Spoofing Linear Cross-Entropy Benchmarking in Shallow Quantum Circuits

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Harvard University

ITCS 2021

Extended Church-Turing Thesis (ECTT)

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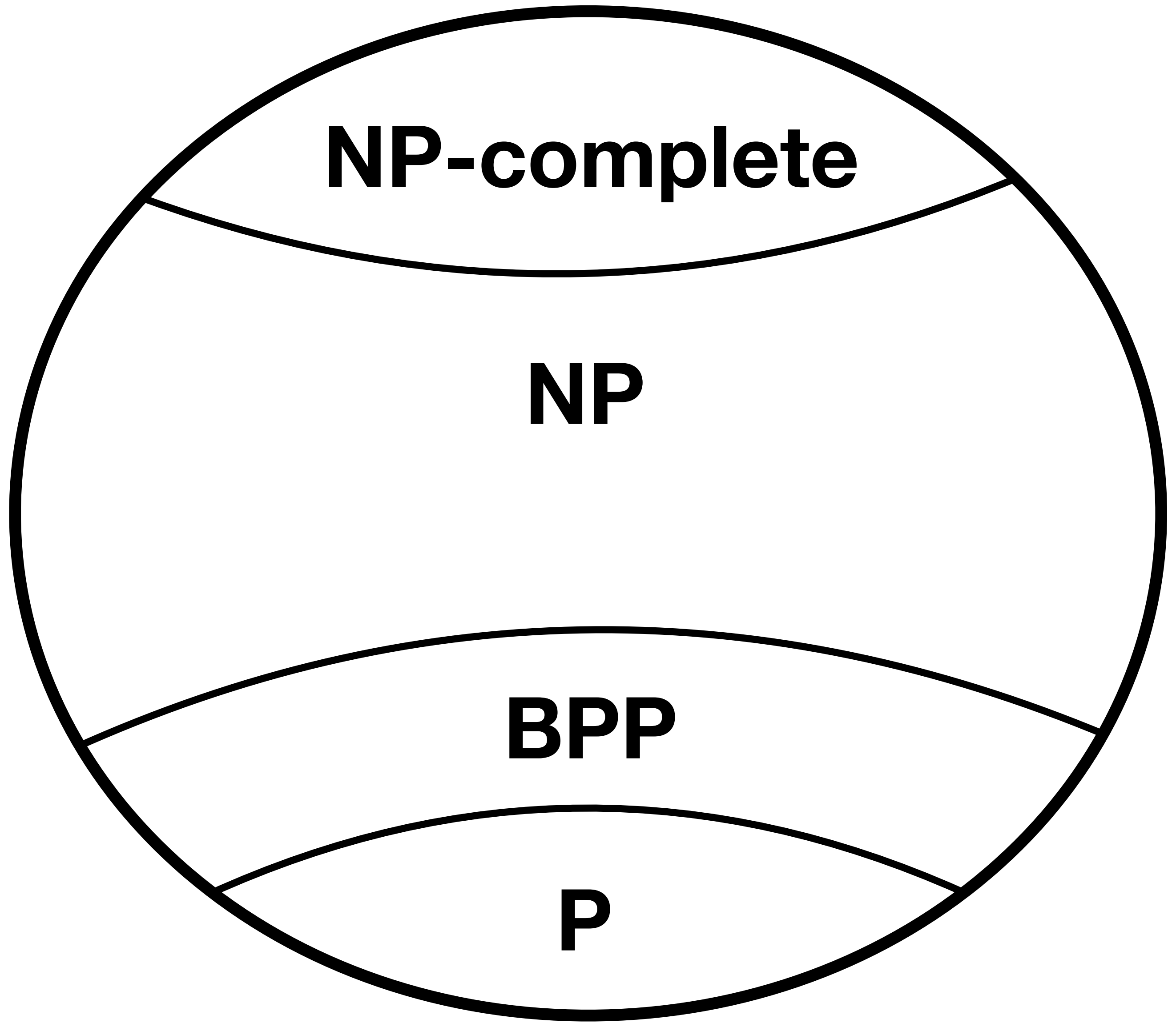
Feasible/Efficient computation in the physical world is in **BPP**.



