unit. It might be a superconducting loop chilled to near absolute zero, a single trapped ion held in place by electromagnetic fields, or a photon traveling through a waveguide.

The specific implementation varies by company, but the fundamental problem is the same across all of them: physical qubits are extraordinarily fragile.

They lose their quantum state — a process called decoherence — when disturbed by heat, vibration, electromagnetic interference, or even the act of measurement itself.

Error rates on current physical qubits sit roughly in the range of 0.1% to 1% per gate operation. That sounds small until you realise that useful quantum algorithms require millions of gate operations. Errors compound fast.

So when a company announces it has 1,000 physical qubits, the relevant follow-up question is: what's the error rate on each one?

**A thousand noisy qubits and a thousand high-fidelity qubits are not the same product. Not even close.**

## NOISY QUBITS



ERROR RATE  
(per gate)

**~1%**

## HIGH-FIDELITY QUBITS



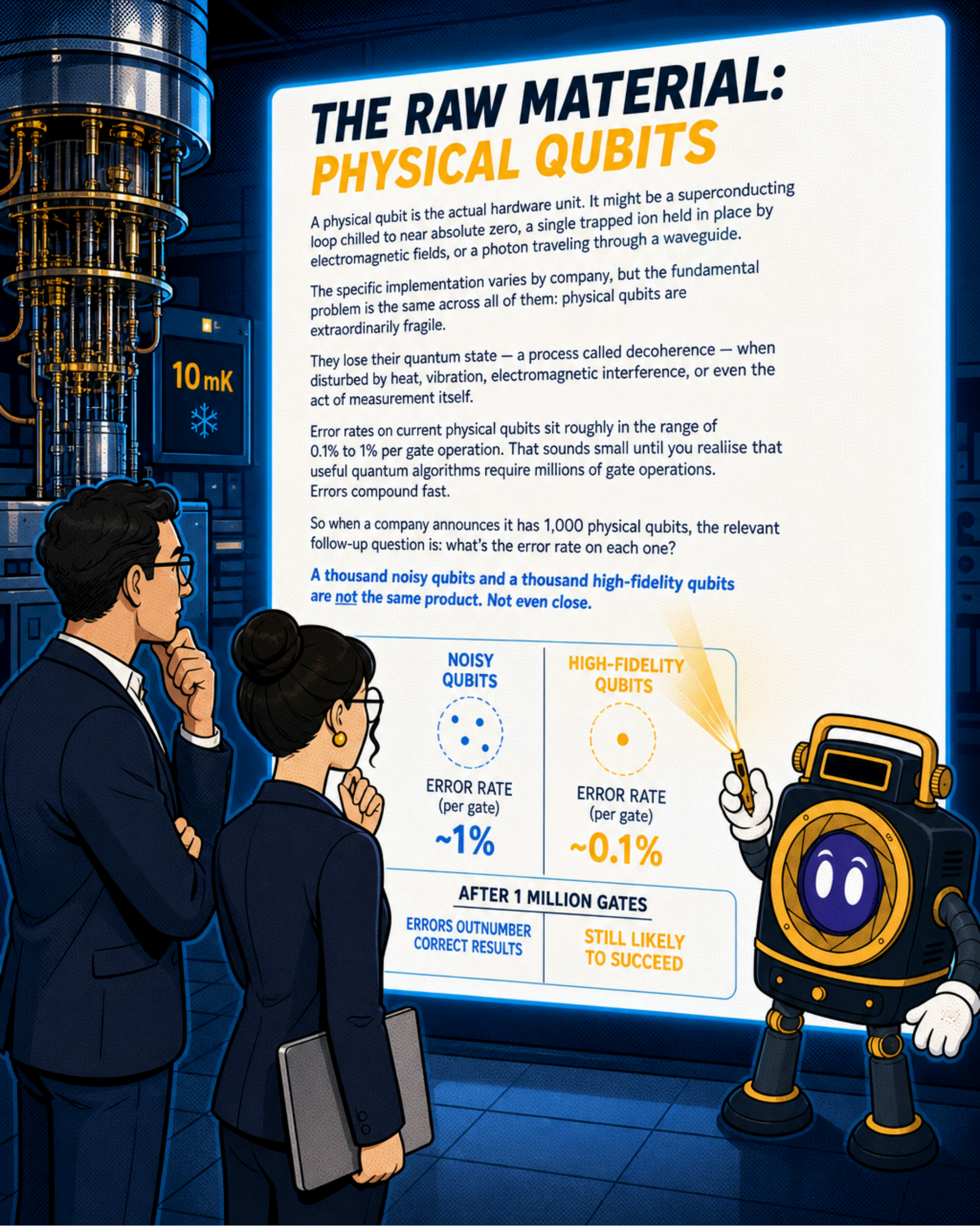
ERROR RATE  
(per gate)

**~0.1%**

## AFTER 1 MILLION GATES

ERRORS OUTNUMBER  
CORRECT RESULTS

STILL LIKELY  
TO SUCCEED



# The construct that actually does useful work: logical qubits



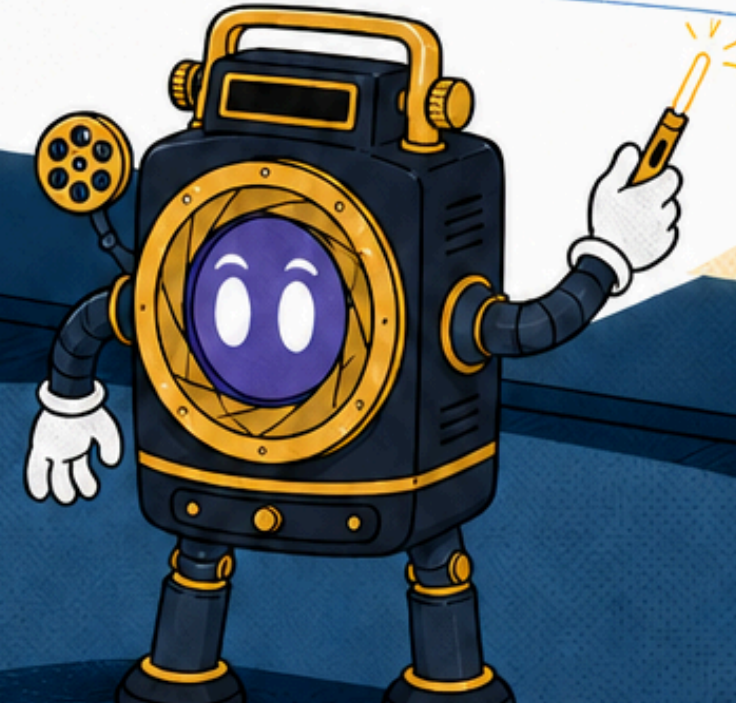
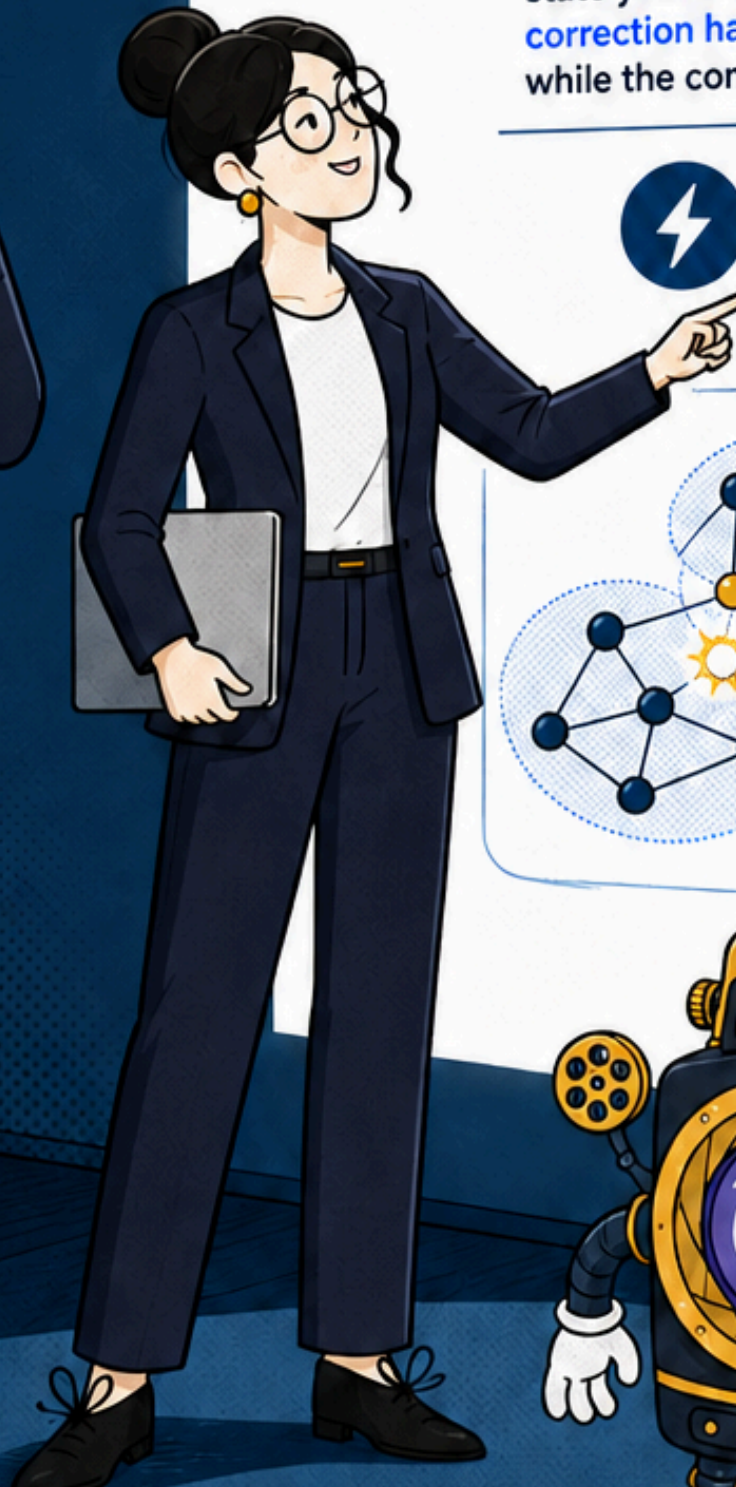
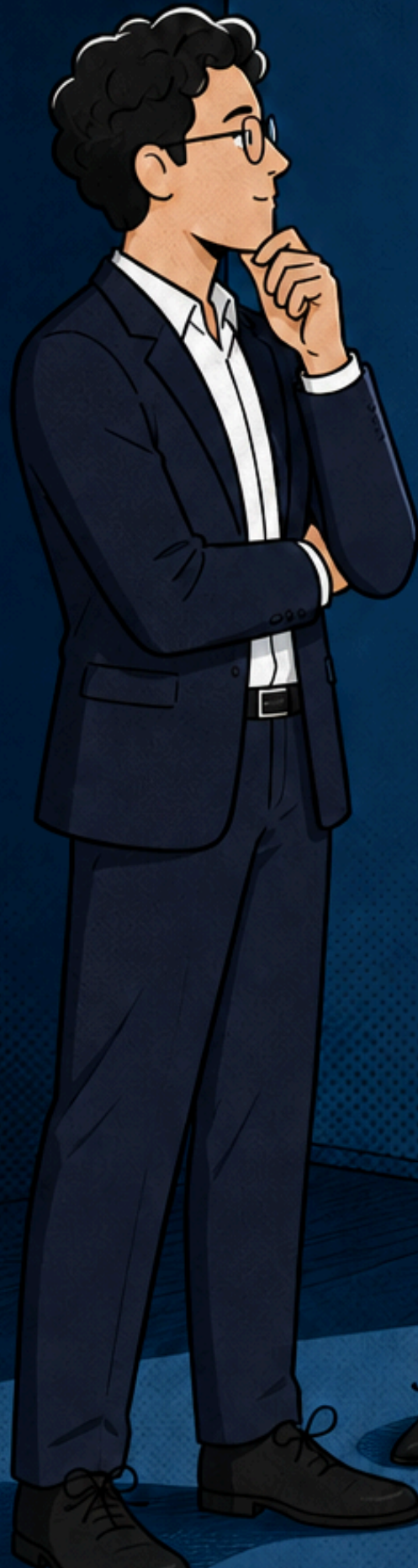
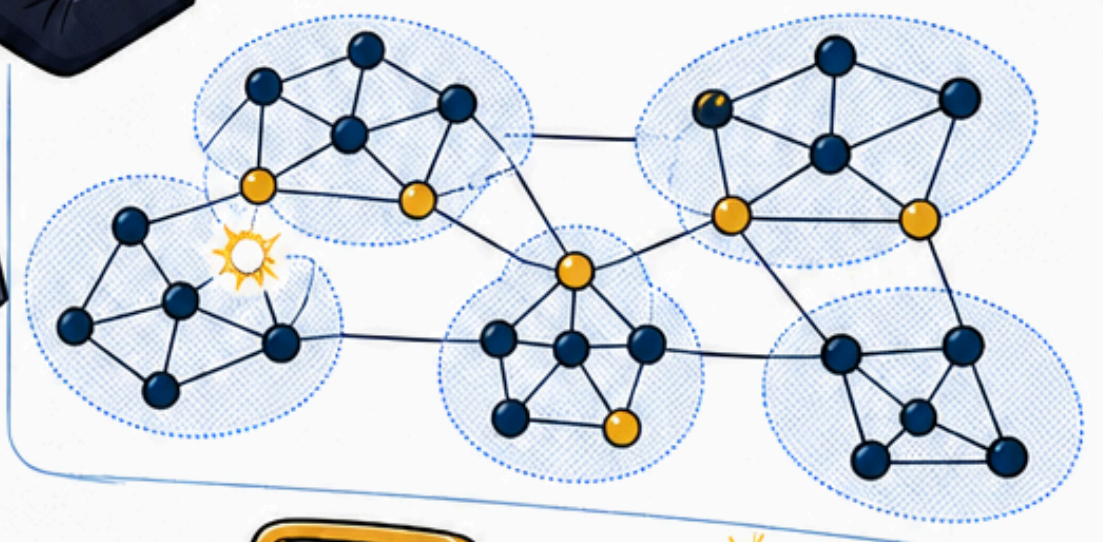
A logical qubit is what you get when you take many physical qubits and wire them together in a way that protects the underlying information from errors. The quantum information isn't stored in any single physical qubit — it's **distributed across the entire group**. That distribution is the protection.



