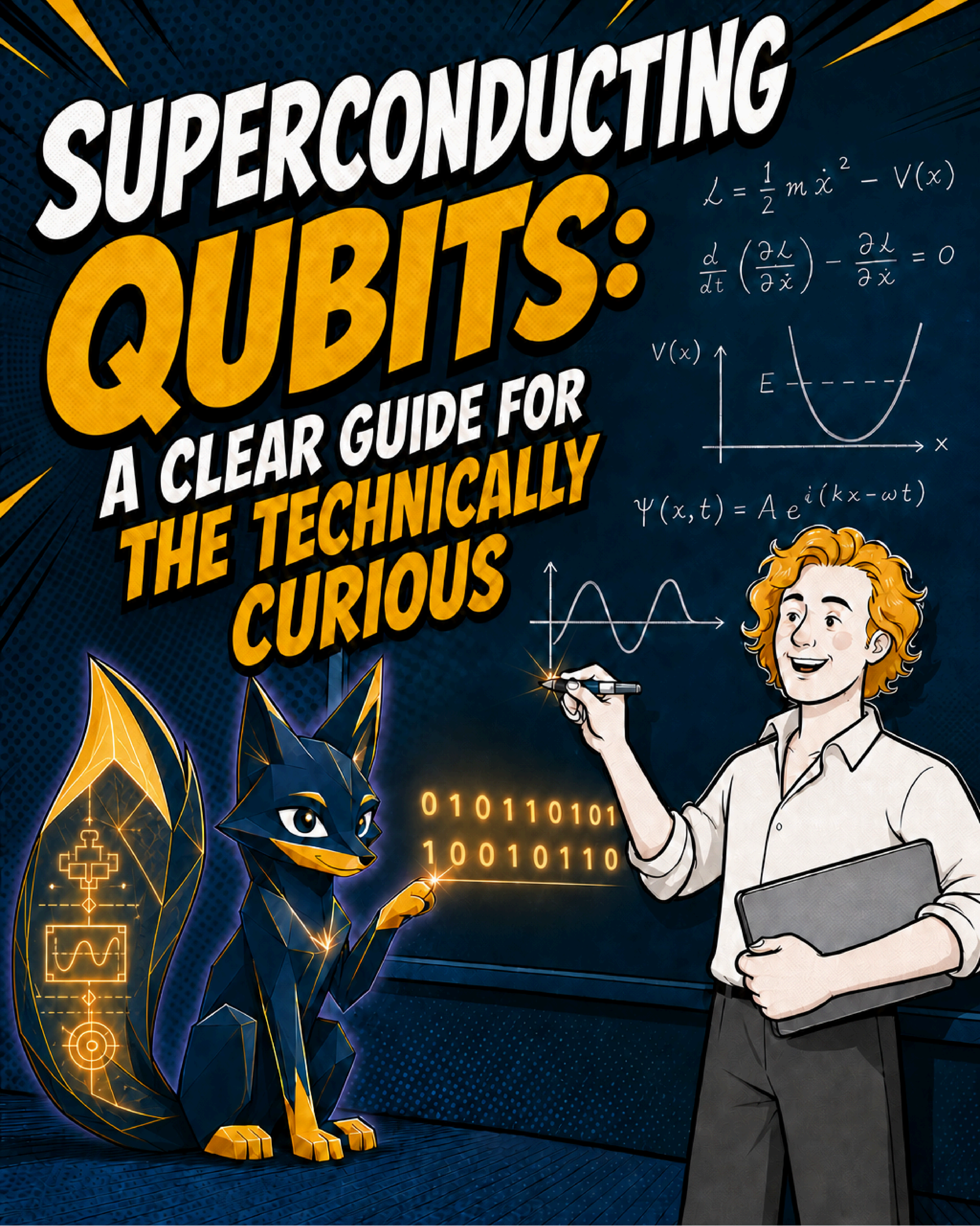
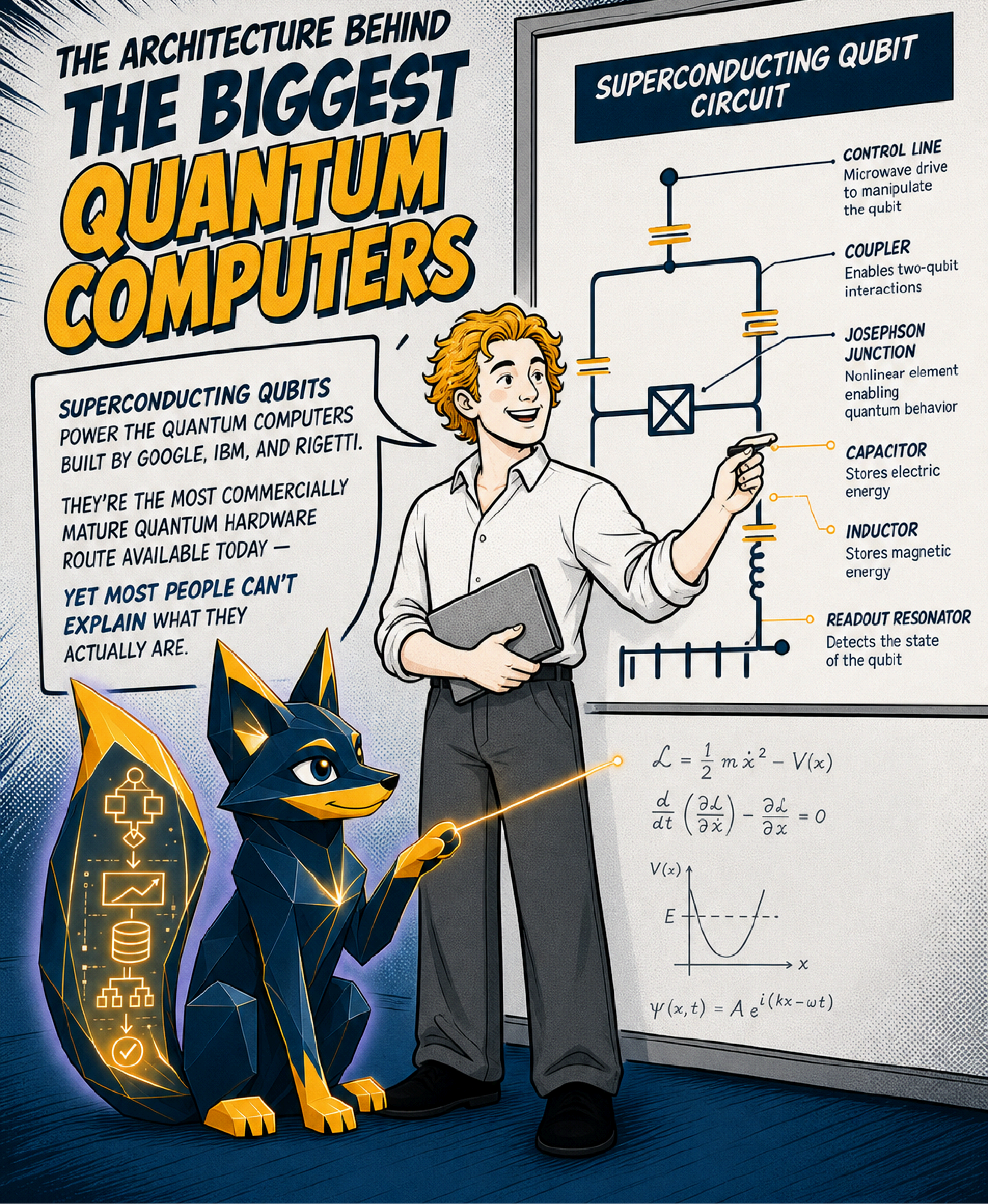
SUPERCONDUCTING QUBITS:

A CLEAR GUIDE FOR THE TECHNICALLY CURIOUS



THE ARCHITECTURE BEHIND THE BIGGEST QUANTUM COMPUTERS



YOU DON'T NEED A PHYSICS PhD TO CARE ABOUT THIS

- **Founders** pitching deep tech investors.
- **CMOs** marketing to technical buyers.
- **IR professionals** explaining quantum programs to retail shareholders.

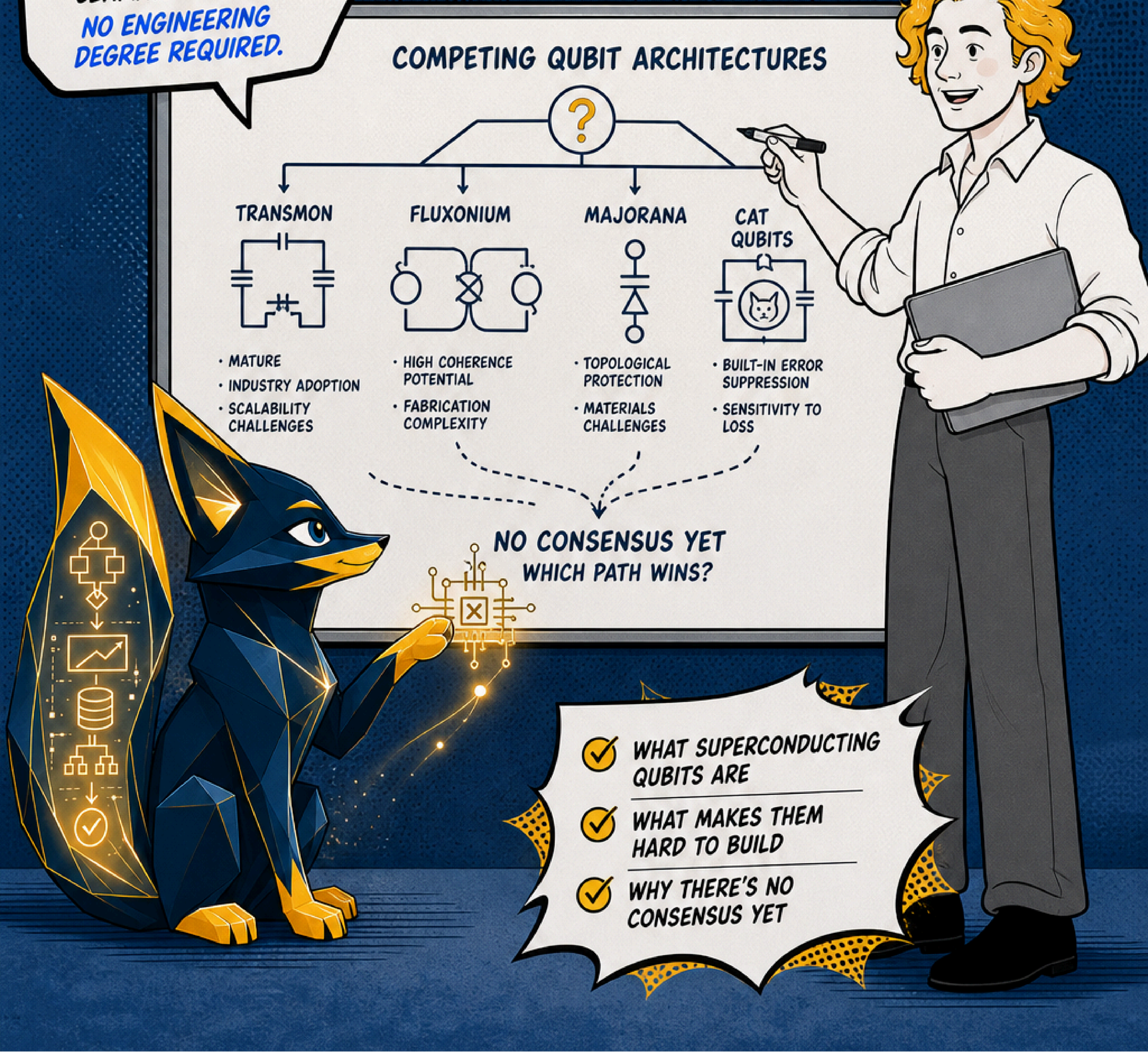
All three groups benefit from speaking the language — even at a surface level.

WHAT YOU'LL ACTUALLY WALK AWAY UNDERSTANDING

BY THE END:

WHAT SUPERCONDUCTING QUBITS ARE, WHAT MAKES THEM GENUINELY HARD TO BUILD, AND WHY THE FIELD STILL HAS NO CONSENSUS ON WHICH ARCHITECTURE ULTIMATELY WINS.

NO ENGINEERING DEGREE REQUIRED.



COMPETING QUBIT ARCHITECTURES

TRANSMON
- MATURE
- INDUSTRY ADOPTION
- SCALABILITY CHALLENGES

FLUXONIUM
- HIGH COHERENCE POTENTIAL
- FABRICATION COMPLEXITY

MAJORANA
- TOPOLOGICAL PROTECTION
- MATERIALS CHALLENGES

CAT QUBITS
- BUILT-IN ERROR SUPPRESSION
- SENSITIVITY TO LOSS

NO CONSENSUS YET
WHICH PATH WINS?

- ✓ WHAT SUPERCONDUCTING QUBITS ARE
- ✓ WHAT MAKES THEM HARD TO BUILD
- ✓ WHY THERE'S NO CONSENSUS YET

FIRST: WHAT MAKES A BIT "QUANTUM"?

$$\mathcal{L} = \frac{1}{2} m \dot{x}^2 - V(x)$$

$$\frac{d}{dt}\left(\frac{\partial \mathcal{L}}{\partial \dot{x}}\right) - \frac{\partial \mathcal{L}}{\partial x} = 0$$

BINARY IS THE CLASSICAL WAY.

A classical bit is either 0 or 1. It's the foundation of every email, every pixel, every calculation. Fast, predictable, and built to scale.

QUBITS CAN BE BOTH.

