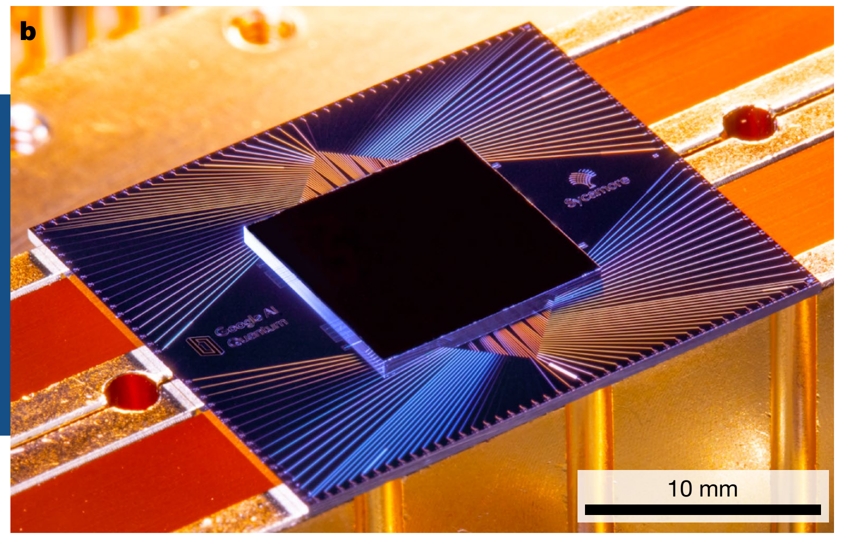
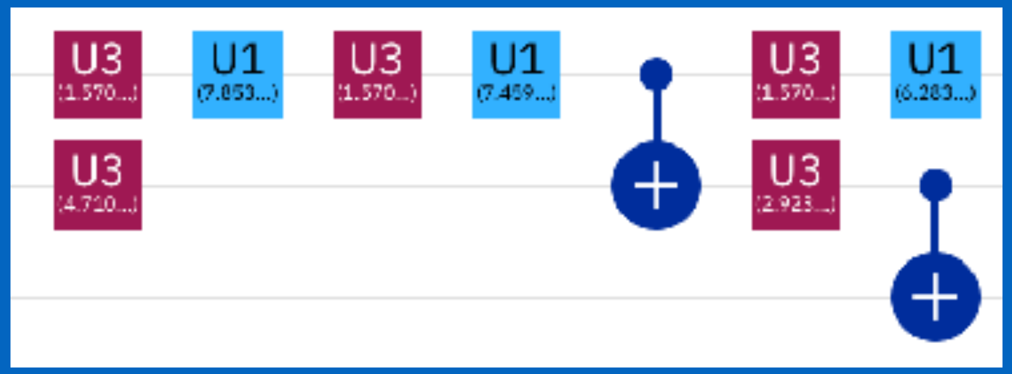
Outline

1. Quantum devices



2. Hands-on: Noise models



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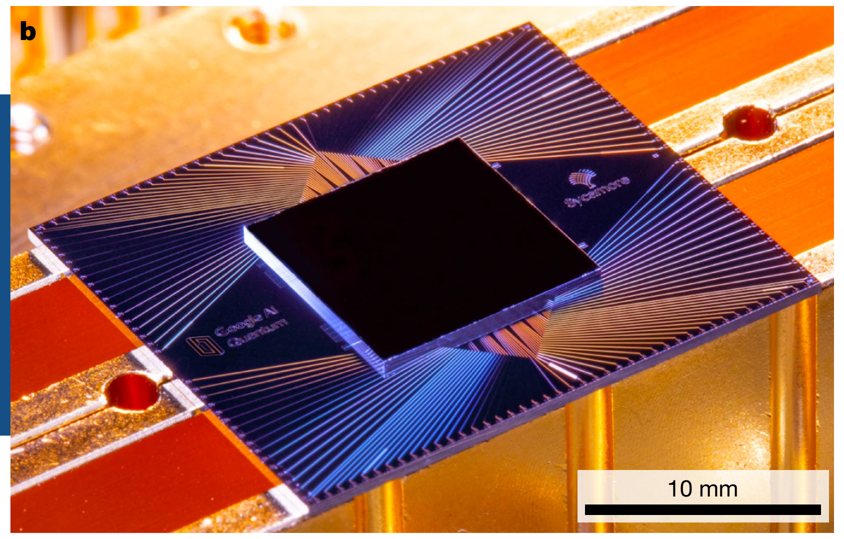