The core idea is **redundancy**. If one physical qubit in the group flips due to noise, the surrounding qubits collectively still hold enough information to detect and correct the error, without ever collapsing the quantum state you're trying to protect. Think of it as **error correction happening in the background**, continuously, while the computation runs.



That's what "fault-tolerant" means in practice. It doesn't mean errors never happen. It means the system corrects them **faster than they accumulate**.



# HOW SURFACE CODES DETECT ERRORS

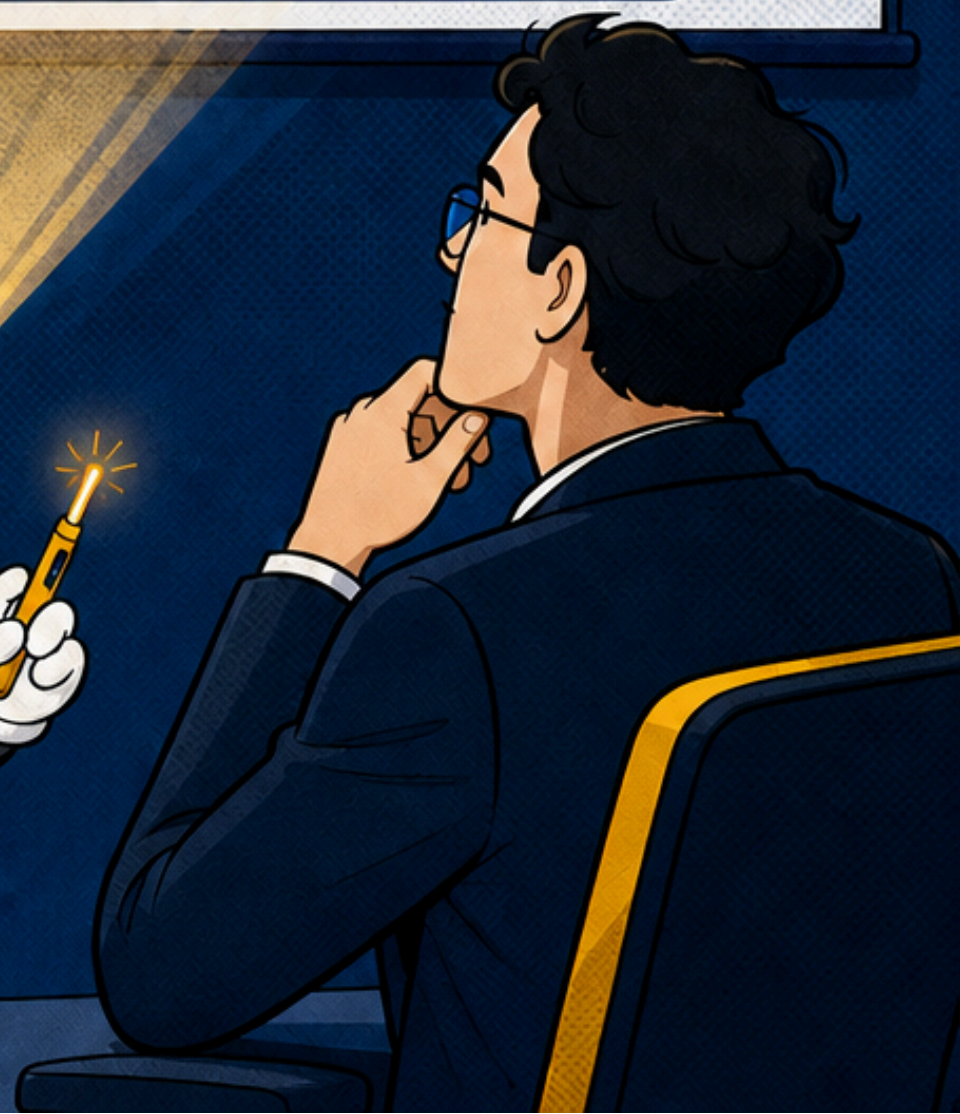
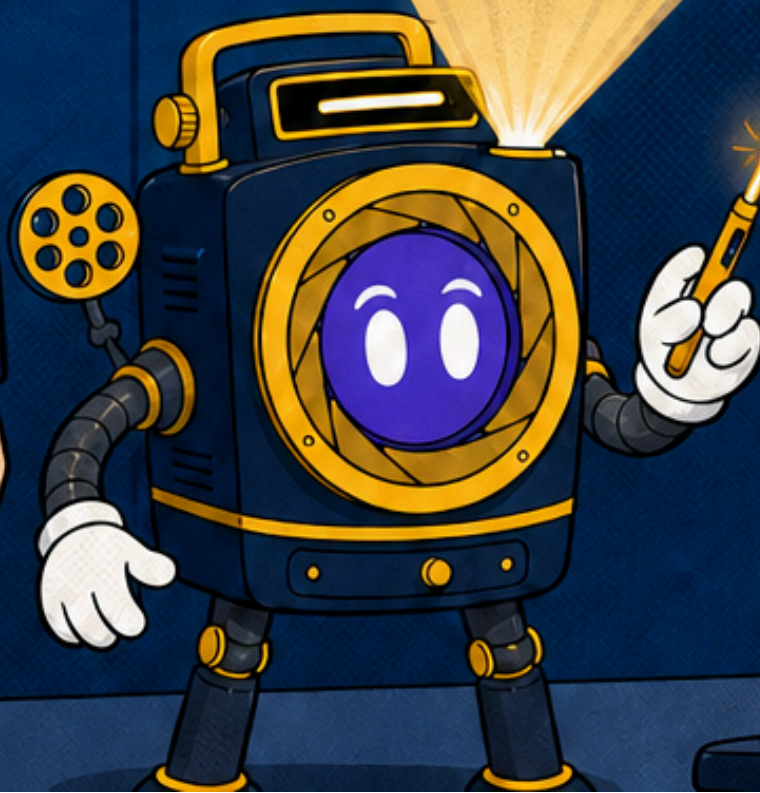
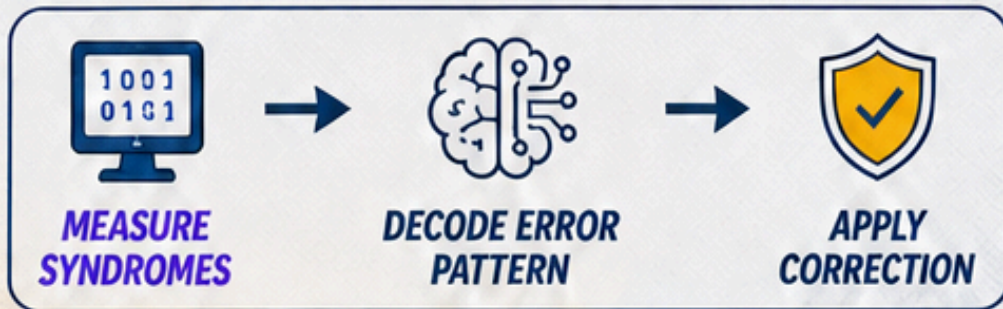
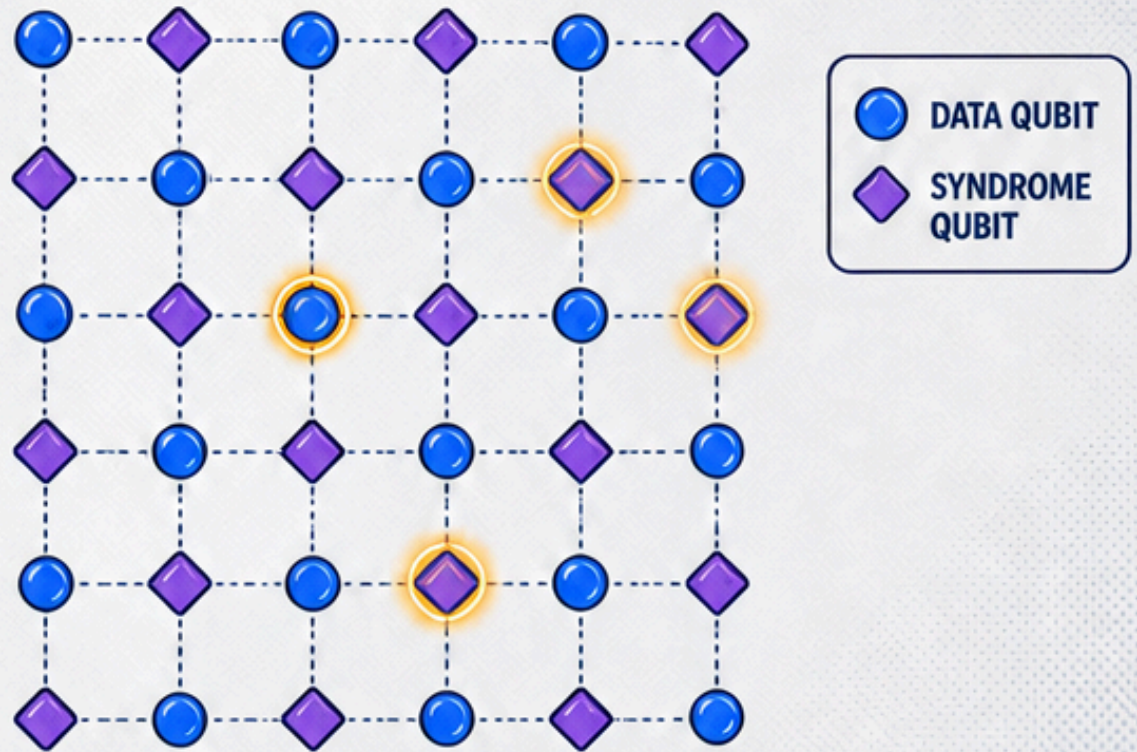
Physical qubits sit in a 2D grid.

**Data qubits** carry the quantum state;

**syndrome qubits** monitor neighbours for parity changes — subtle shifts signalling an error without revealing the underlying information.

