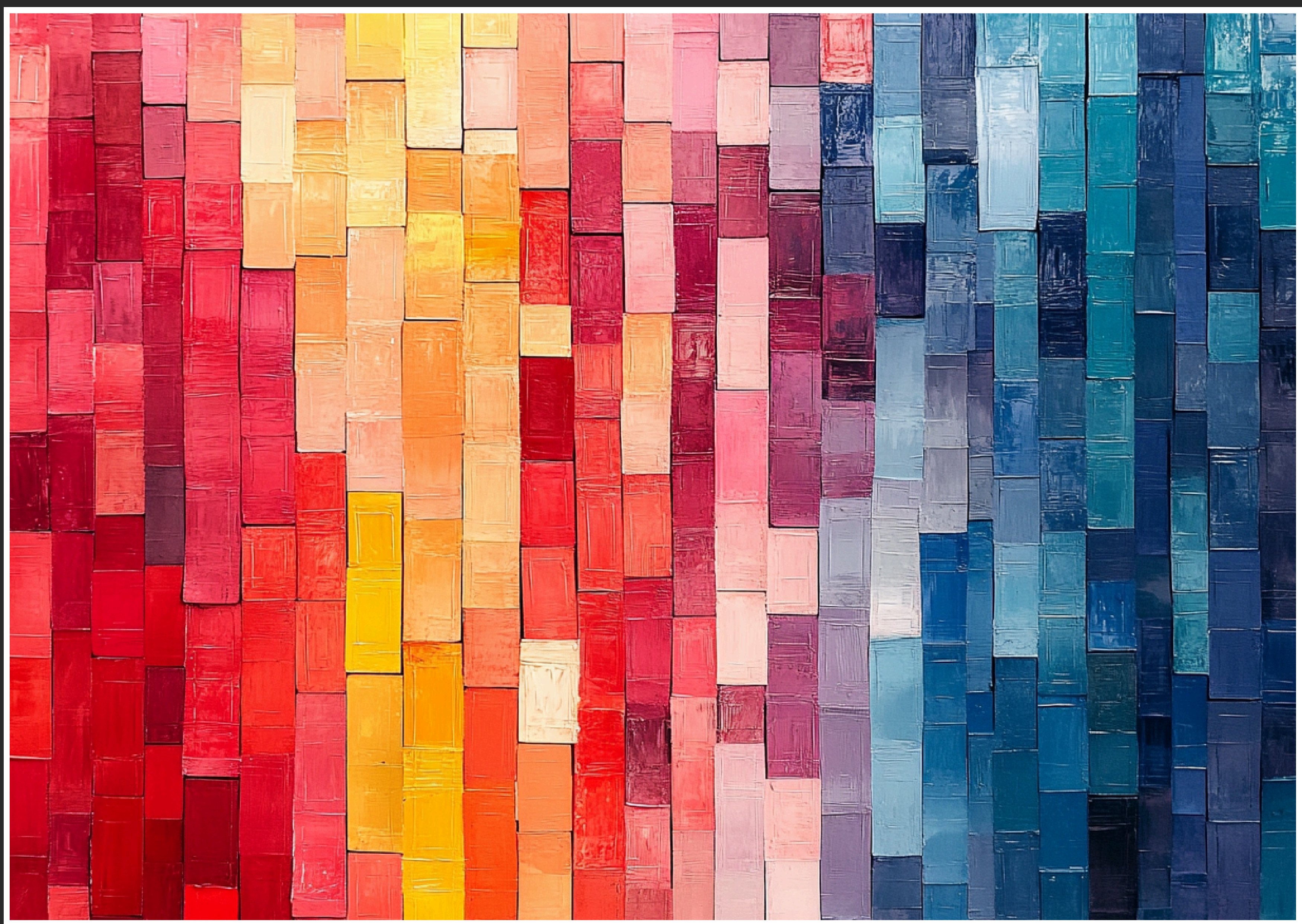
Not all errors are equal

Different types of errors shape quantum error correction thresholds in different ways



QCDESIGN

For quantum computers to work, they need to be below what's known as the **fault tolerance threshold**.

This threshold tells us how much of a particular error a system can handle before quantum error correction fails.

But what kinds of errors can happen inside a quantum computer?