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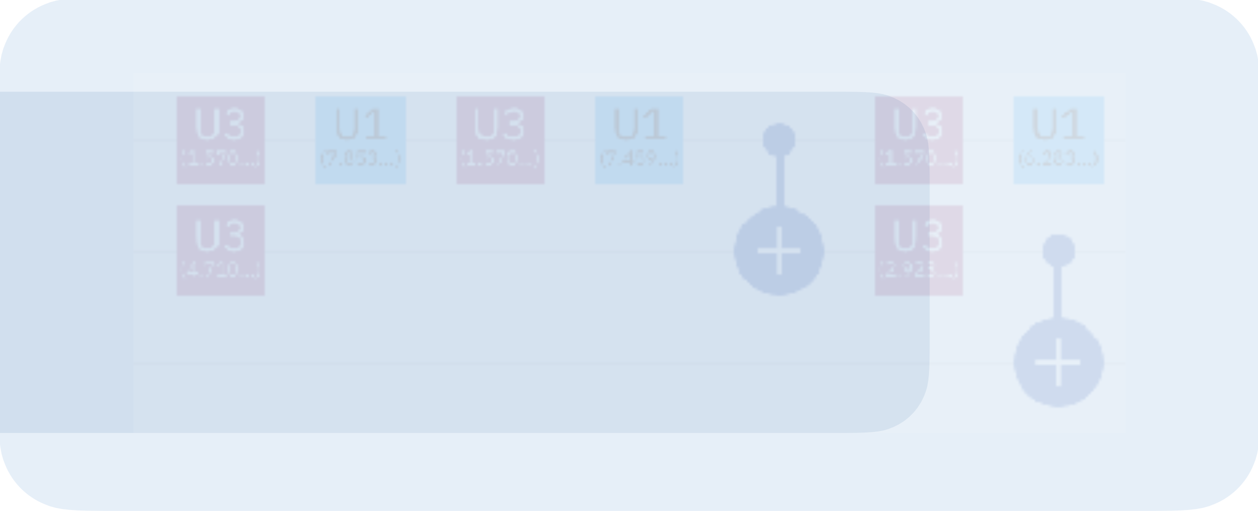


DiVincenzo Criteria

A quantum computer must satisfy the following:

- Scalable physical system with well-defined qubits
- Ability to initialize qubits
- Ability to measure qubits
- Universal set of quantum gates
- Qubit decoherence times much longer than gate latency

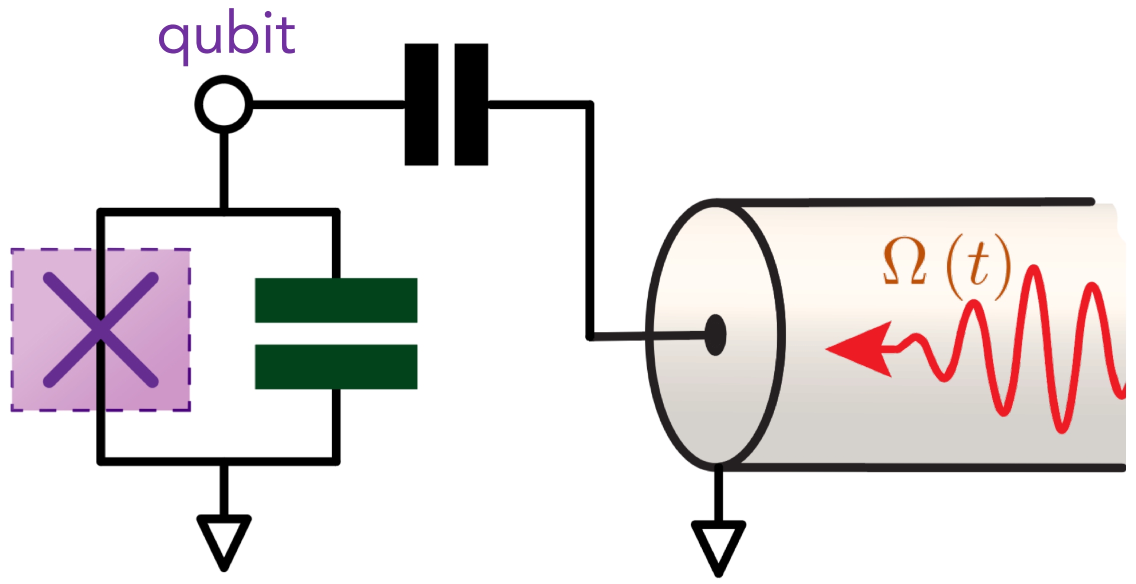
A variety of different physical systems are being explored, each with strengths

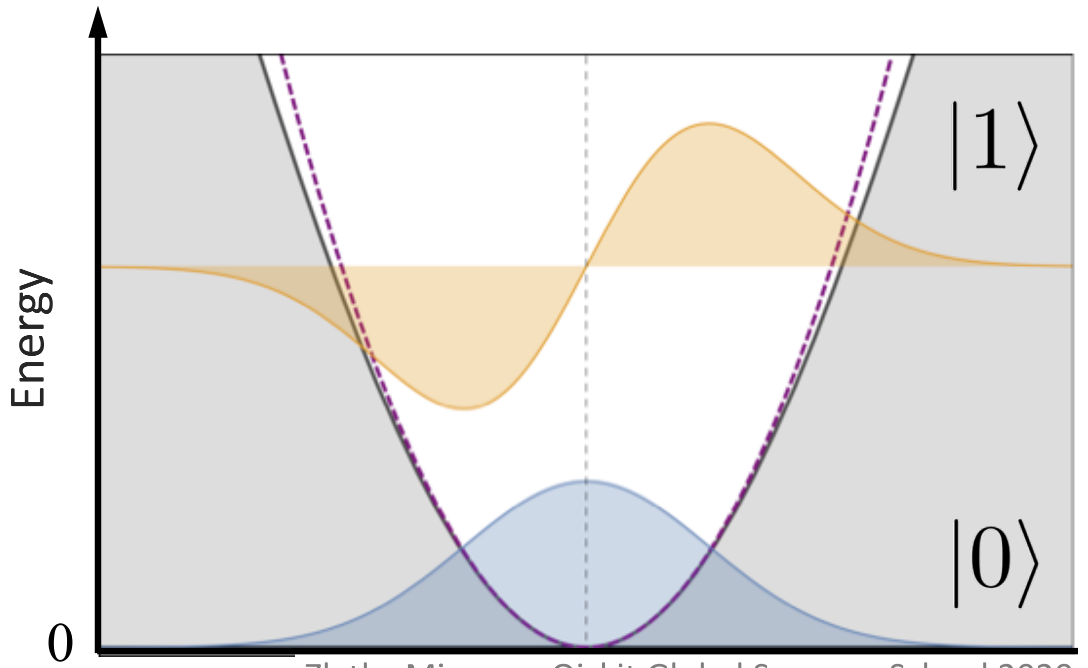
- Superconducting circuits
- Trapped ions
- Rydberg atoms
- Photonics
- Topological materials
- …