A classical decoder then identifies the likely error pattern and applies a correction.

The cycle runs **continuously** during computation.



# The error threshold — and Google's Willow milestone



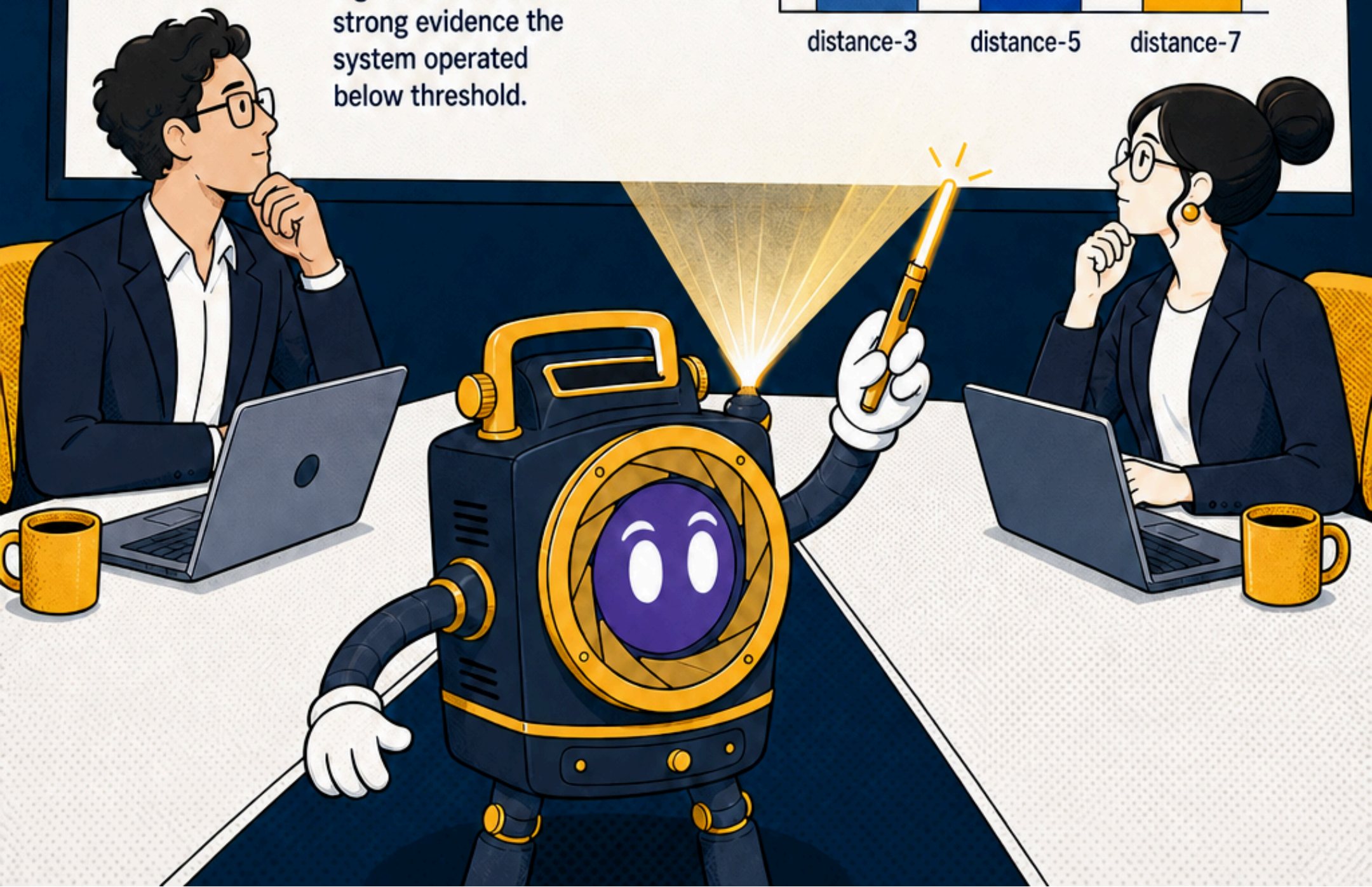
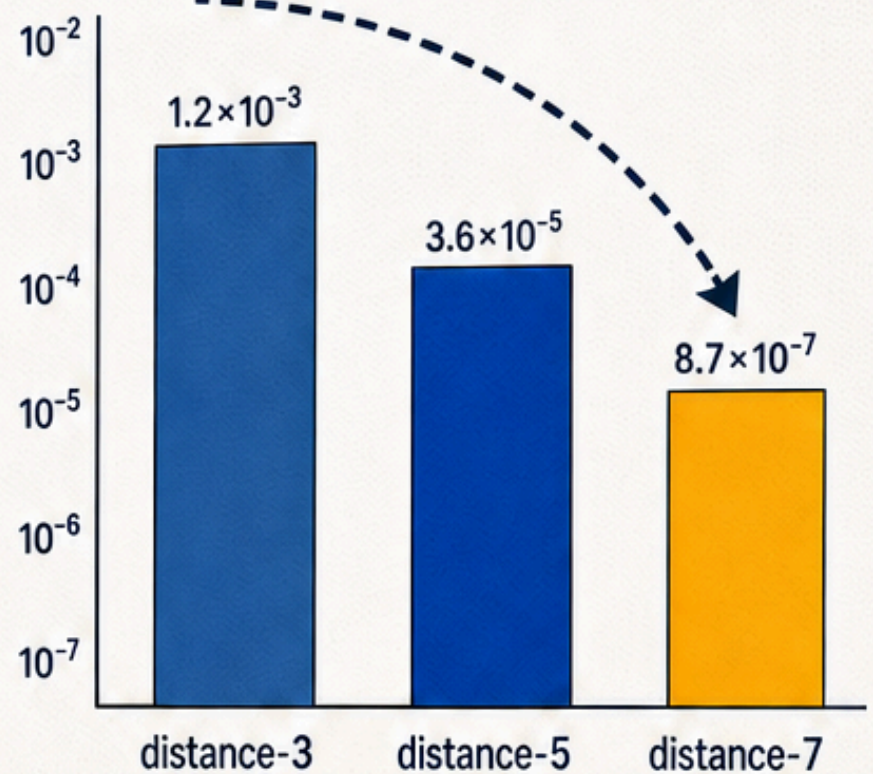
The surface code has a theoretical error threshold of roughly **0.5–1%** per gate.

Below that rate, adding more physical qubits exponentially suppresses logical errors.



Google's Willow chip (Dec 2024) scaled from distance-**3** → **5** → **7**, progressively cutting logical error rates — strong evidence the system operated below threshold.

Logical error rate (↓ better)

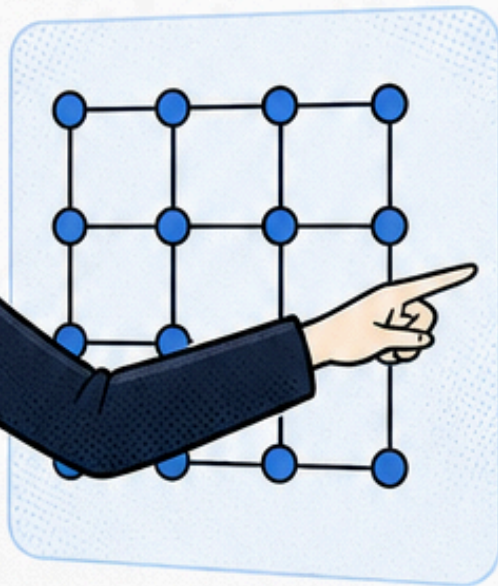


# Color codes vs. surface codes

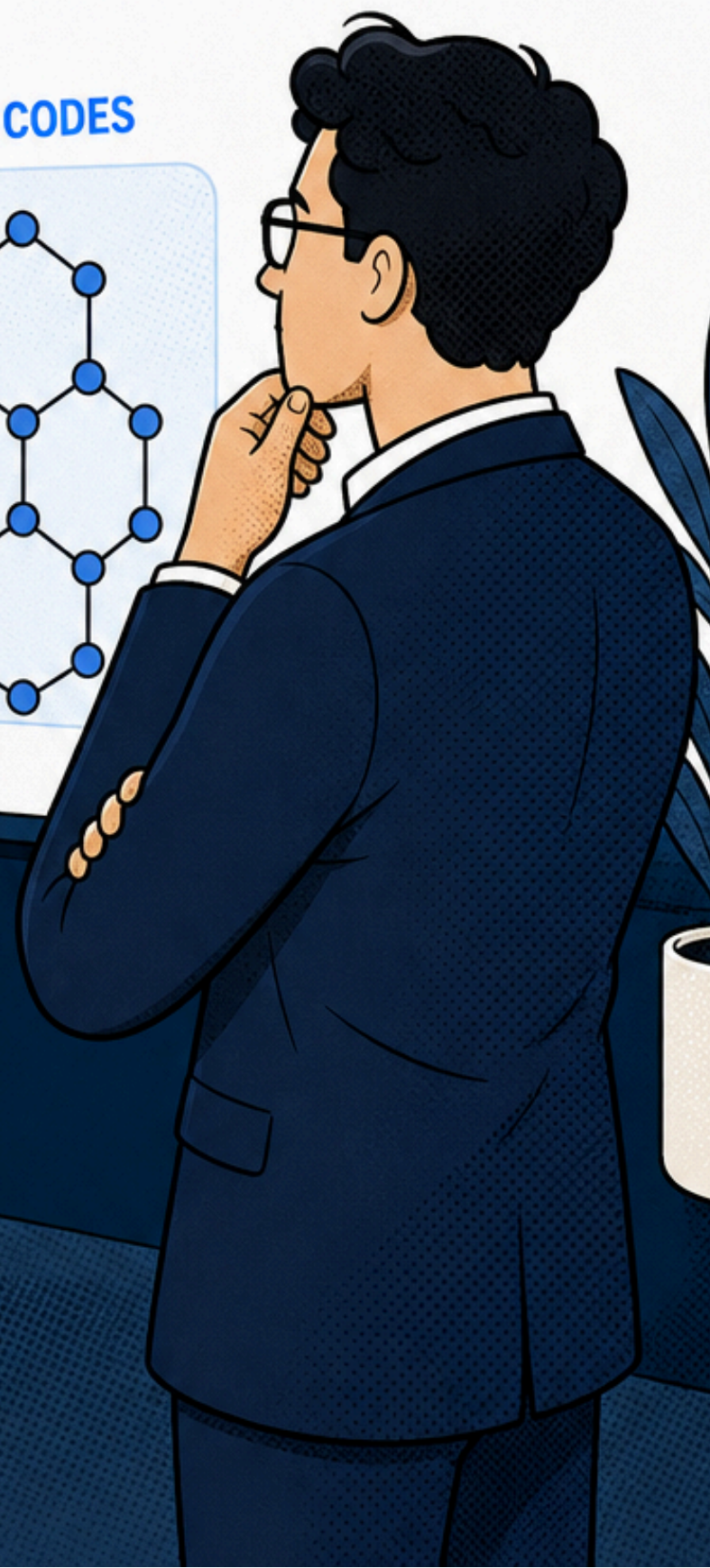
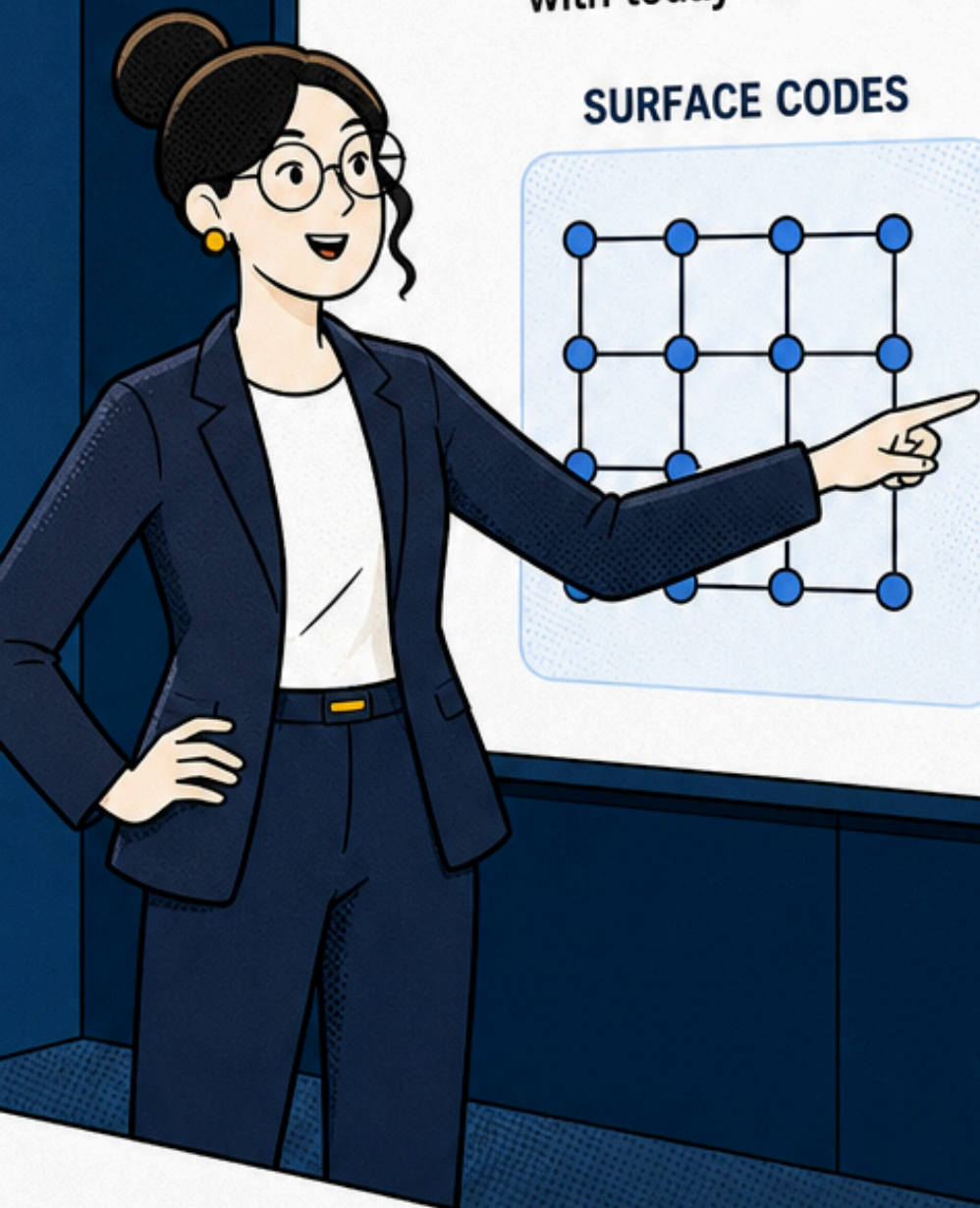
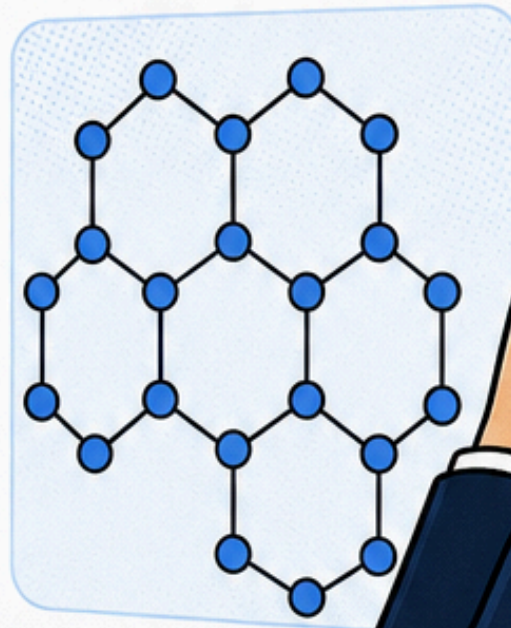
**Color codes** use a hexagonal or higher-connectivity lattice instead of a square grid.