A qubit exists in superposition—a probabilistic combination of 0 and 1—until you measure it and it collapses to one or the other.

MORE STATES, AT ONCE.

Operate while it's still spinning, and you process many possible outcomes simultaneously.

EXPONENTIAL POWER.

n qubits represent 2^n states at once.

10 qubits = 1,024 states.

Around 265–280 qubits? More states than atoms in the observable universe.

THEORY IS BEAUTIFUL. ENGINEERING IS HARD.

That's the theory. The engineering reality is considerably more complicated.

WHY YOU NEED TO GET TO
NEAR ABSOLUTE ZERO

Superconducting qubits are made from materials that, when cooled to temperatures close to absolute zero, lose all electrical resistance. At normal temperatures, electrons passing through a metal collide with atoms, generating heat and losing energy. That constant jostling is incompatible with the delicate quantum states a qubit needs to maintain.

At around **15 millikelvin** (roughly −273.135°C, or about 0.015 degrees above absolute zero), certain metals enter a superconducting state. Electrons pair up into what physicists call Cooper pairs and flow without resistance, without friction, without the thermal noise that would otherwise destroy any quantum information almost instantly.

That temperature is colder than outer space. The cosmic microwave background, the ambient temperature of the universe, sits at about **2.7 kelvin.** The dilution refrigerators that house superconducting quantum processors operate at a fraction of that.

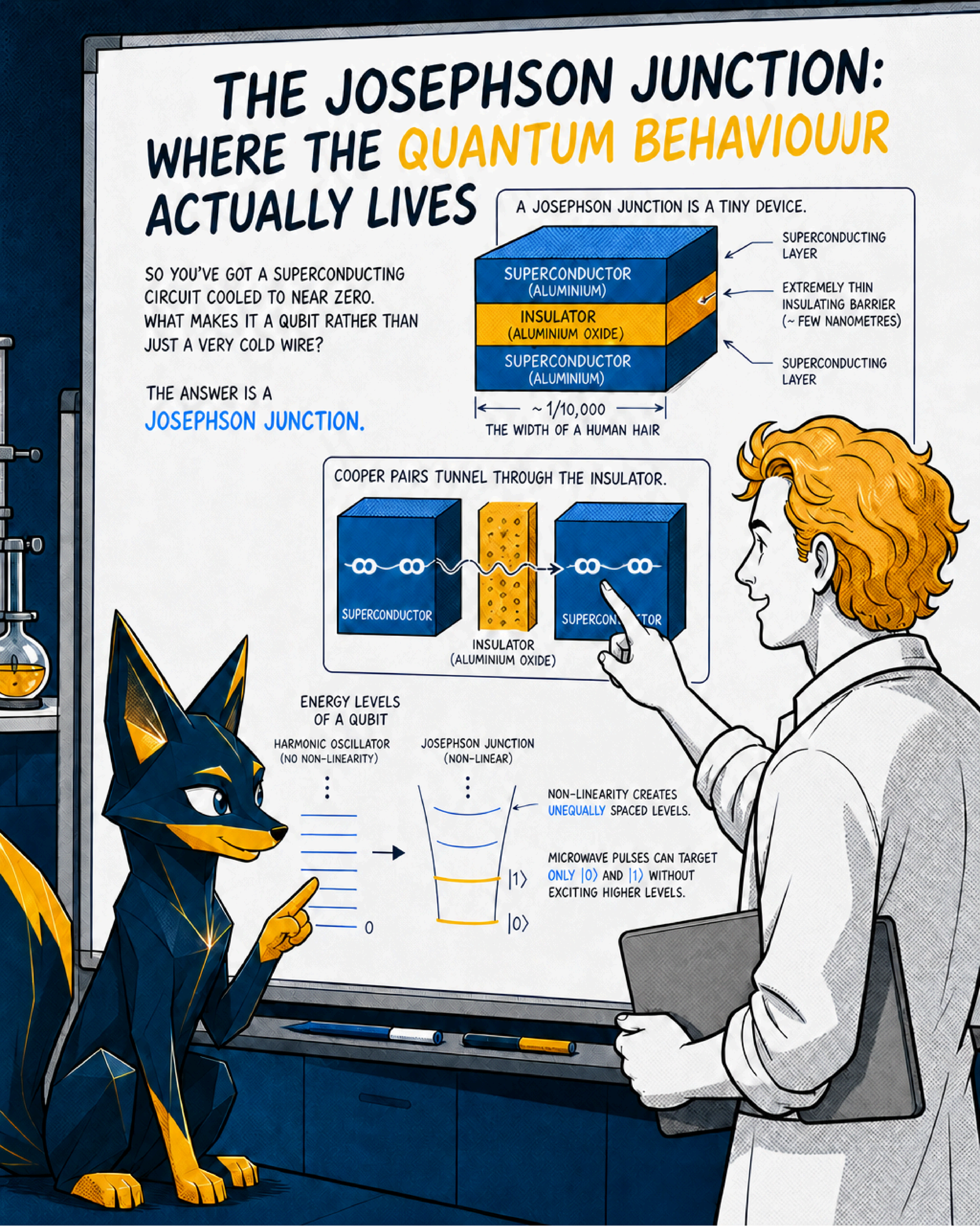
This is not a small infrastructure ask. These refrigerators are large, expensive, and slow to cool down. They need to be isolated from vibration, electromagmet interference, and even the heat generated by the control electronics nearby. Every qubit you add to a chip makes the engineering problem harder, because more qubits need more control lines, and more control lines mean more potential sources of noise and heat creeping into a system that can't tolerate either.

Scaling the wiring is, in fact, one of the dominant engineering bottlenecks in the field right now. A machine with a thousand qubits in conventional packaging needs thousands of coaxial cables routed through the refrigerator. Solving that without introducing noise is a serious materials and packaging challenge that the industry is actively working on.

THE JOSEPHSON JUNCTION: WHERE THE QUANTUM BEHAVIOUUR ACTUALLY LIVES

SO YOU'VE GOT A SUPERCONDUCTING CIRCUIT COOLED TO NEAR ZERO. WHAT MAKES IT A QUBIT RATHER THAN JUST A VERY COLD WIRE?

THE ANSWER IS A **JOSEPHSON JUNCTION.**



A JOSEPHSON JUNCTION IS A TINY DEVICE.

COOPER PAIRS TUNNEL THROUGH THE INSULATOR.

ENERGY LEVELS OF A QUBIT

NON-LINEARITY CREATES UNEQUALLY SPACED LEVELS.

MICROWAVE PULSES CAN TARGET ONLY $|0\rangle$ AND $|1\rangle$ WITHOUT EXCITING HIGHER LEVELS.

WHAT IS DECOHERENCE

AND WHY DOES IT MATTER?

Superconducting qubits are **extraordinarily sensitive** – that's what makes them useful. But that same sensitivity makes them **vulnerable** to stray electromagnetic fields, thermal fluctuations, vibration, even cosmic rays. **Decoherence** is the process by which a qubit loses its quantum state to the environment. The quantum state leaks away before the computation is done.