Quantum devices

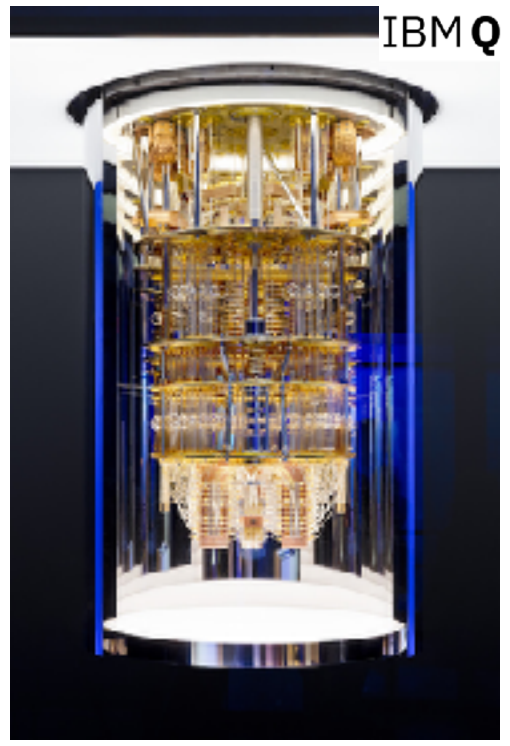
Superconducting circuits

Google IBM Q rigetti





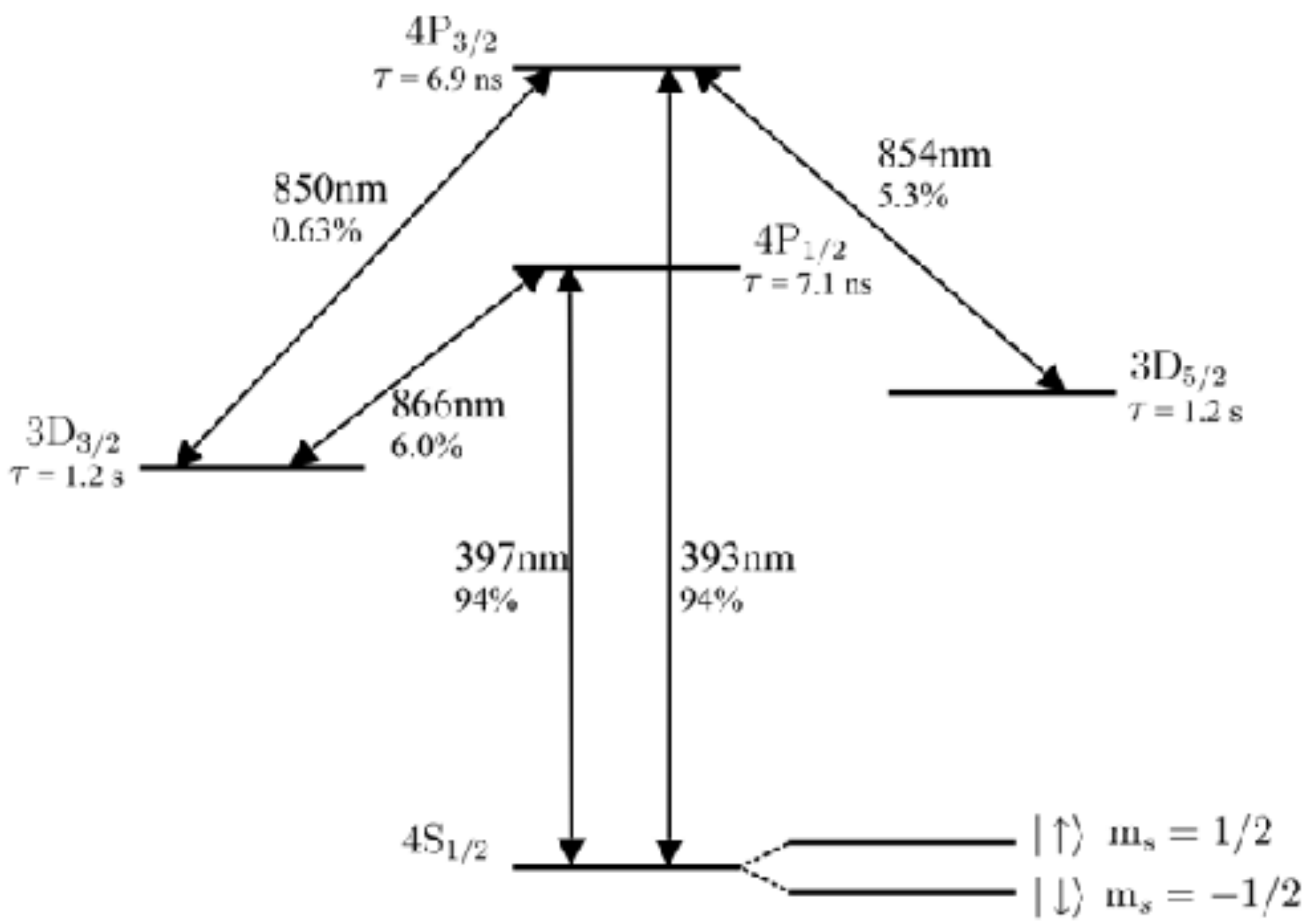
Zlatko Minev — Qiskit Global Summer School 2020