Some logical gate operations are easier to perform natively — a practical advantage — but they typically demand **higher physical qubit fidelity** to function reliably, making them harder to implement with today's hardware.

SURFACE CODES



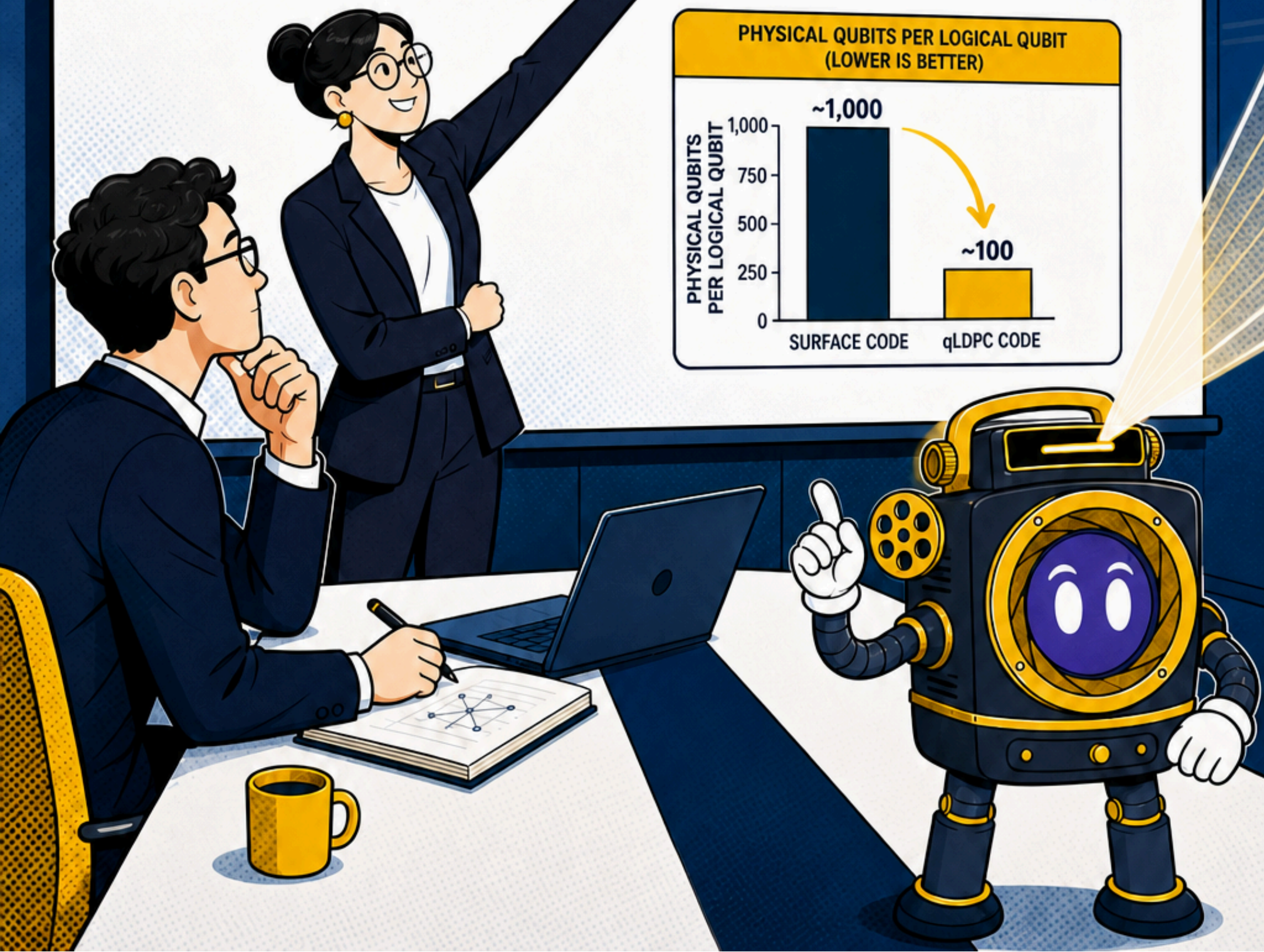
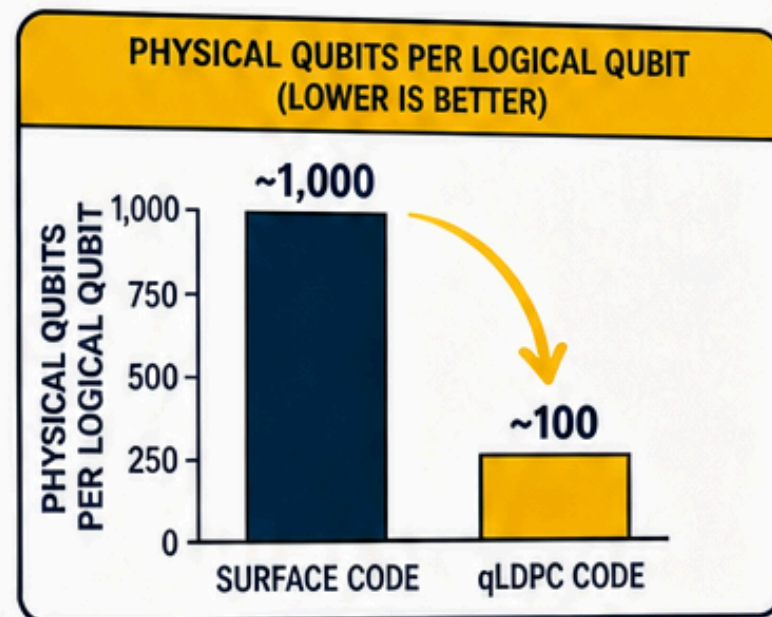
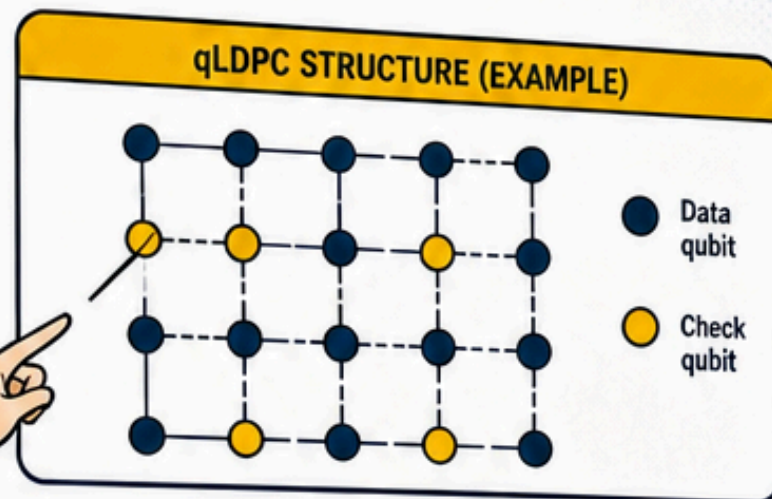
COLOR CODES



# qLDPC codes — fewer qubits, same protection

Quantum low-density parity-check (qLDPC) codes promise fault-tolerance with far fewer physical qubits per logical qubit than surface codes require.

IBM demonstrated qLDPC-encoded logical qubits in 2023–2024, signalling growing industry interest in lower-overhead alternatives to surface codes.



# The ratio that defines hardware maturity

# 1,000–10,000

physical qubits per logical qubit

1,000–10,000 physical qubits are required per logical qubit under today's **surface codes**. This number **separates genuine progress from marketing**.



