Physical vs. Logical Qubits

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What is a physical qubit?

- A **physical qubit** is a concrete, hardware implementation of a two-level system:
  - superconducting transmon, trapped ion, spin in a quantum dot, NV center, photon, ...
- Each physical qubit:
  - has a finite coherence time (T_1, T_2),
  - suffers from bit-flip and phase-flip errors,
  - is directly controlled by microwave/laser pulses or other hardware controls.
- Useful for small experiments, but error rates are typically too high for long algorithms.

What is a logical qubit?

- A **logical qubit** is an *encoded* qubit:

$$|0_L\rangle,\ |1_L\rangle$$

  stored across many physical qubits using a quantum error-correcting code.
- The code allows:
  - detection and correction of physical errors,
  - reduction of the effective error rate per logical qubit,
  - construction of fault-tolerant logical gates.
- Example: surface code can require hundreds to thousands of physical qubits per logical qubit for very low logical error rates.

- Logical qubits enable **fault-tolerant quantum computing**.
- Many logical qubits are needed for large-scale algorithms (e.g. Shor, chemistry, QPE).

over many noisy qubits;