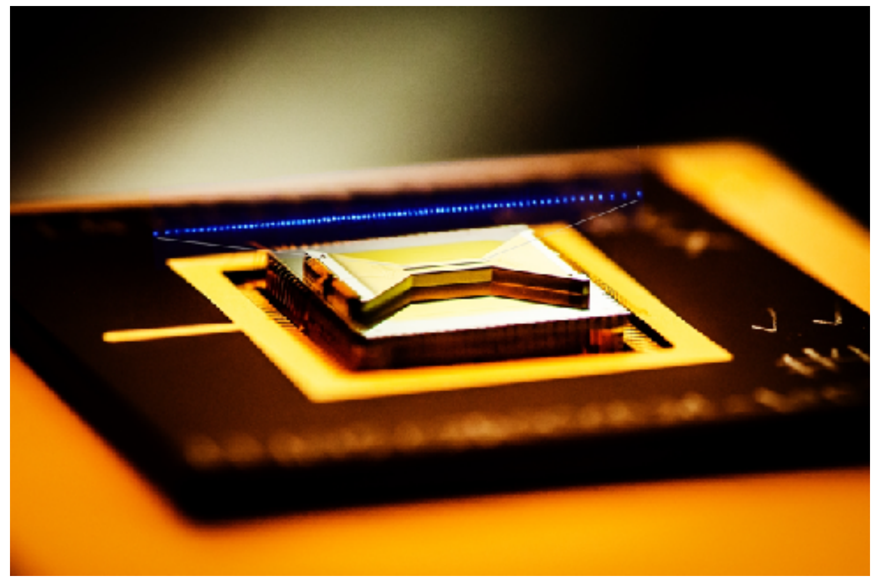


Qubits: Nonlinear quantum oscillator
Gates: Coupled microwave pulses

Trapped ions

IONQ QUANTINUUM





Qubits: Atomic energy levels (optical/hyperfine)
Gates: Coupled laser pulses

Rapid advances in qubit coherence times and quantum gates

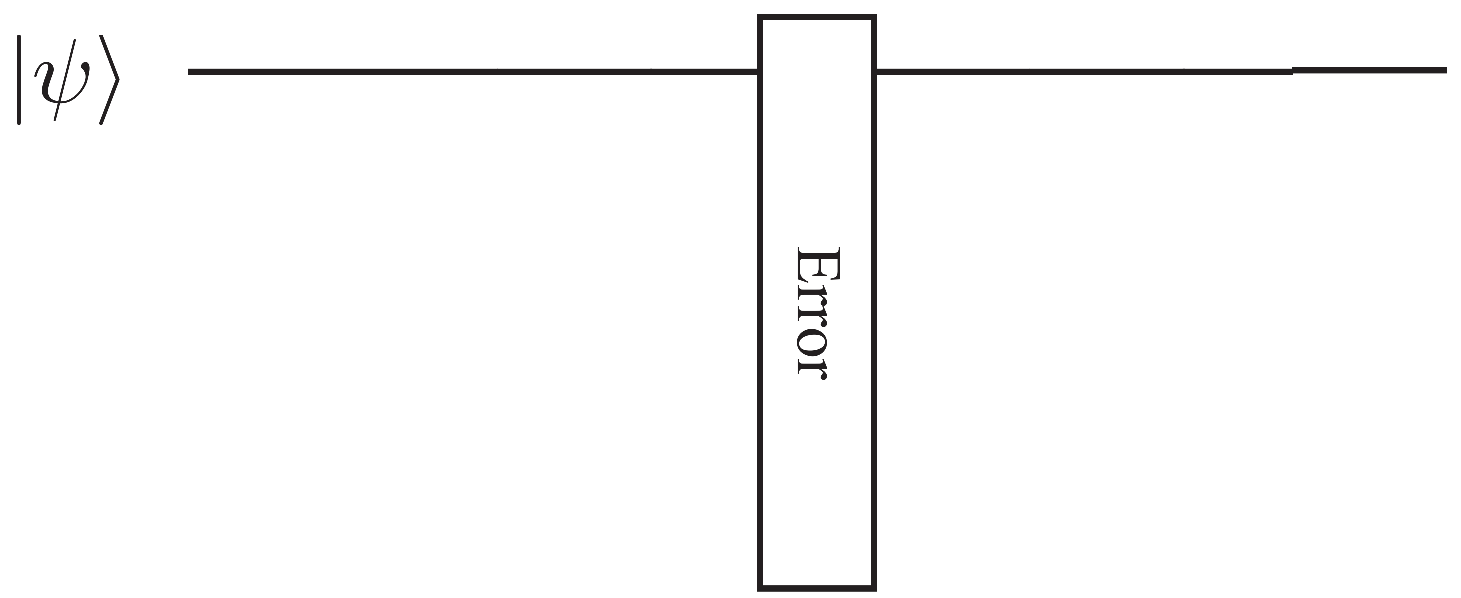
State-of-the-art: $\mathcal{O}(10-100)$ qubits, $\mathcal{O}(100)$ two-qubit operations