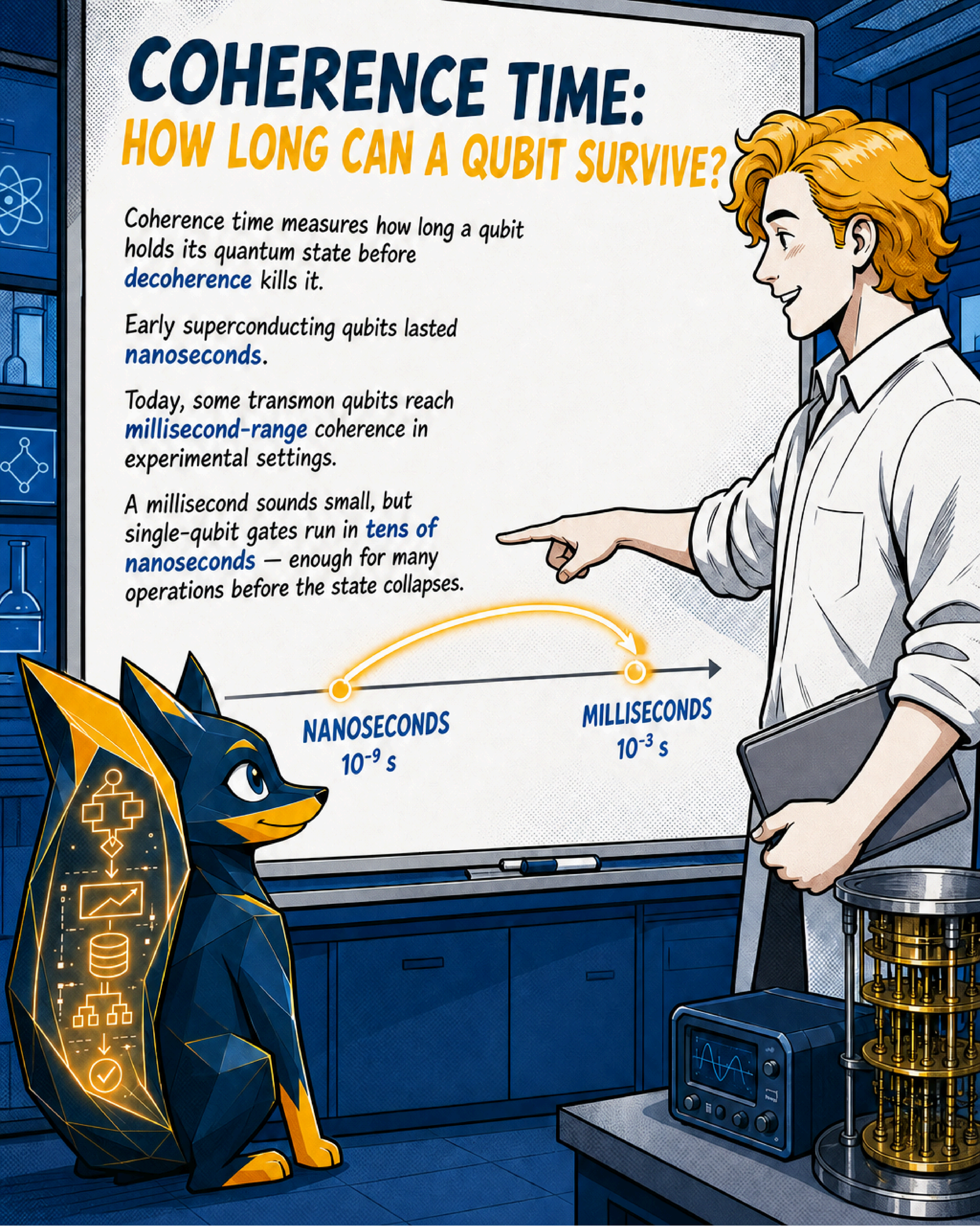
COHERENCE TIME:
HOW LONG CAN A QUBIT SURVIVE?

Coherence time measures how long a qubit holds its quantum state before **decoherence** kills it.

Early superconducting qubits lasted **nanoseconds**.

Today, some transmon qubits reach **millisecond-range** coherence in experimental settings.

A millisecond sounds small, but single-qubit gates run in **tens of nanoseconds** — enough for many operations before the state collapses.