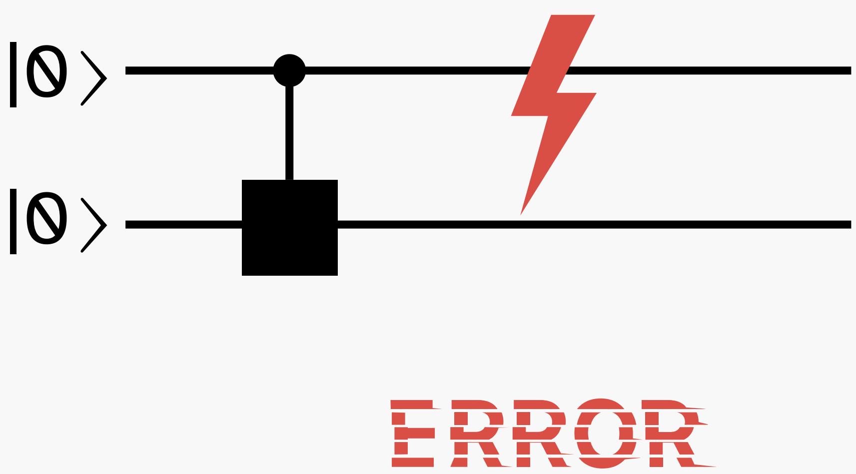
And how are they different?

Errors on data qubits

The simplest type of error is known as **depolarizing noise**.

It scrambles the quantum information encoded in **data qubits**.

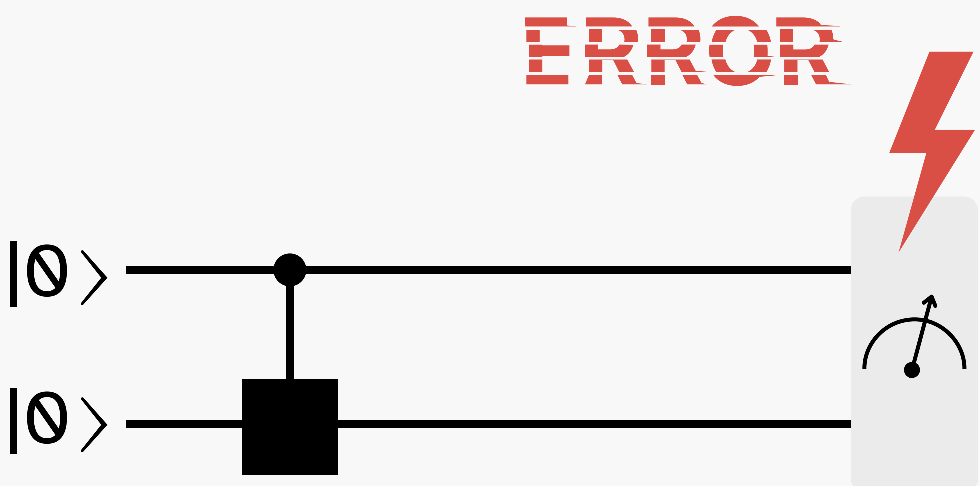
Some of the best codes available can handle depolarising noise probabilities up to ~19%



Measurement error

We can also get errors when we measure qubits.