Quantum error correction

Idea: Encode one logical qubit in a larger set of physical qubits

Example: Bit flip code

- Suppose a bit flip (X gate) occurs with probability p



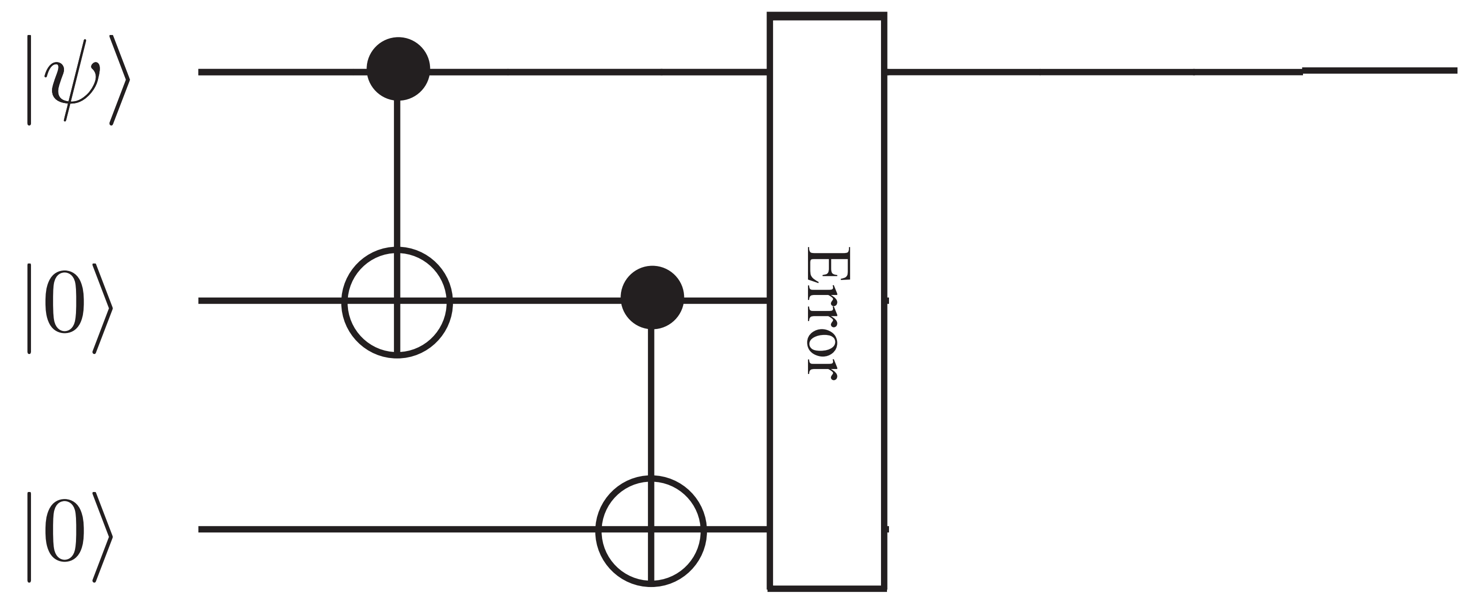
Devitt, Munro, Nemoto (2013)

Quantum error correction

Idea: Encode one logical qubit in a larger set of physical qubits

Example: Bit flip code

- Suppose a bit flip (X gate) occurs with probability p
- Encode our qubit $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$ into three qubits: $|\psi_{\text{encoded}}\rangle = \alpha|000\rangle + \beta|111\rangle$



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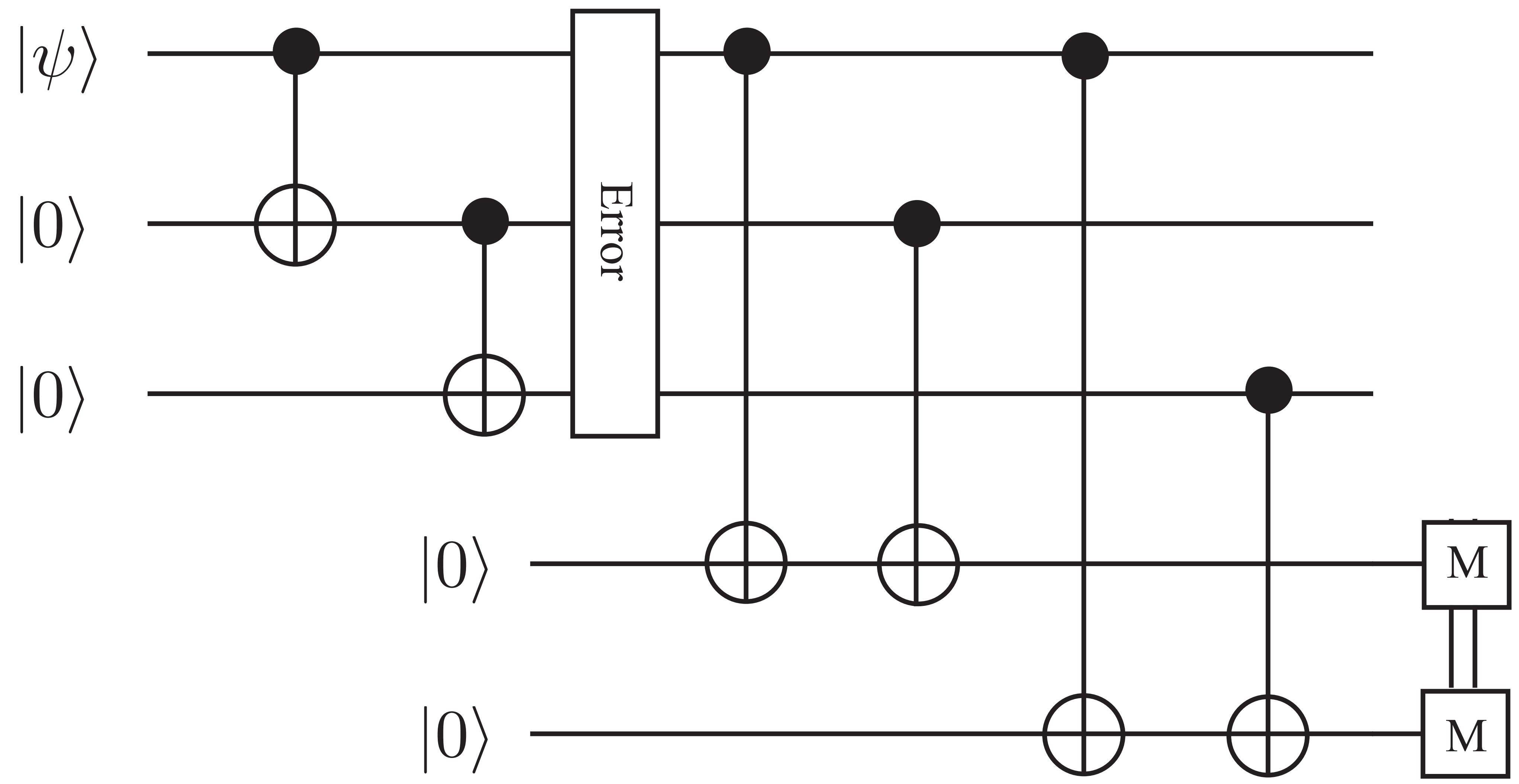
- Introduce ancilla qubits to measure the parity of the three qubits