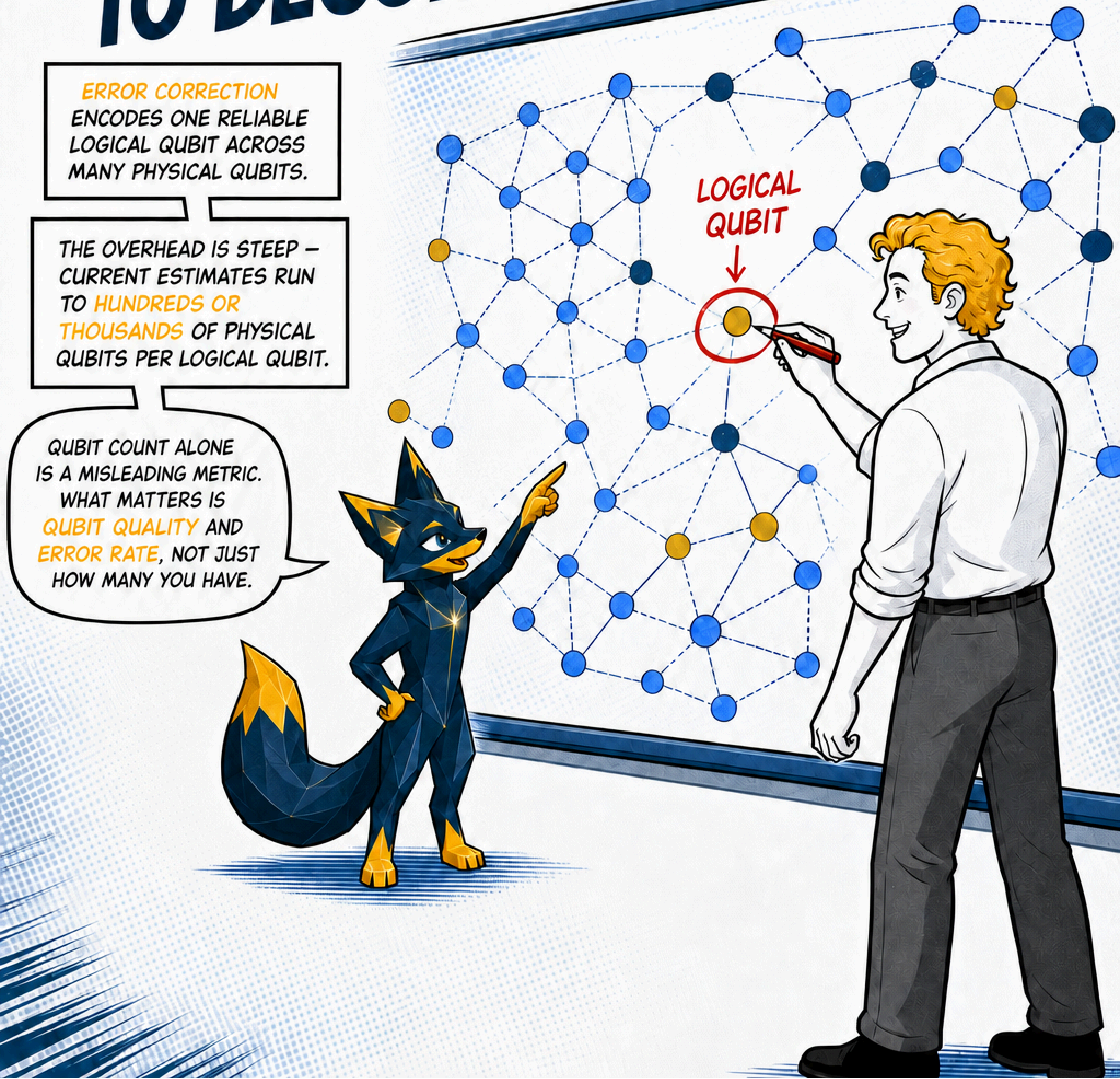


WHY DECOHERENCE IS SO HARD TO ELIMINATE

IT'S A GAME OF DIMINISHING RETURNS

REQUIRING EXTREMELY CLEAN FABRICATION AND CAREFUL ENGINEERING AT EVERY LAYER OF THE STACK.