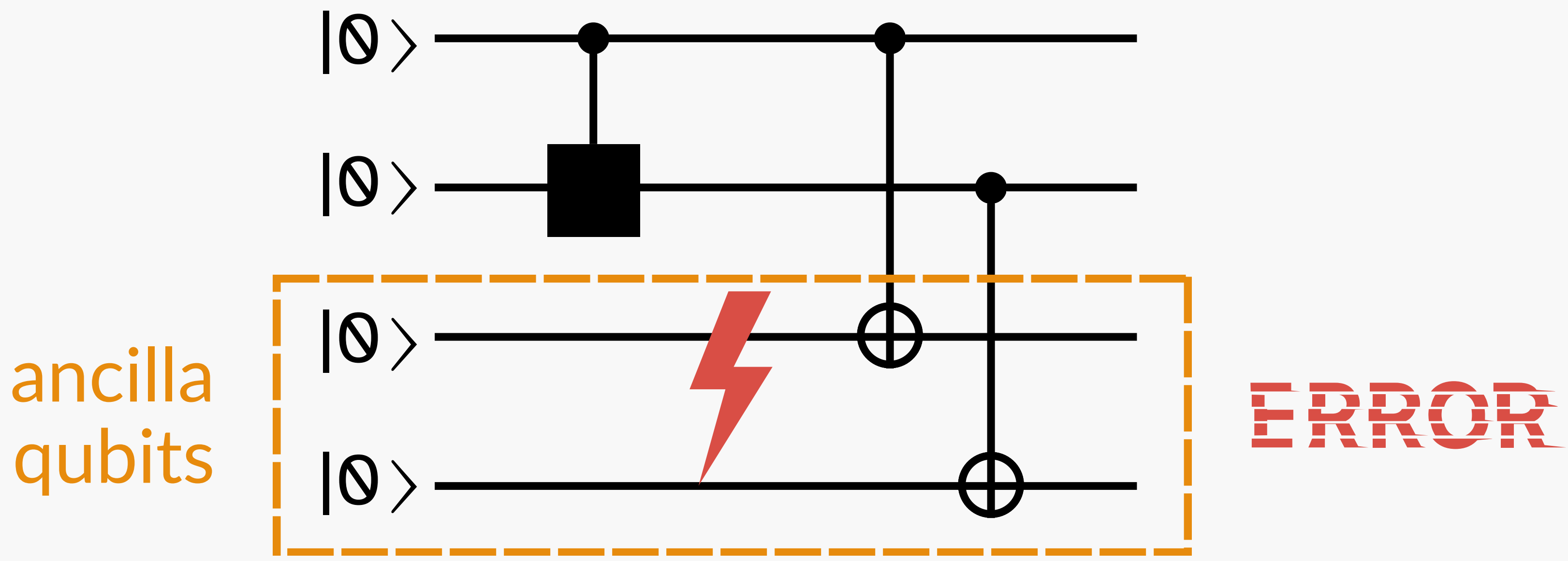
These errors can bring the threshold down from around 19% (for data qubits alone) to 3%.



Errors on ancilla qubits

But a quantum computer needs more than data qubits. It uses helper qubits, known as **ancilla qubits**, to assist in quantum operations or error correction.

These ancilla qubits are not storing the information for the logical qubits, but they can also pick up errors, which affect the computation.

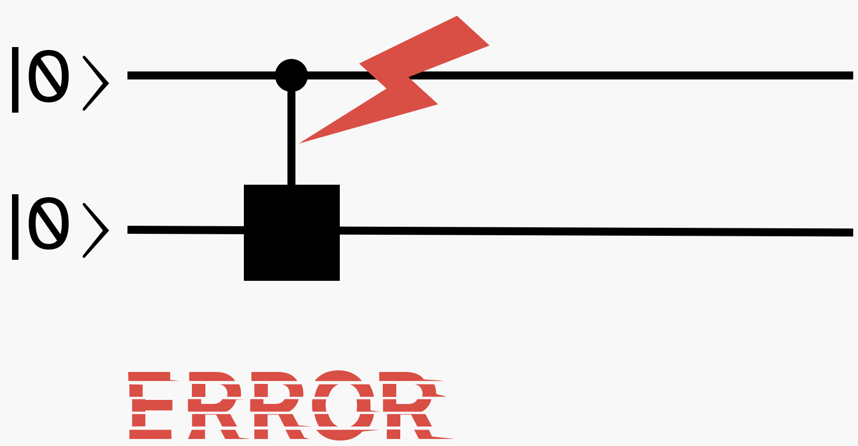


Gate error

Errors can also occur when we operate gates between qubits.

Considering all these errors at the same time—on the data qubits, on the ancilla qubits, and on the gates—is known as the **circuit noise model** in error correction.

The threshold for circuit noise is lower still: around 1%.



Erasure error

Another kind of error occurs when you lose all information from a qubit *and* know which qubit lost all its information.