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Quantum error correction

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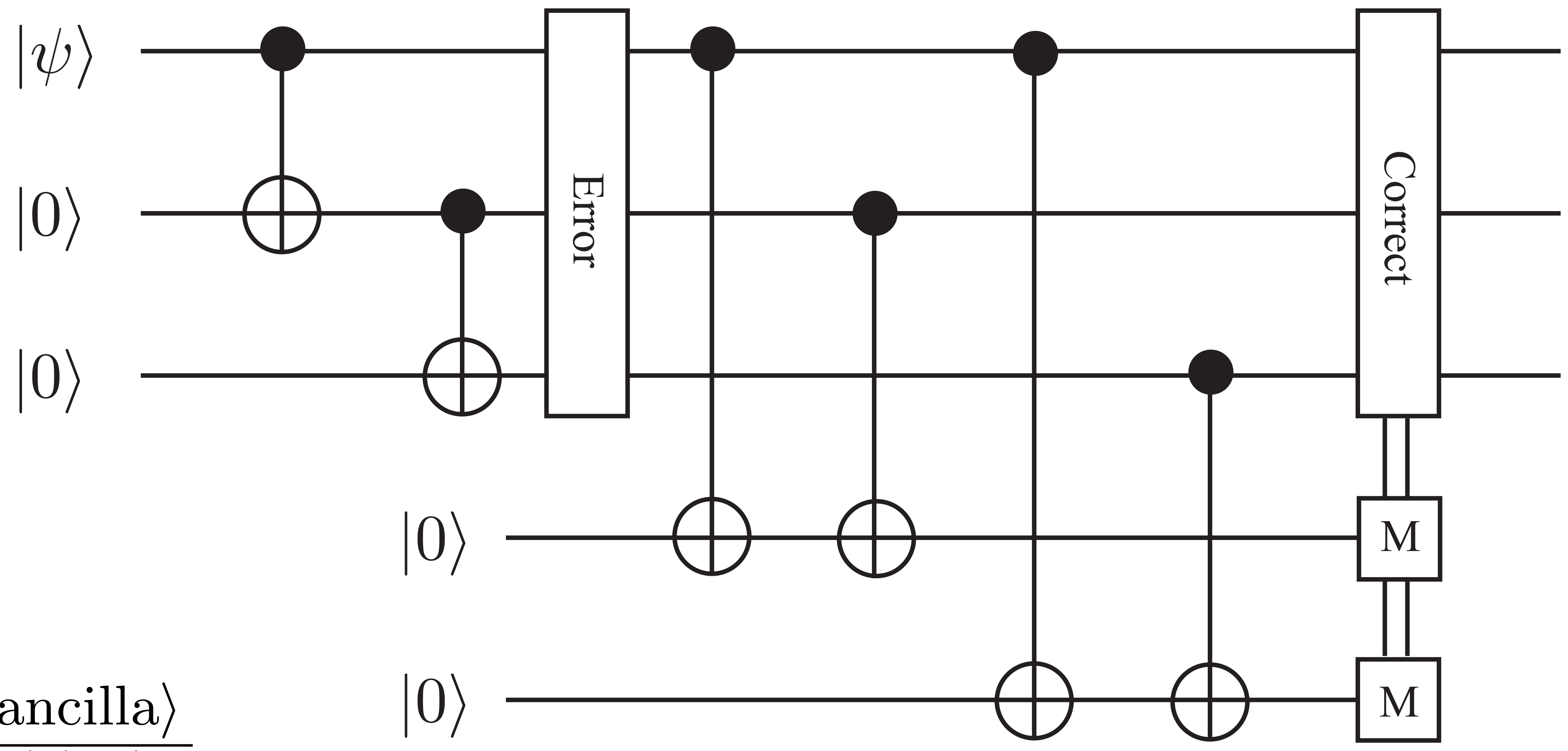
- Introduce ancilla qubits to measure the parity of the three qubits
- Perform correction