ERROR CORRECTION: THE COSTLY ANSWER TO DECOHERENCE

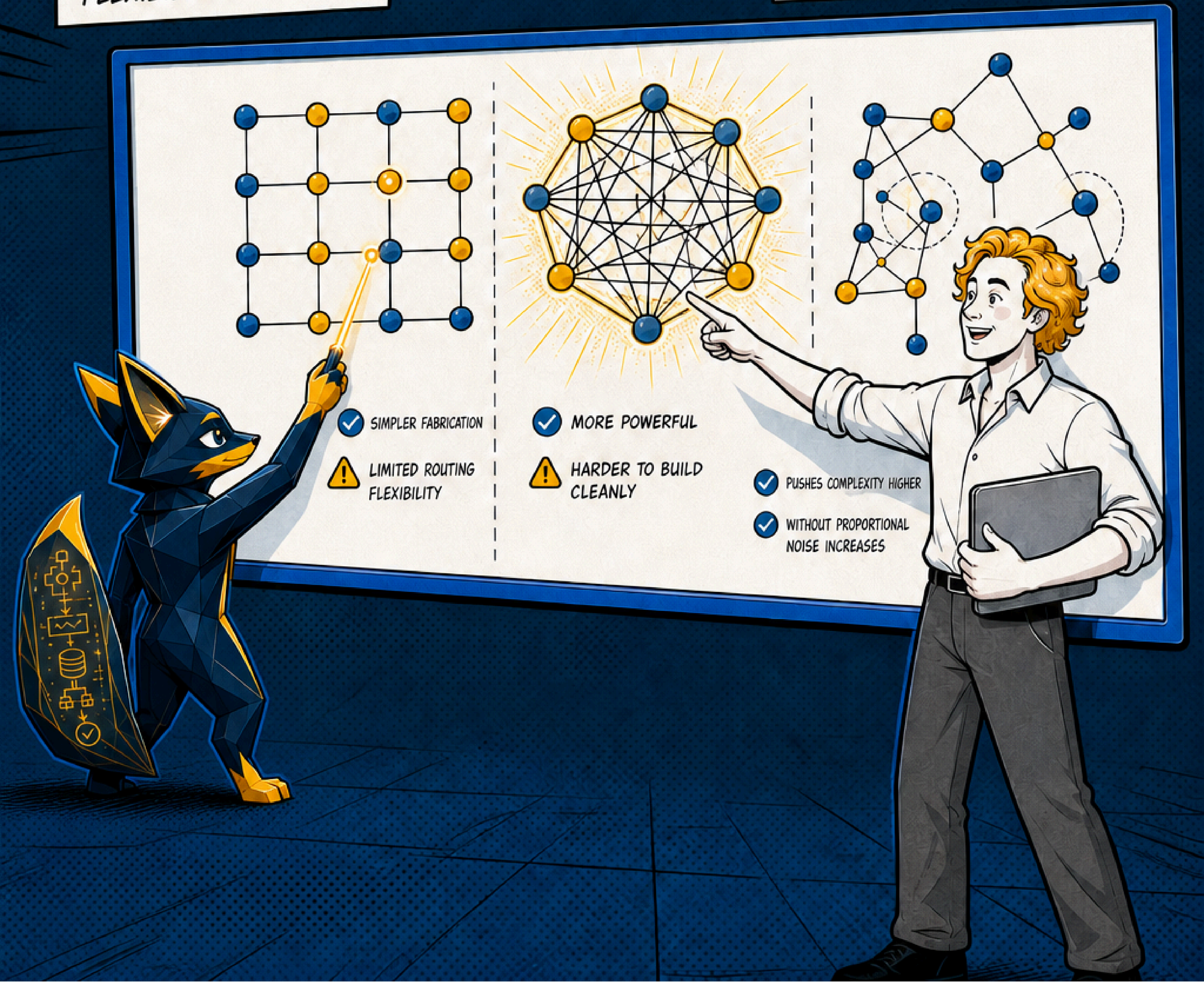


WHY QUBIT CONNECTIVITY CHOICES SPLIT THE FIELD

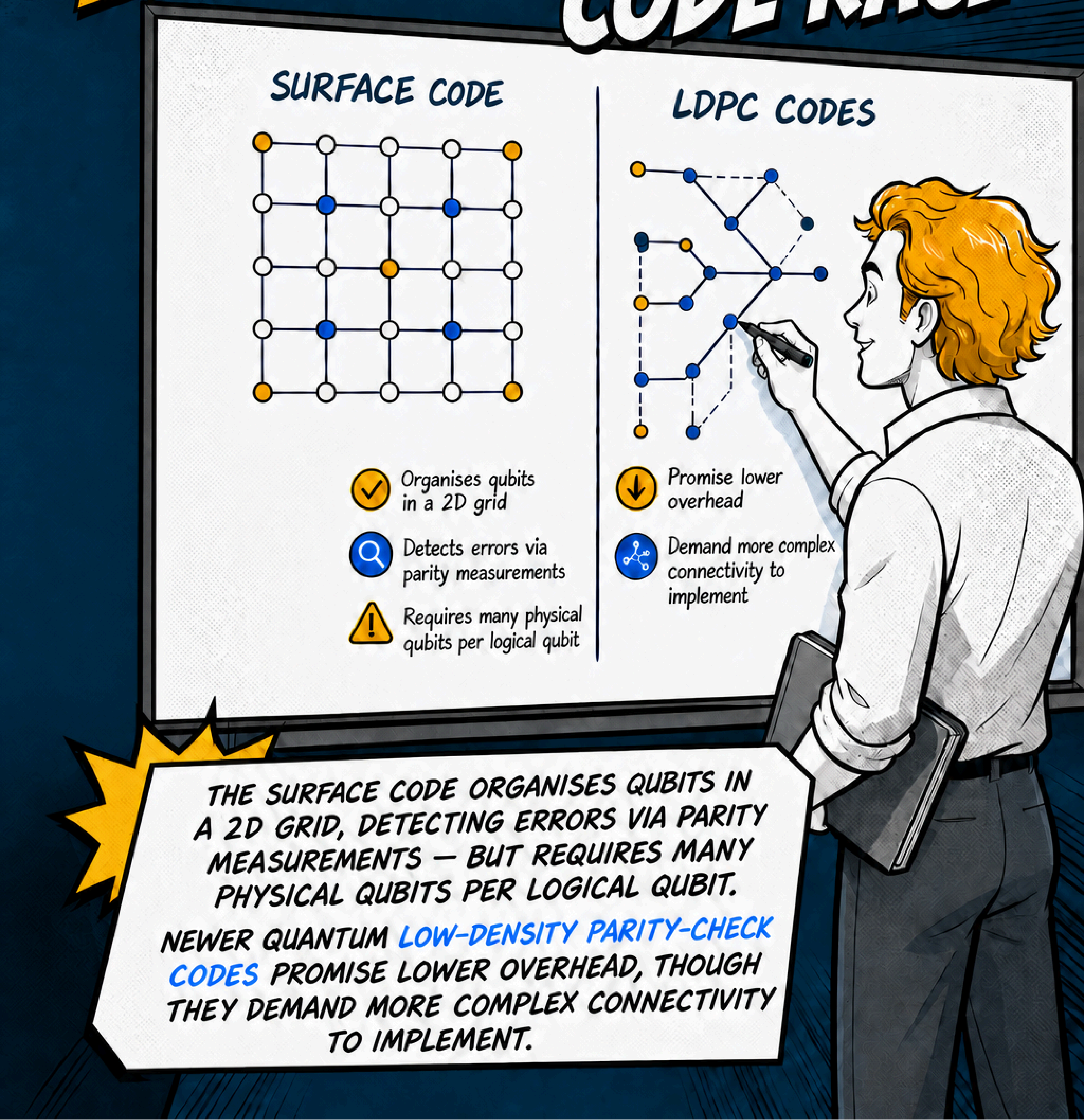
SOME DESIGNS CONNECT EACH QUBIT ONLY TO NEAREST NEIGHBOURS, SIMPLIFYING FABRICATION BUT LIMITING ROUTING FLEXIBILITY.

DENSER CONNECTIVITY IS MORE POWERFUL BUT HARDER TO BUILD CLEANLY.

IBM'S RECENT PROCESSORS EXPLORE NEW COUPLER DESIGNS TO PUSH CIRCUIT COMPLEXITY HIGHER WITHOUT PROPORTIONAL NOISE INCREASES.



THE ERROR CORRECTION CODE RACE

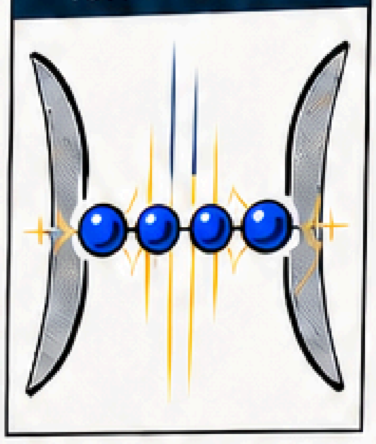


THE SURFACE CODE ORGANISES QUBITS IN A 2D GRID, DETECTING ERRORS VIA PARITY MEASUREMENTS — BUT REQUIRES MANY PHYSICAL QUBITS PER LOGICAL QUBIT.

NEWER QUANTUM LOW-DENSITY PARITY-CHECK CODES PROMISE LOWER OVERHEAD, THOUGH THEY DEMAND MORE COMPLEX CONNECTIVITY TO IMPLEMENT.

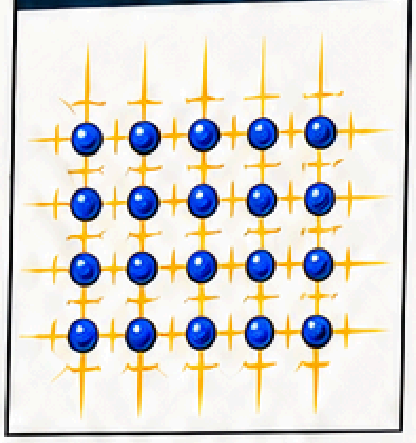
SUPERCONDUCTING QUBITS FACE REAL RIVALS

TRAPPED ION SYSTEMS



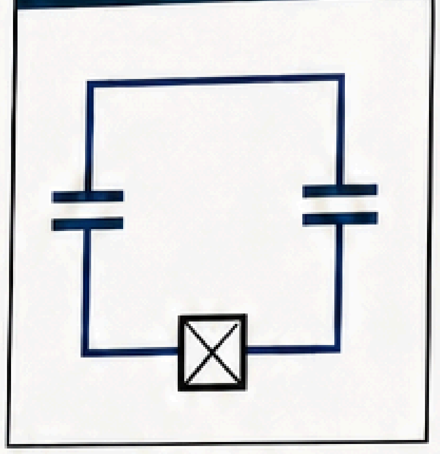
ACHIEVE **HIGHER PHYSICAL FIDELITY** PER QUBIT.

NEUTRAL ATOM APPROACHES



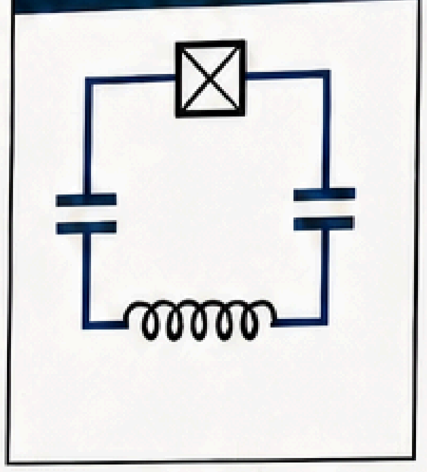
DEMONSTRATE **SCALABILITY** ADVANTAGES.