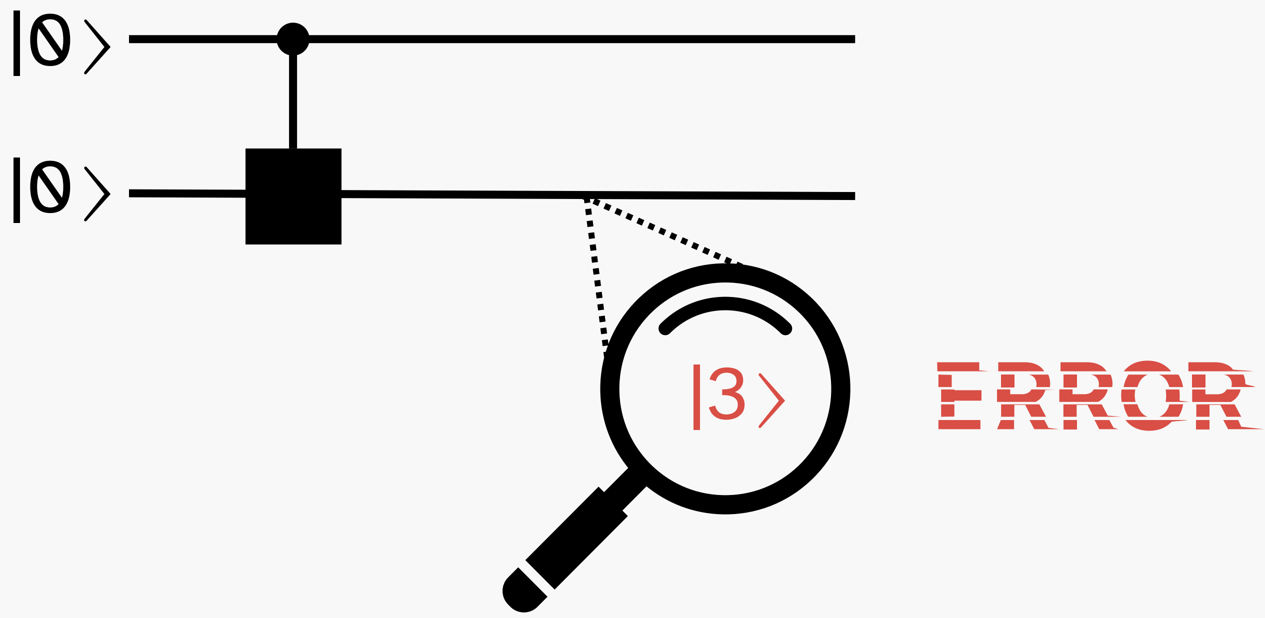
Because we know where the information was lost, the thresholds for erasure errors are much higher 25%-50% depending on the architecture.

Leakage error

In qubits made of superconducting circuits or neutral atoms, physical qubits aren't perfect two-level systems.

Sometimes the information can leak into one of the higher levels, taking the qubit outside of the 0/1 basis. This is known as a **leakage error,** a particularly onerous one since it has no threshold.

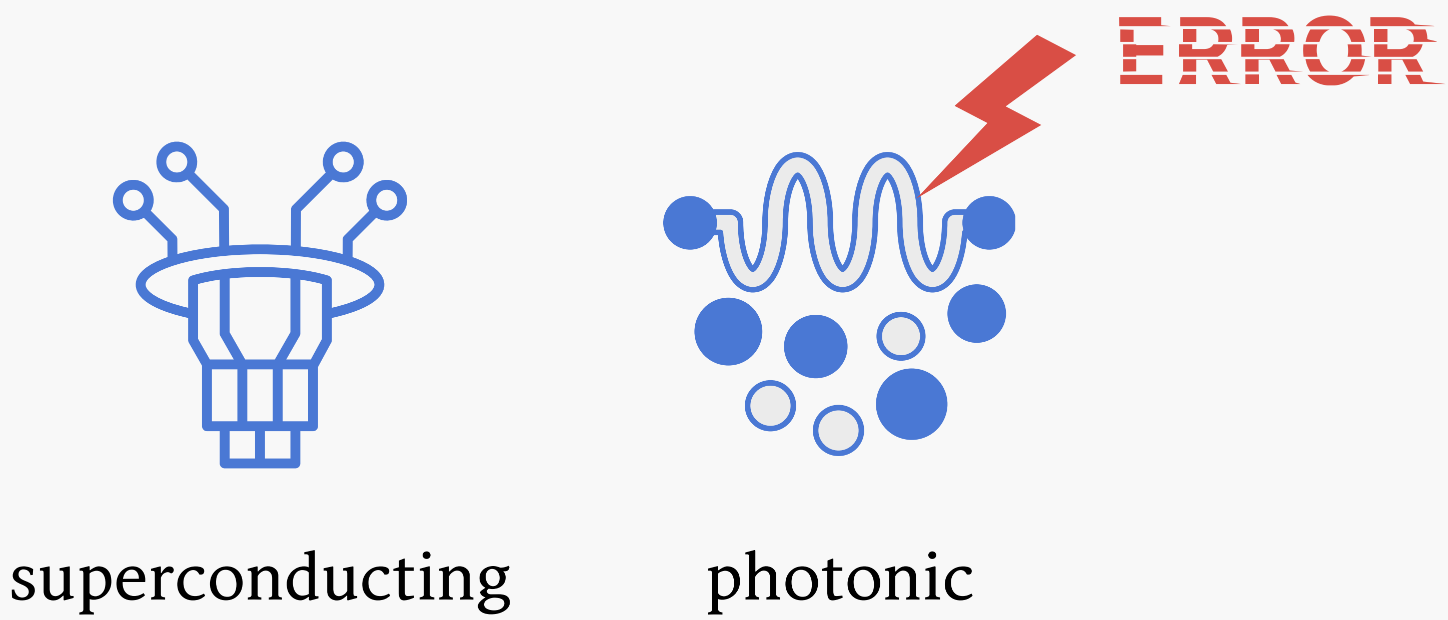
That's why many teams are working on **leakage mitigation**, which restores a threshold.