Error Location	Final State, $\|\text{data}\rangle\,\|\text{ancilla}\rangle$
No Error	$\alpha\,\|000\rangle\,\|00\rangle + \beta\,\|111\rangle\,\|00\rangle$
Qubit 1	$\alpha\,\|100\rangle\,\|11\rangle + \beta\,\|011\rangle\,\|11\rangle$
Qubit 2	$\alpha\,\|010\rangle\,\|10\rangle + \beta\,\|101\rangle\,\|10\rangle$
Qubit 3	$\alpha\,\|001\rangle\,\|01\rangle + \beta\,\|110\rangle\,\|01\rangle$

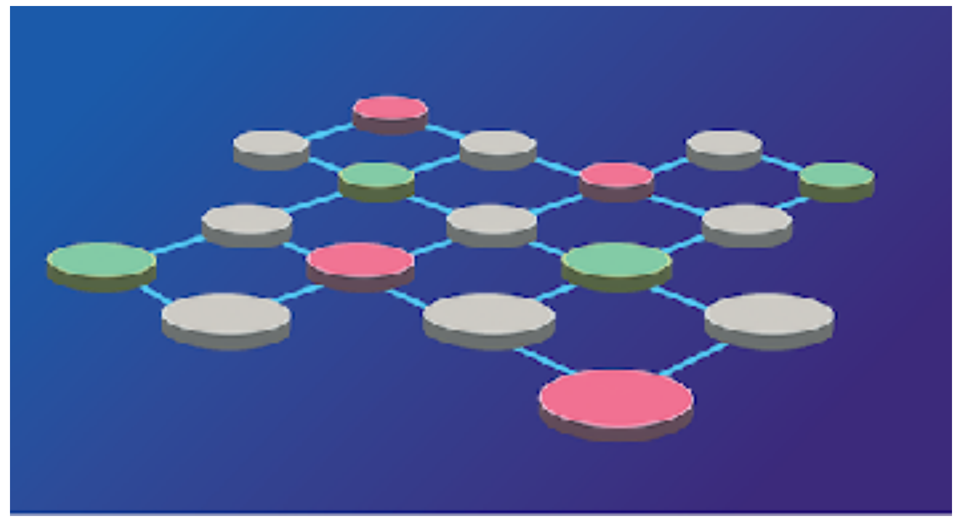
Devitt, Munro, Nemoto (2013)

Quantum error correction

Idea: Encode one logical qubit in a larger set of physical qubits

There are a variety of error correction codes:

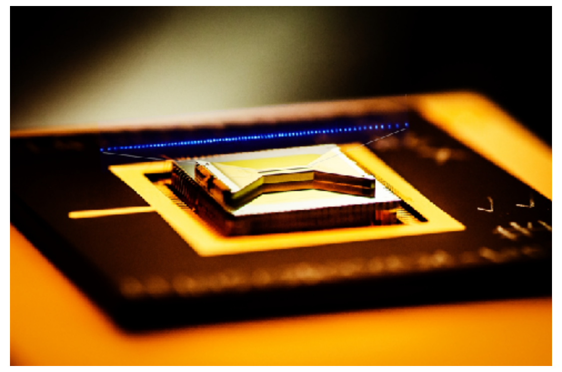
- Shor code
- Steane code
- Surface codes
- …



Quantum threshold theorem: If errors are below a certain threshold, then you can correct errors faster than you introduce them