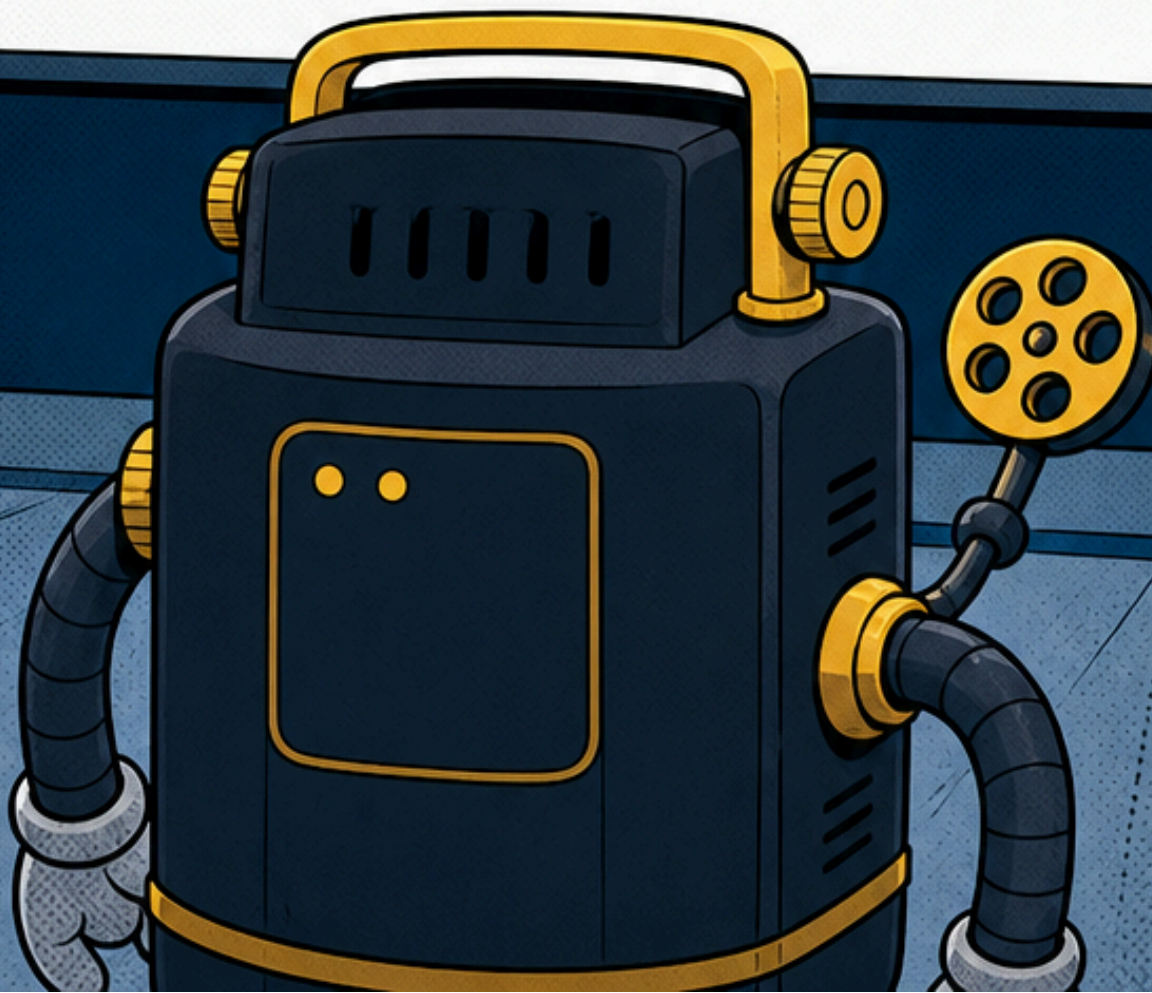
Target error rate



Physical gate fidelity



Error-correcting code used



# WHY FIDELITY TRUMPS QUBIT COUNT

10,000  
PHYSICAL QUBITS



99.9%  
GATE FIDELITY



ROUGHLY  
10-100  
LOGICAL QUBITS

10,000  
PHYSICAL QUBITS



99%  
GATE FIDELITY



POSSIBLY  
ZERO  
FUNCTIONAL  
LOGICAL QUBITS

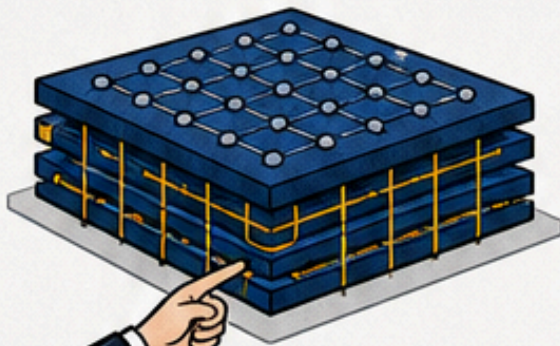


BETTER PHYSICAL QUBITS MEAN FEWER ARE NEEDED PER LOGICAL QUBIT.



# ARCHITECTURE DIFFERENCES: SUPERCONDUCTING VS. TRAPPED-ION

## SUPERCONDUCTING (IBM, GOOGLE, RIGETTI)

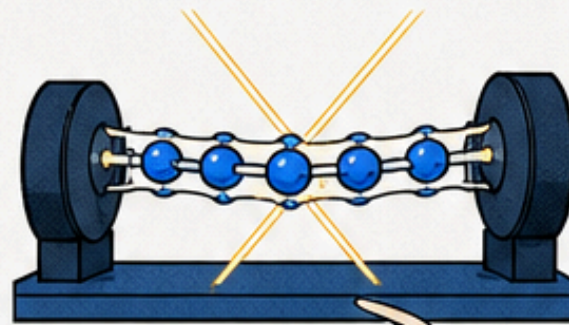


HUNDREDS TO THOUSANDS  
OF PHYSICAL QUBITS  
PER LOGICAL QUBIT  
UNDER SURFACE CODES



● PHYSICAL QUBIT  
○ LOGICAL QUBIT

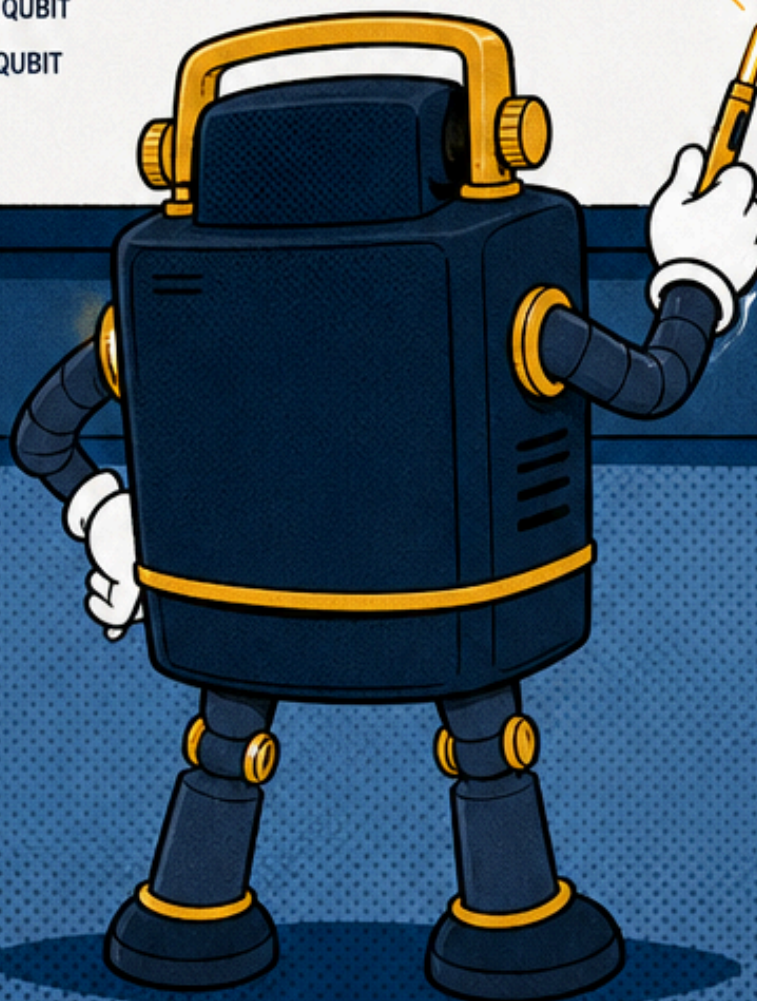
## TRAPPED-ION (QUANTINUUM, IONQ)



LOWER OVERHEAD  
DUE TO HIGHER  
NATIVE GATE FIDELITY



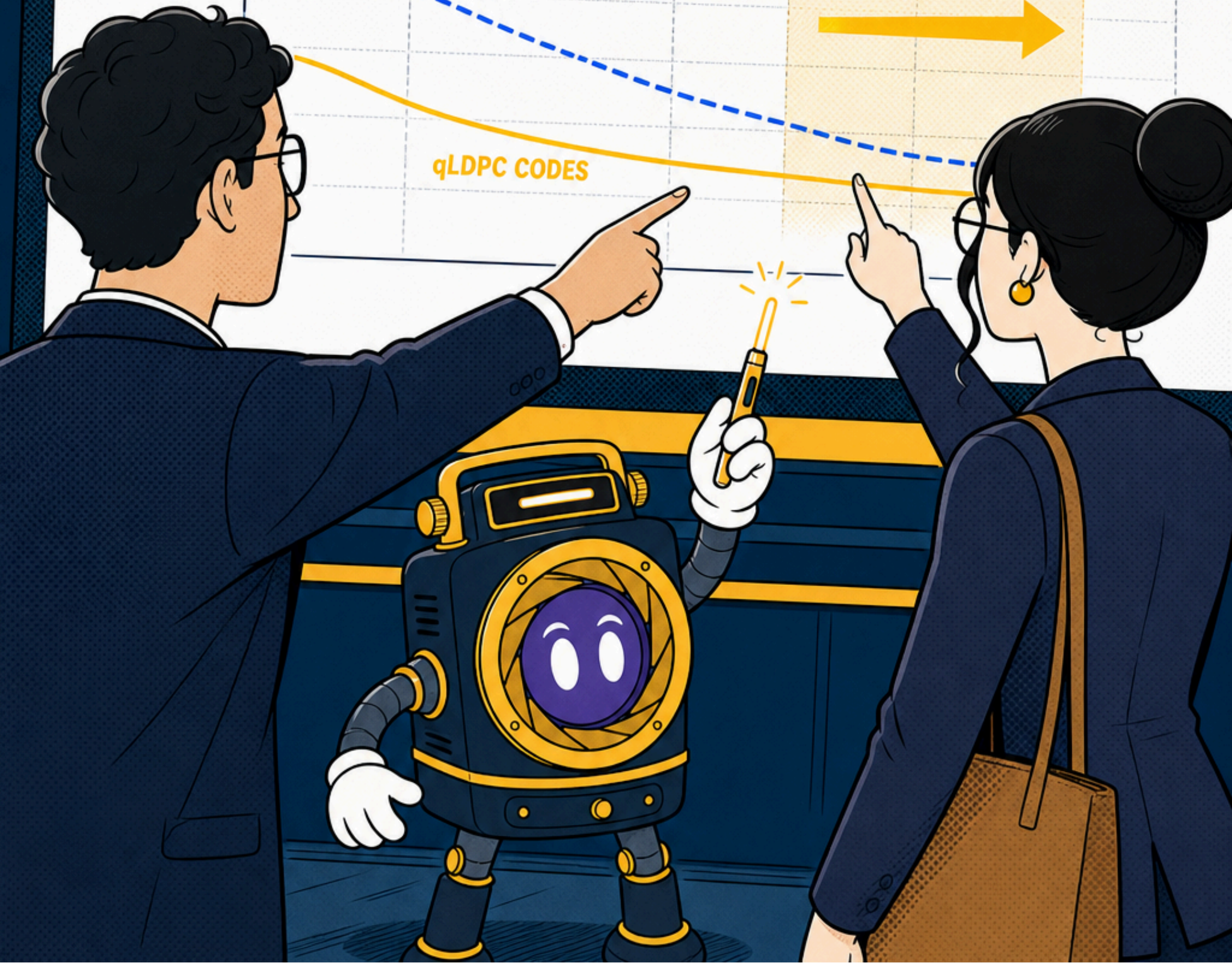
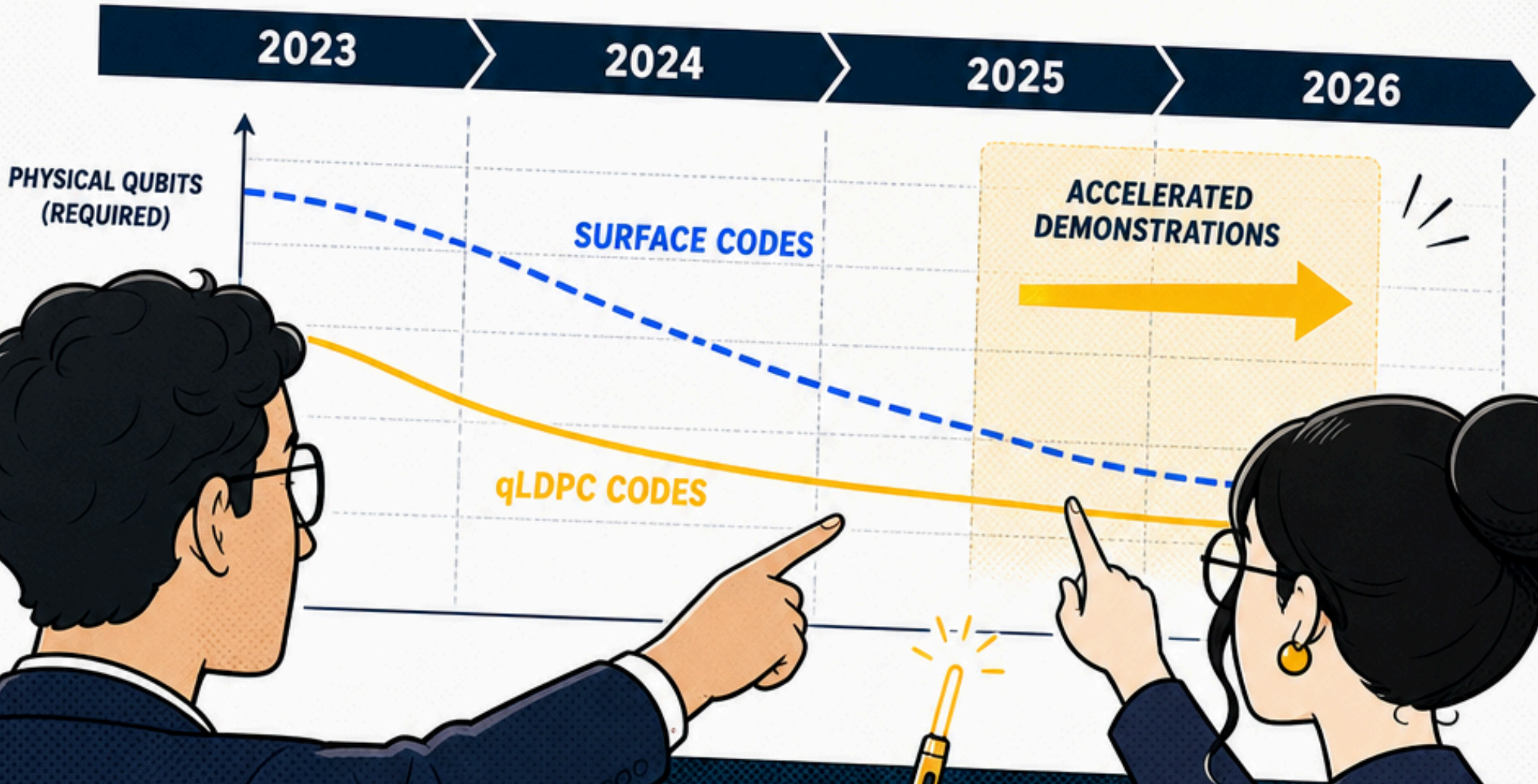
● ION QUBIT