Different systems

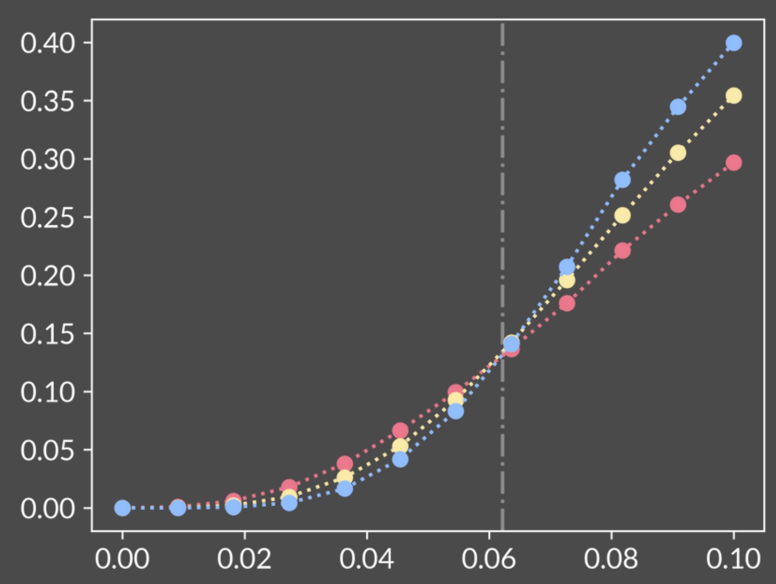
The errors just mentioned are typical for **superconducting qubit** systems, but other systems also have unique errors.

For example photonic systems have **optical loss** (where you lose a qubit **without knowing** that it was lost) and **fusion failure** errors that occur randomly in trying to implement 2-qubit gates.

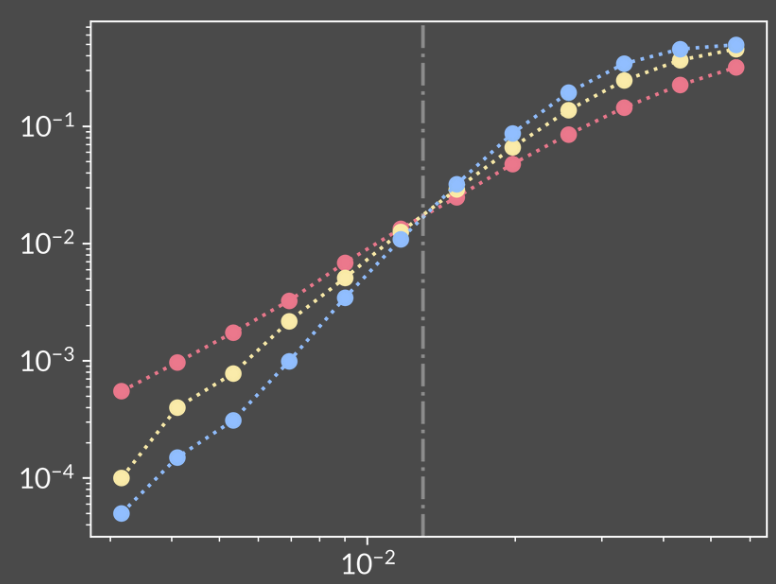


Different types of errors impact the system in unique ways, and therefore lead to drastically different threshold plots.