SUPERCONDUCTING TRANSMONS



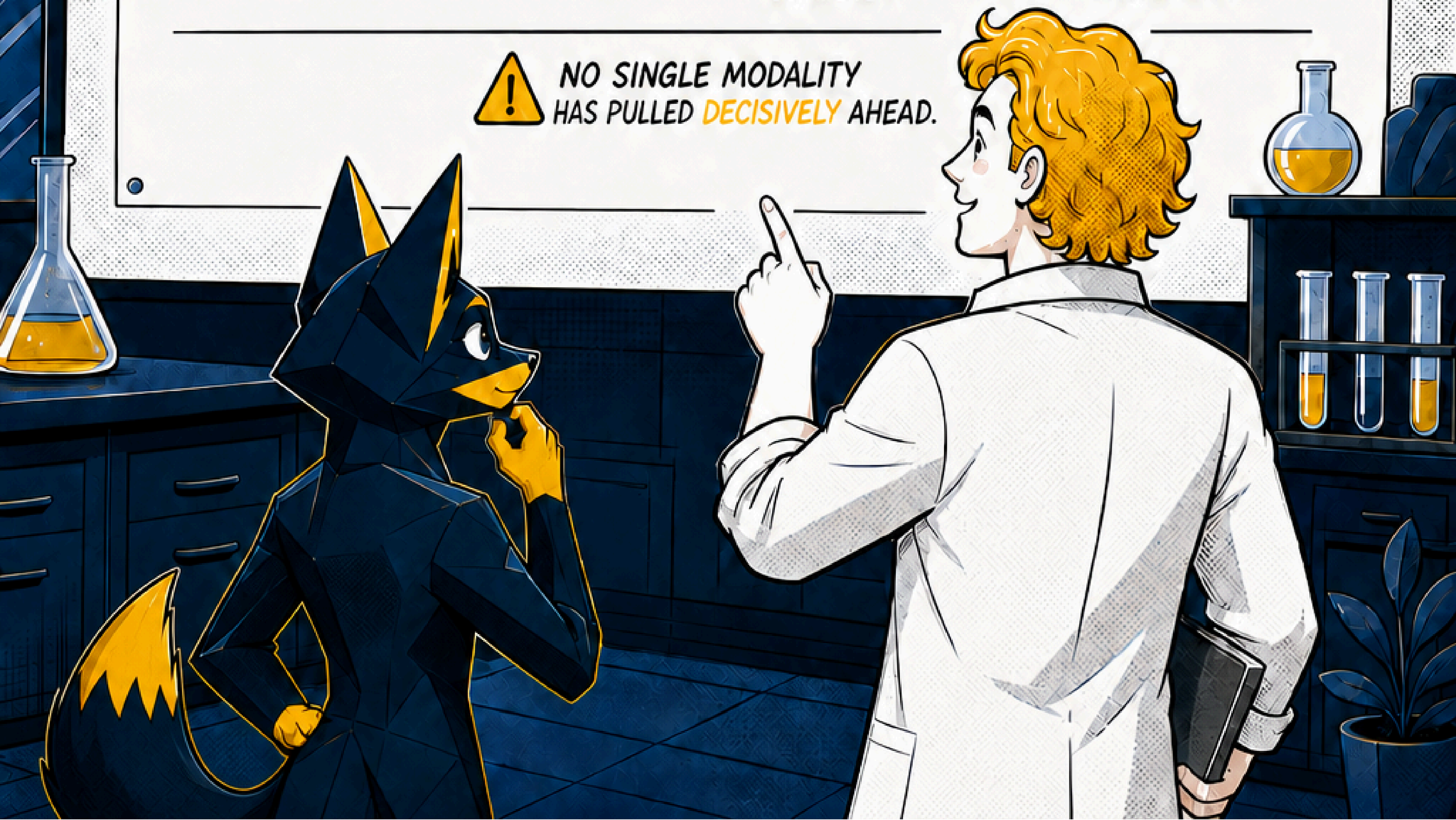
EVEN WITHIN SUPERCONDUCTING DESIGNS, **TRANSMONS** COMPETE...

SUPERCONDUCTING FLUXONIUMS

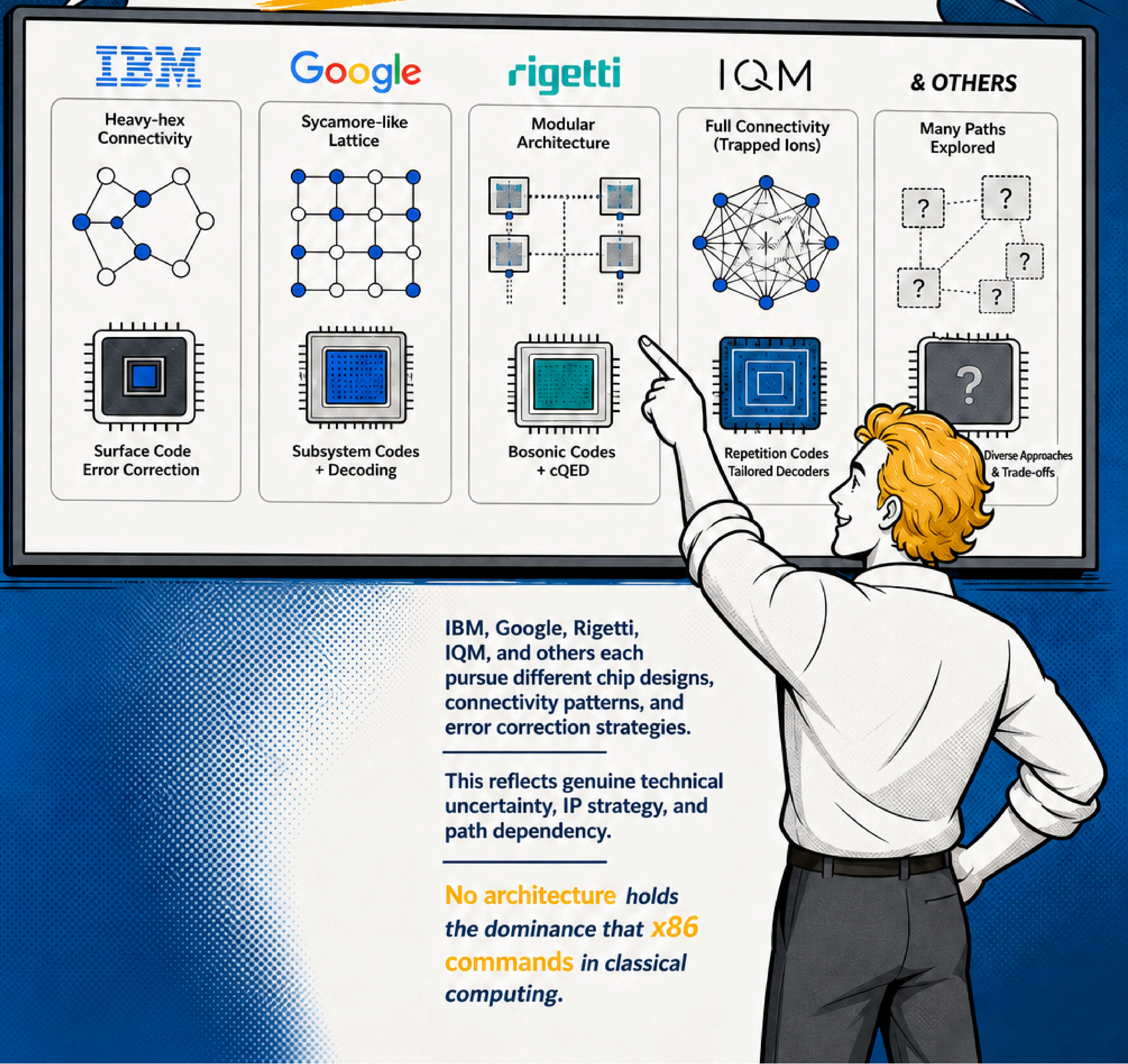


...WITH **FLUXONIUM** VARIANTS OFFERING DIFFERENT COHERENCE PROPERTIES.