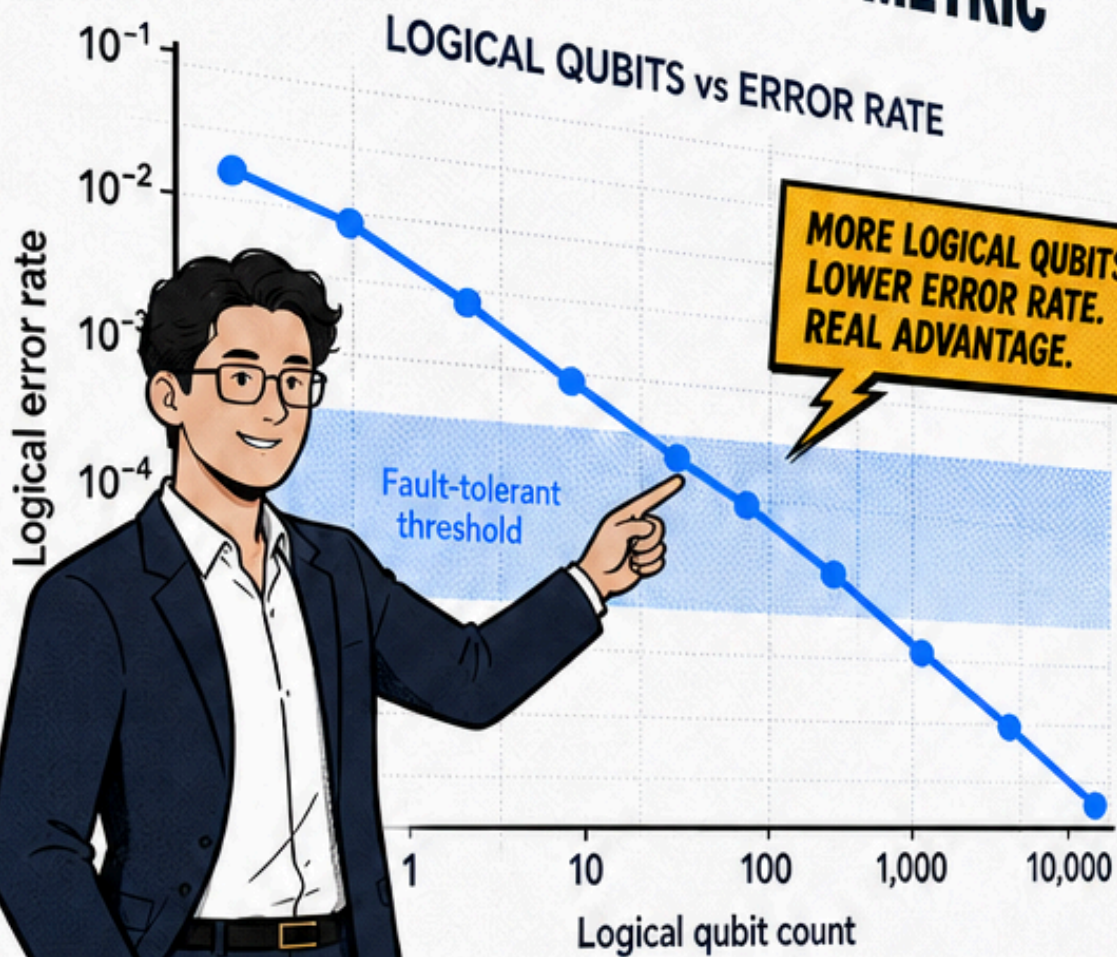
# THE EFFICIENCY RACE: 2023-2026

IBM demonstrated qLDPC-related improvements in 2023-2024, protecting logical qubits with fewer physical qubits than comparable surface codes.

By 2025-2026, Quantinuum, QuEra, and others pushed logical qubit demonstrations rapidly forward.



# WHY LOGICAL QUBIT COUNT IS THE REAL INVESTMENT METRIC



Logical qubits — **error-corrected**, **stable**, and **usable** for complex algorithms — are what determine when quantum advantage becomes commercially real.

## SYSTEM COMPARISON

SYSTEM	PHYSICAL QUBITS	VERIFIED LOGICAL QUBITS	LOGICAL ERROR RATE	CODE
System A	1,024	8	1.2 × 10 <sup>-3</sup>	Surface Code
System B	5,120	32	8.5 × 10 <sup>-4</sup>	Surface Code
System C	10,240	64	3.2 × 10 <sup>-4</sup>	LDPC
Our Platform	3,072	256	6.1 × 10 <sup>-5</sup>	LDPC

- ✓ VERIFIED LOGICAL QUBITS
- ✓ ERROR RATE
- ✓ CODE & OPERATIONS

**WHAT MATTERS:**  
STABLE, VERIFIABLE, USABLE.

# THE LOGICAL QUBIT THRESHOLDS THAT MATTER **COMMERCIALY**

~100

## HIGH-QUALITY LOGICAL QUBITS

### EARLY UTILITY THRESHOLD

(LEADING HARDWARE FIRMS ARE APPROACHING THIS, NOT YET SUSTAINED)

1,000-10,000

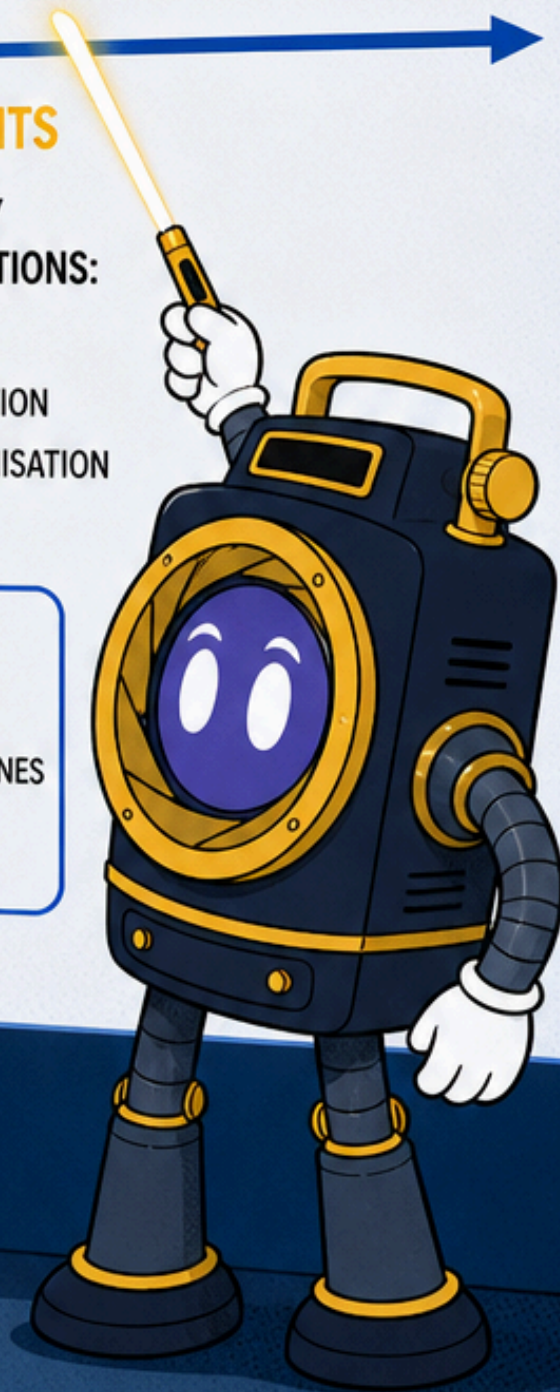
## LOGICAL QUBITS

### COMMERCIALY IMPACTFUL APPLICATIONS:

- DRUG DISCOVERY
- MATERIALS SIMULATION
- LARGE-SCALE OPTIMISATION



PROJECTED ARRIVAL OF THE 1K-10K RANGE:  
**MID-2030s** — THOUGH TIMELINES VARY WIDELY AND REMAIN HIGHLY UNCERTAIN.



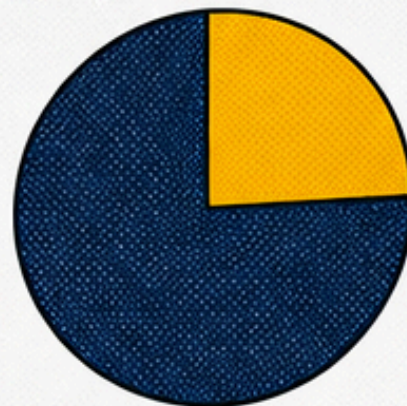
# THE HIDDEN OVERHEAD: MAGIC STATE DISTILLATION

Running universal quantum algorithms requires non-Clifford gates — operations that demand dedicated *magic state factories* consuming a large share of the physical qubit budget.

This overhead is invisible in raw qubit counts.

The real cost of a fault-tolerant algorithm is significantly higher than the logical qubit number alone implies.