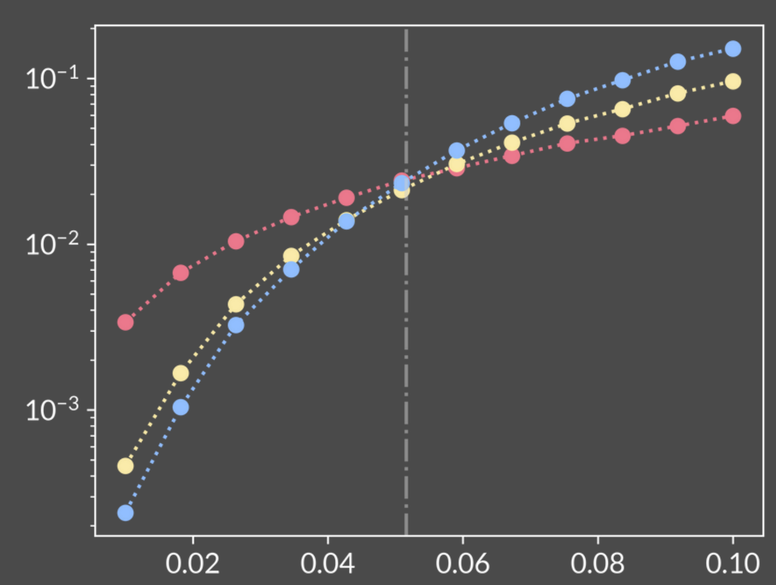
Depolarizing noise



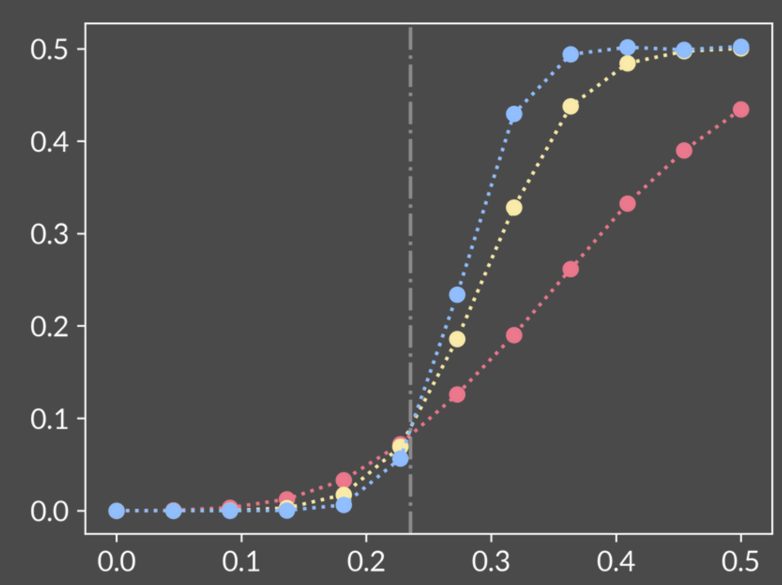
Mitigated leakage



Scattering

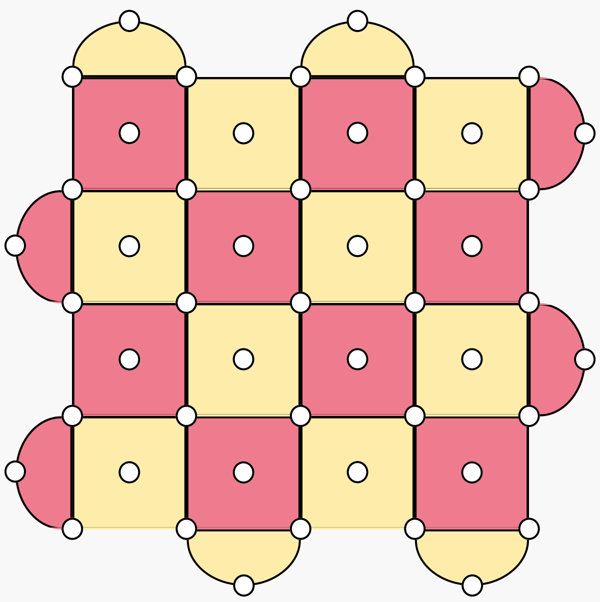


Optical loss

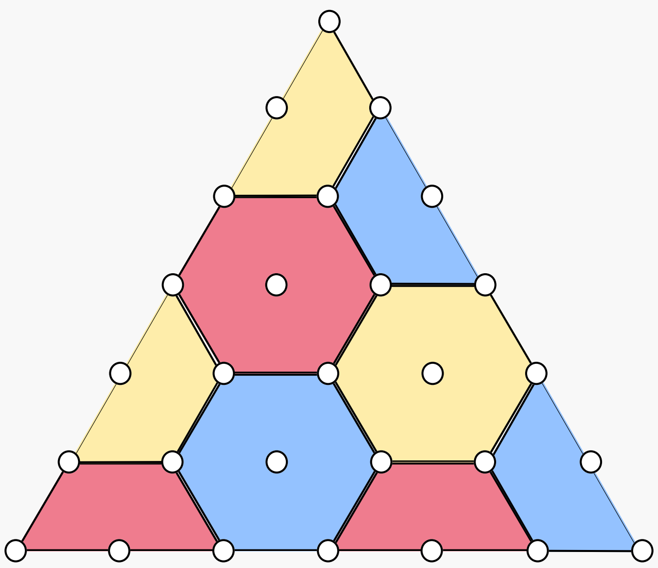


...and others as well!

And different error correction codes are designed to handle different types of imperfections.



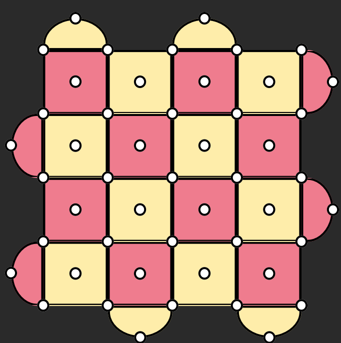
Surface code

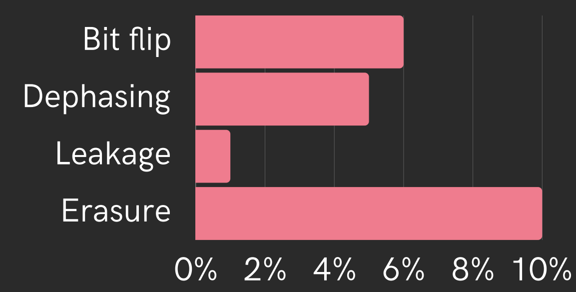


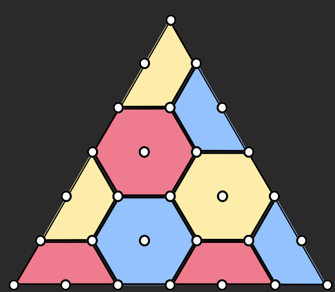
Color code

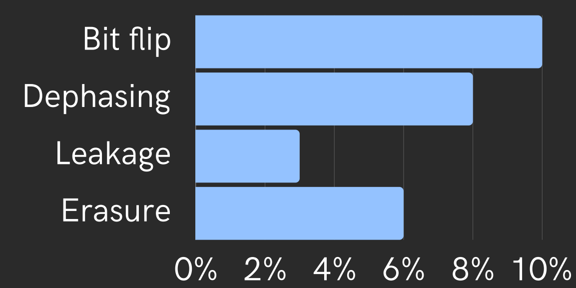
That's why we built Plaquette™!

Plaquette simplifies threshold calculations, making it easier to account for different types of error, so hardware teams can choose codes that match their system's dominant errors.









Thresholds for different codes

Learn more about Plaquette™

If you're interested to learn how to use Plaquette to plan out your hardware roadmap, we're happy to chat.

Contact us here on LinkedIn™, or head on over to the website at qc.design.

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