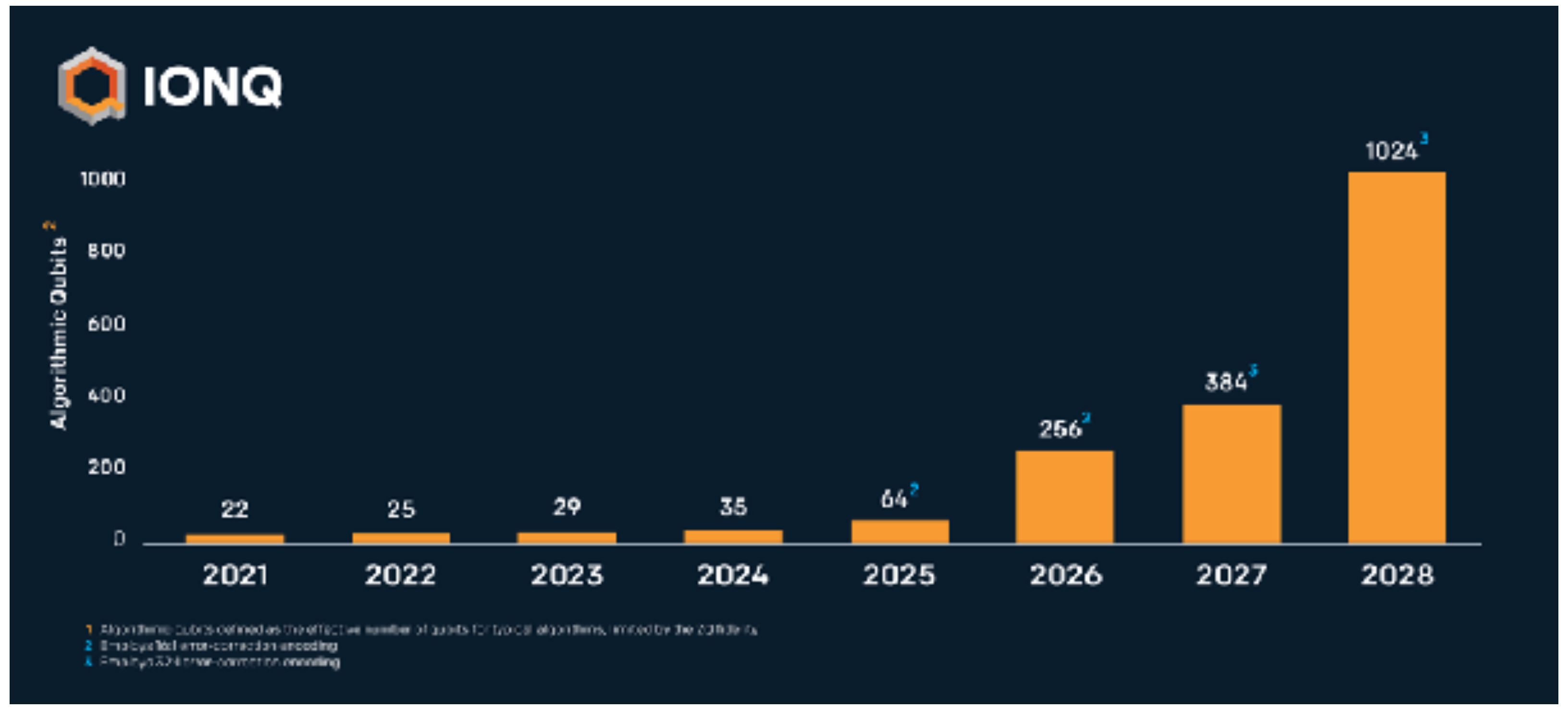
→ Demonstrating "break-even" point is active goal of research

Current quantum devices



Few qubits

Current devices are limited to $\mathcal{O}(10) - \mathcal{O}(100)$ qubits



Need more qubits to achieve quantum advantage

Decoherence

The quantum state of a qubit is stable only for a limited time

T_1: decay time $|1\rangle \rightarrow |0\rangle$

T_2: dephasing time

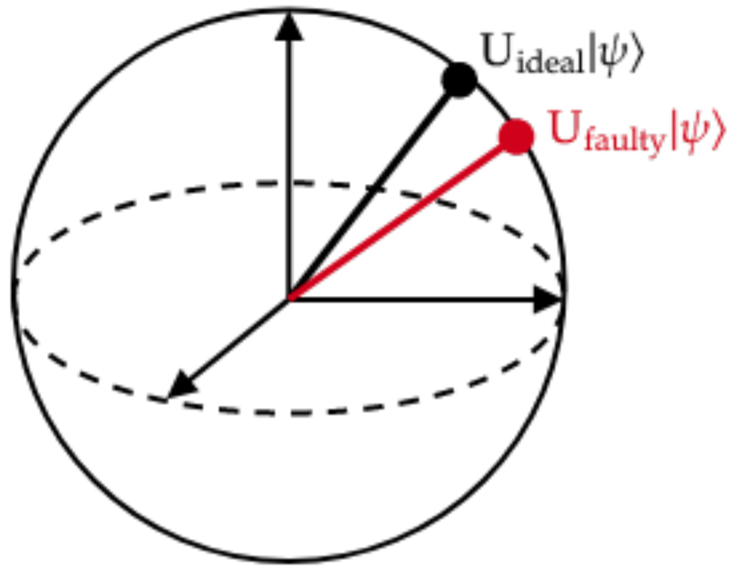
$$|1\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

Need longer coherence times to increase the "gate depth" of circuits

Gate noise

Single- and two-qubit gate operations are imperfect

$$U_{\text{faulty}} = A\ U_{\text{ideal}}$$



Need smaller gate noise to perform quantum error correction

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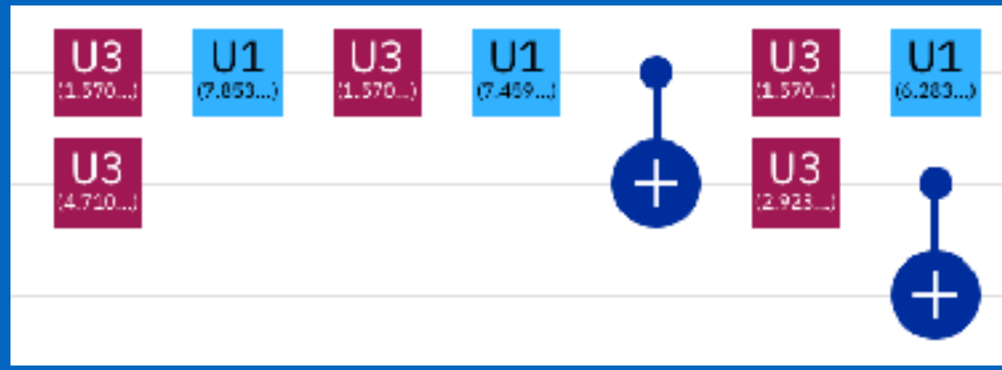
2. Hands-on: Noise models



Hands-on: Noise models

https://colab.research.google.com/drive/1Sv9ZTftGAtzFsy1MQV_g0CZhWesGRbmO?usp=share_link

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