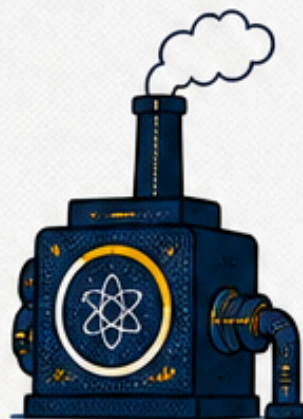
## QUBIT ALLOCATION



LOGICAL QUBITS  
**25%**

OVERHEAD (MAGIC STATE FACTORIES)  
**75%**

## OVERHEAD BREAKDOWN

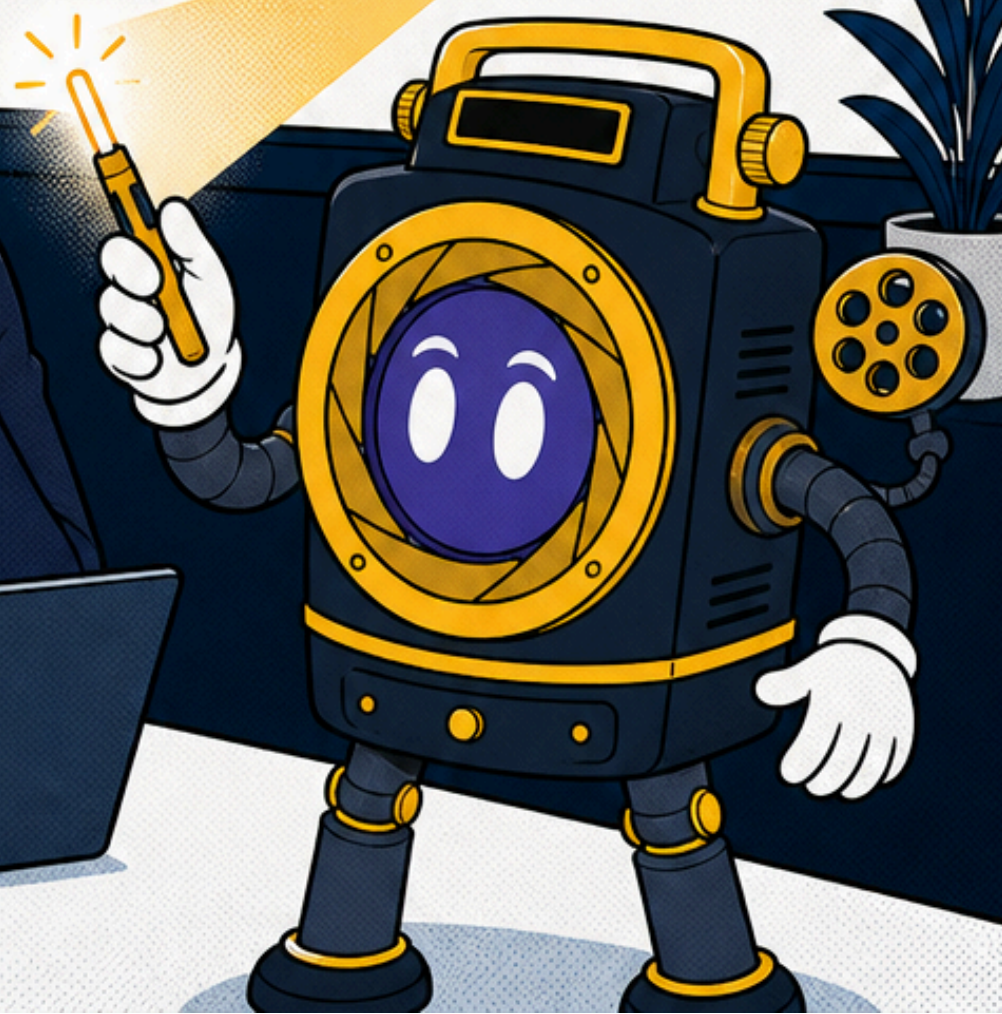


MAGIC STATE FACTORIES **60%**

ROUTING & SWAP NETWORK **10%**

SYNDROME EXTRACTION **3%**

SPARE QUBITS **2%**



# 50 GREAT LOGICAL QUBITS BEATS 10,000 PHYSICAL ONES

50 LOGICAL QUBITS  
HIGH-FIDELITY, BELOW-THRESHOLD



CREDIBLE PATH TO 50

10,000 PHYSICAL QUBITS  
NO PROVEN ERROR CORRECTION



A company with 50 high-fidelity logical qubits and a **credible path to 50** is a fundamentally different investment proposition from one with 10,000 physical qubits and no demonstrated below-threshold error correction.

ASK:



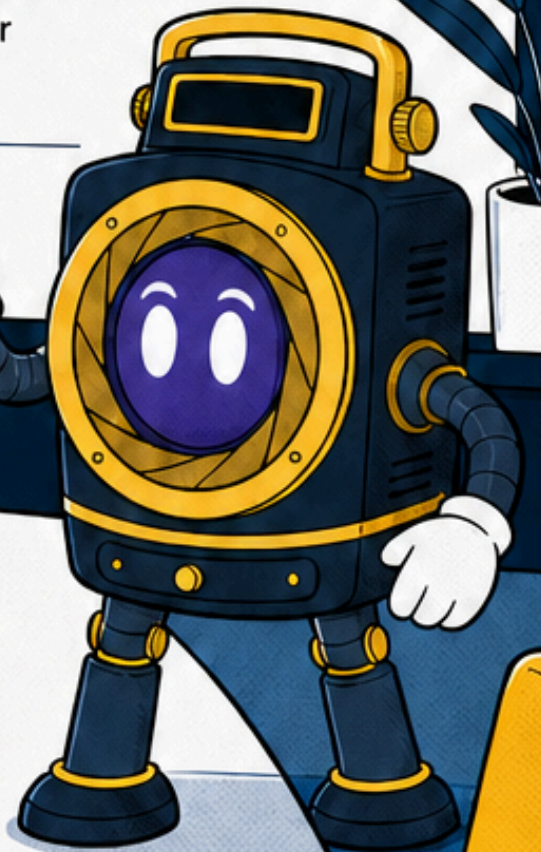
VERIFIED  
LOGICAL COUNT



ERROR  
RATE



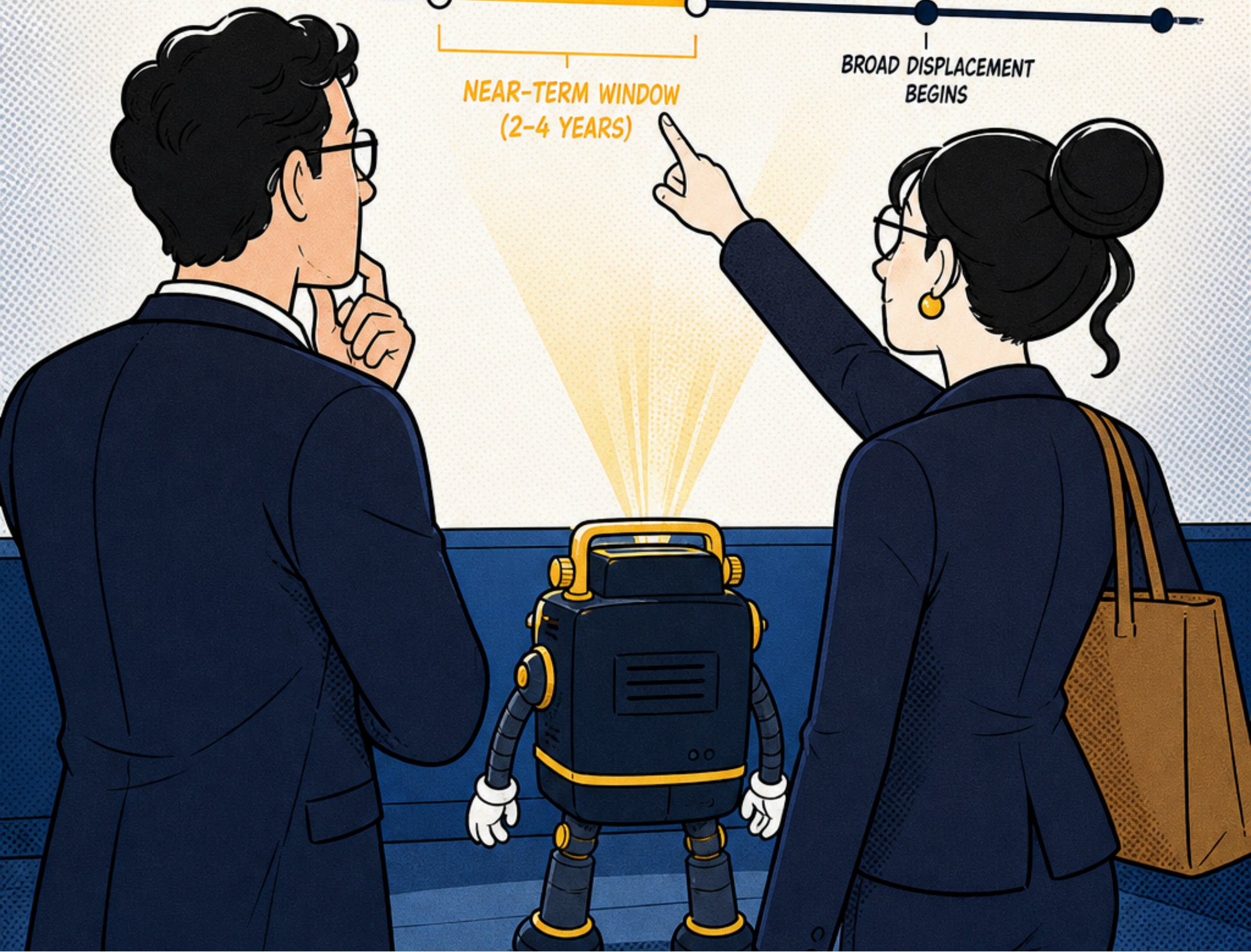
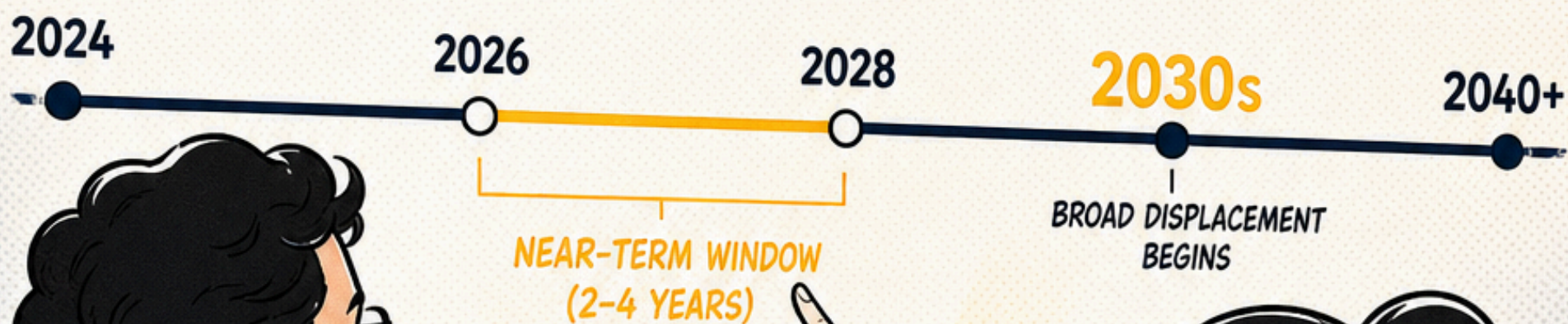
CODE  
USED



# THE NEAR-TERM REALITY

FOR FOUNDERS IN MATERIALS SCIENCE, DRUG DISCOVERY, OPTIMISATION, AND CRYPTOGRAPHY: **NEAR-TERM QUANTUM ADVANTAGE** — IF IT ARRIVES IN 2-4 YEARS — WILL APPEAR IN NARROW PROBLEM CLASSES VIA **HYBRID QUANTUM-CLASSICAL CLOUD**.

BROAD DISPLACEMENT OF CLASSICAL INFRASTRUCTURE IS A **2030s** STORY, NOT A 2026 ONE.