⚠ NO SINGLE MODALITY HAS PULLED **DECISIVELY** AHEAD.



THE HARDWARE PICTURE IN 2026 REMAINS WIDE OPEN

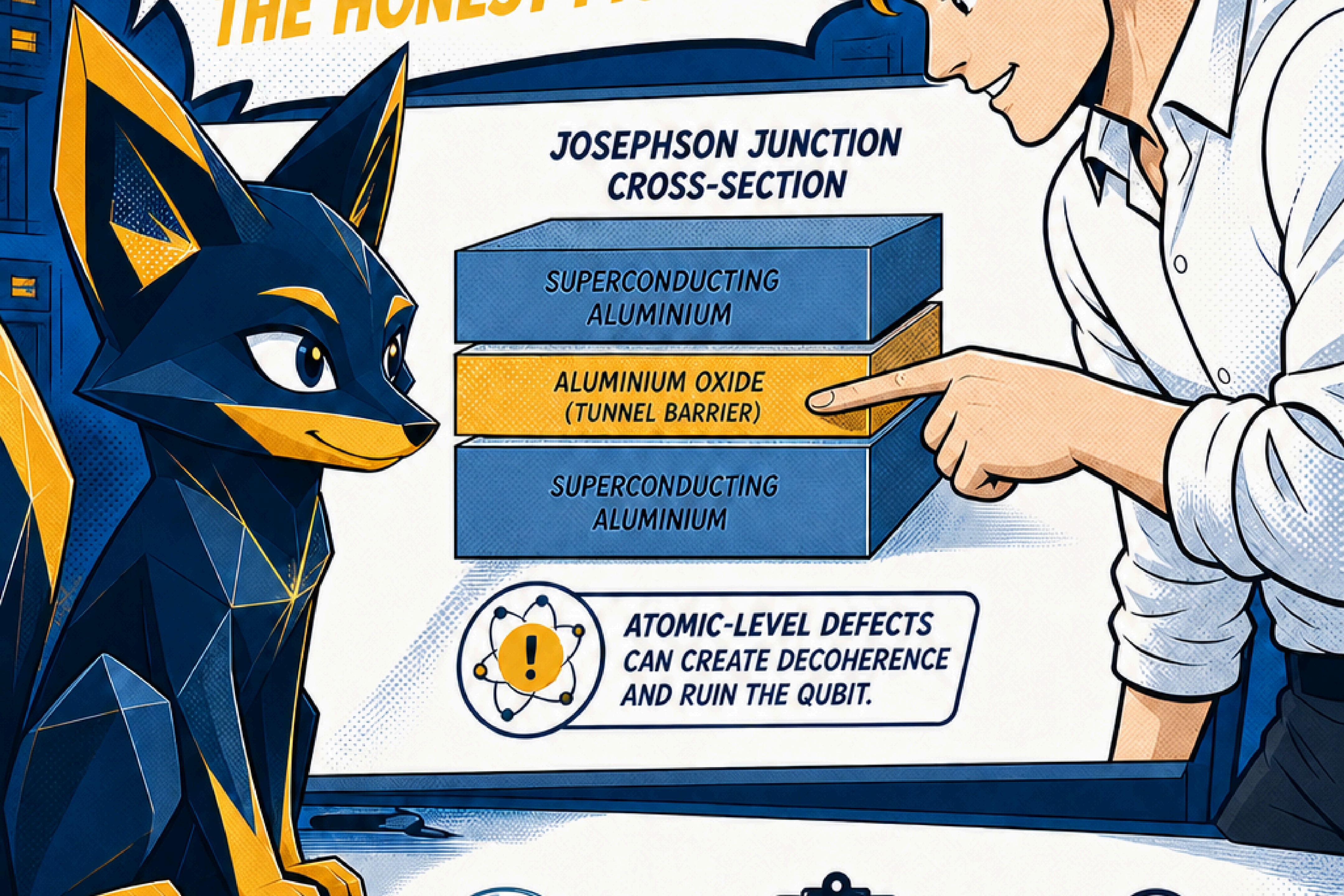


IBM, Google, Rigetti, IQM, and others each pursue different chip designs, connectivity patterns, and error correction strategies.

This reflects genuine technical uncertainty, IP strategy, and path dependency.

No architecture *holds the dominance that* **x86 commands** *in classical computing.*

MANUFACTURABILITY AND COMMERCIAL POTENTIAL: THE HONEST PICTURE



ATOMIC-LEVEL DEFECTS CAN CREATE DECOHERENCE AND RUIN THE QUBIT.

ADJACENT TO SEMICONDUCTOR FABRICATION → FAR MORE DEMANDING THAN STANDARD CHIPS → YIELD & REPRODUCIBILITY ARE ACTIVE RESEARCH AREAS → CLOUD ACCESS IS THE CURRENT COMMERCIAL MODEL

WHAT THIS MEANS IF YOU'RE EXPLAINING IT TO SOMEONE ELSE

1. **SUPERPOSITION**
   HOLDS MULTIPLE STATES SIMULTANEOUSLY UNTIL MEASURED.
   ENABLES A DIFFERENT KIND OF COMPUTATION.

2. **EXTREME COLD**
   REQUIRES TEMPERATURES NEAR ABSOLUTE ZERO: QUANTUM STATES ARE DESTROYED BY THERMAL NOISE.

3. **JOSEPHSON JUNCTION**
   THE CORE MECHANISM: A TINY INSULATING BARRIER THROUGH WHICH QUANTUM PARTICLES TUNNEL.
   PROVIDES CONTROL & NON-LINEAR BEHAVIOUR.

4. **DECOHERENCE**
   PRIMARY ENGINEERING CHALLENGE: QUANTUM STATE IS LOST TO ENVIRONMENTAL NOISE. THAT'S WHY ERROR CORRECTION IS ESSENTIAL—AND WHY HIGH PHYSICAL QUBIT COUNTS ≠ HIGH-QUALITY COMPUTATION.

5. **NO SETTLED STANDARD**
   THE FIELD IS GENUINELY COMPETITIVE ACROSS QUBIT DESIGNS AND QUBIT MODALITIES.

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