# The due diligence layer

Timing and technical milestone clarity are the critical investor filters. A credible pitch explains its logical qubit roadmap, error-correction code, physical-to-logical overhead, and gate fidelity. A pitch leading with raw physical qubit counts and vague "quantum advantage" language hasn't done the work.

## QUBIT ROADMAP



## ERROR-CORRECTION METRICS

CODE	Surface Code
CODE DISTANCE (d)	17
PHYSICAL-TO-LOGICAL OVERHEAD	~2,889:1
LOGICAL ERROR RATE (p <sub>L</sub> )	1.2 × 10 <sup>-15</sup>
FIDELITY (2-QUBIT)	99.92%

## KEY TECHNICAL PILLARS



Logical Qubit Roadmap



Error-Correction Code Strategy



Physical-to-Logical Overhead Efficiency



High-Fidelity Gate Performance

# THE CORE QUESTION

The comprehension gap in quantum investment is real — hard physics, overloaded vocabulary, marketing incentives toward ambiguity. But the core question is always the same:

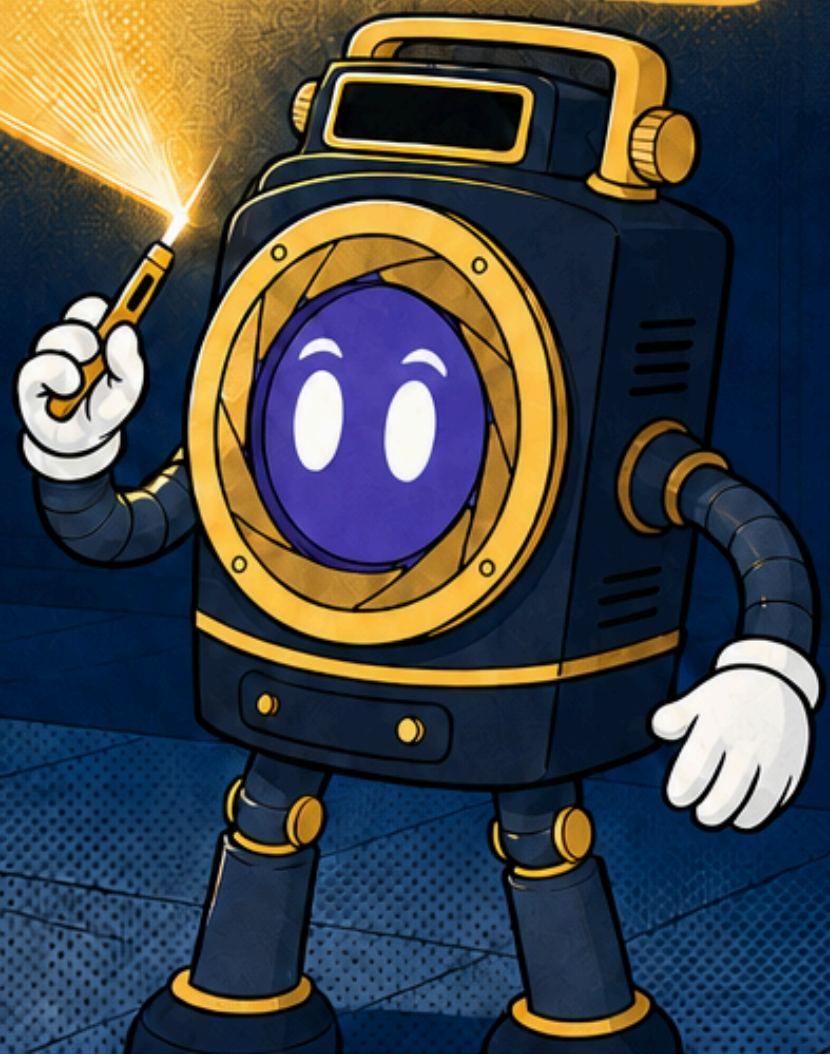
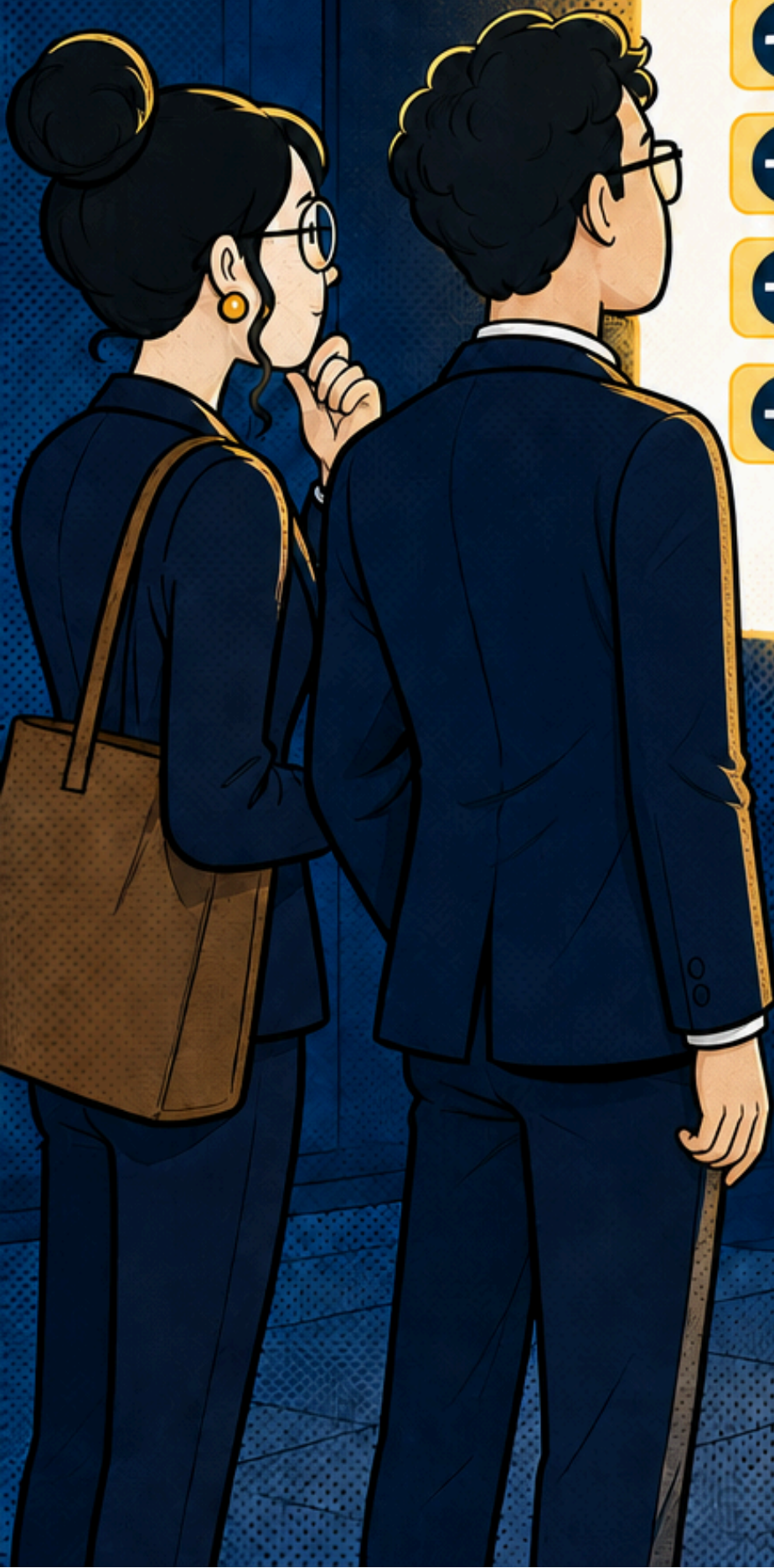
→ How many reliable logical qubits?

→ At what fidelity?

→ On what timeline?

→ At what cost per logical qubit?

*If the pitch can't answer these, the problem isn't yours.*



# INFRAIRIS

At Infrairis, we help complex tech companies — **quantum, deep tech hardware, advanced computing** — turn 30-minute technical briefings into 60-second explainers that investors actually understand.

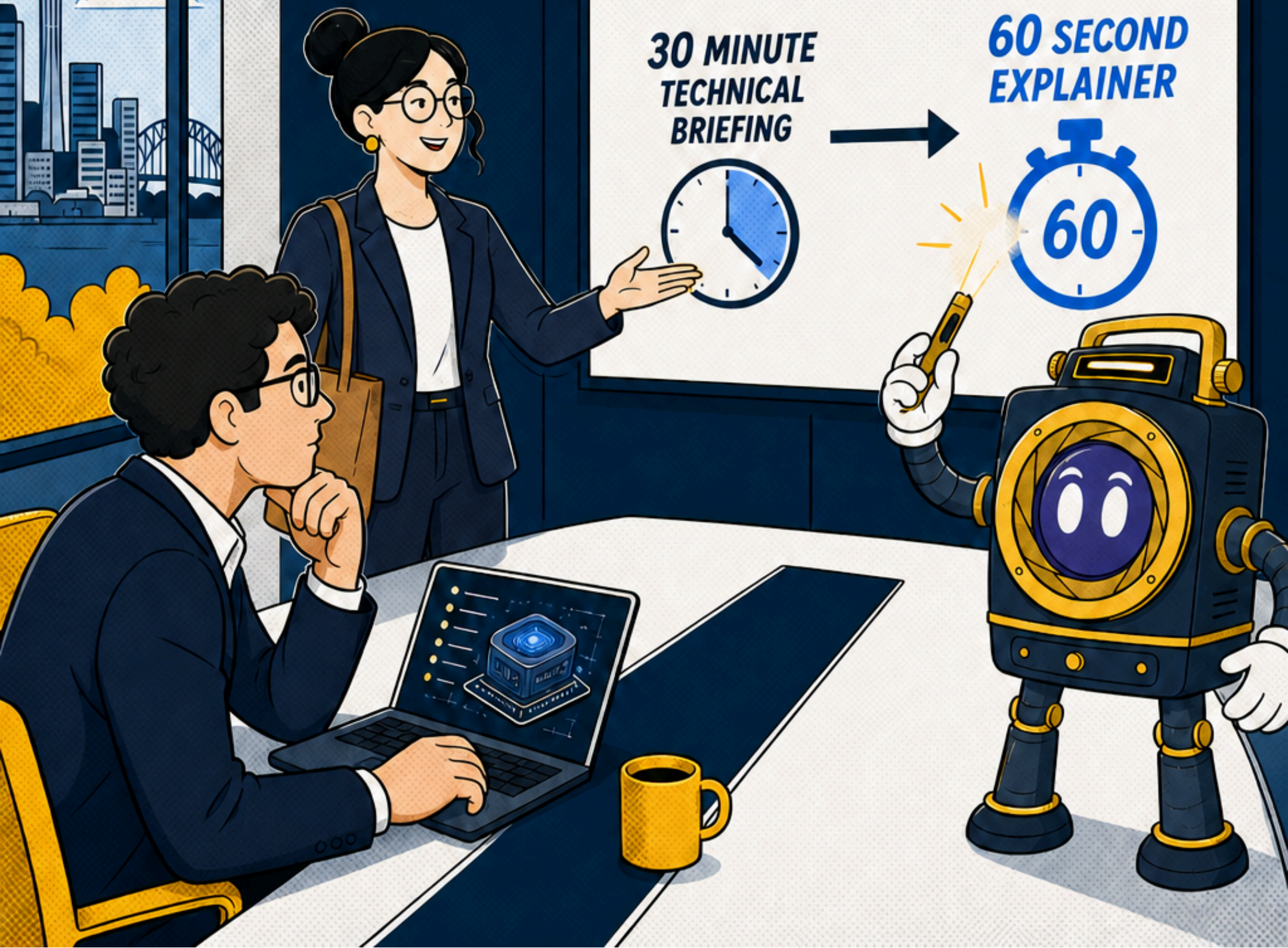
If your product explanation is losing rooms it should be winning, we should talk.

→ [HTTPS://STARTUPS.INFRAIRIS.COM](https://startups.infrairis.com)

30 MINUTE  
TECHNICAL  
BRIEFING



60 SECOND  
EXPLAINER





Don't worry... We can still explain it!