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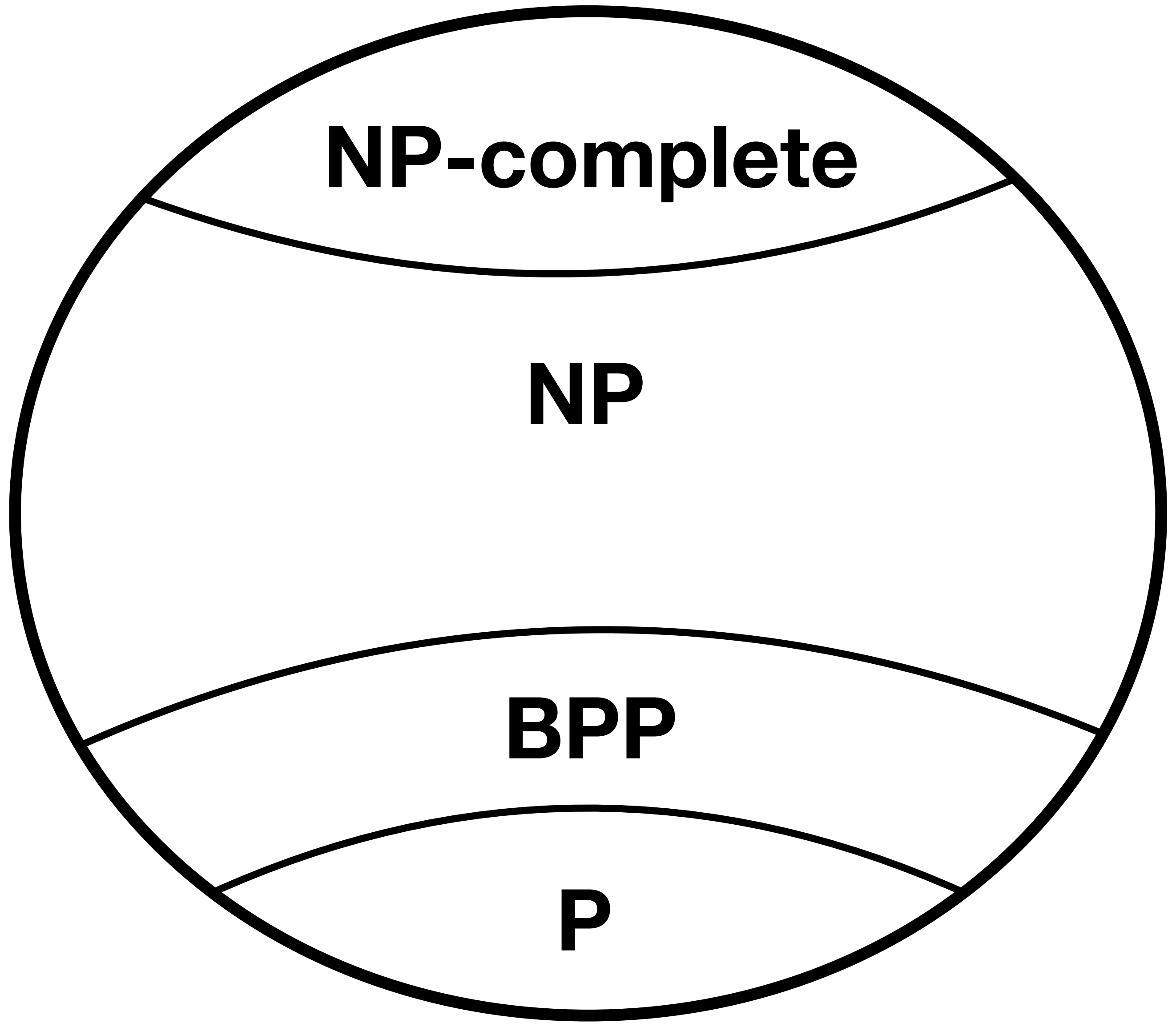

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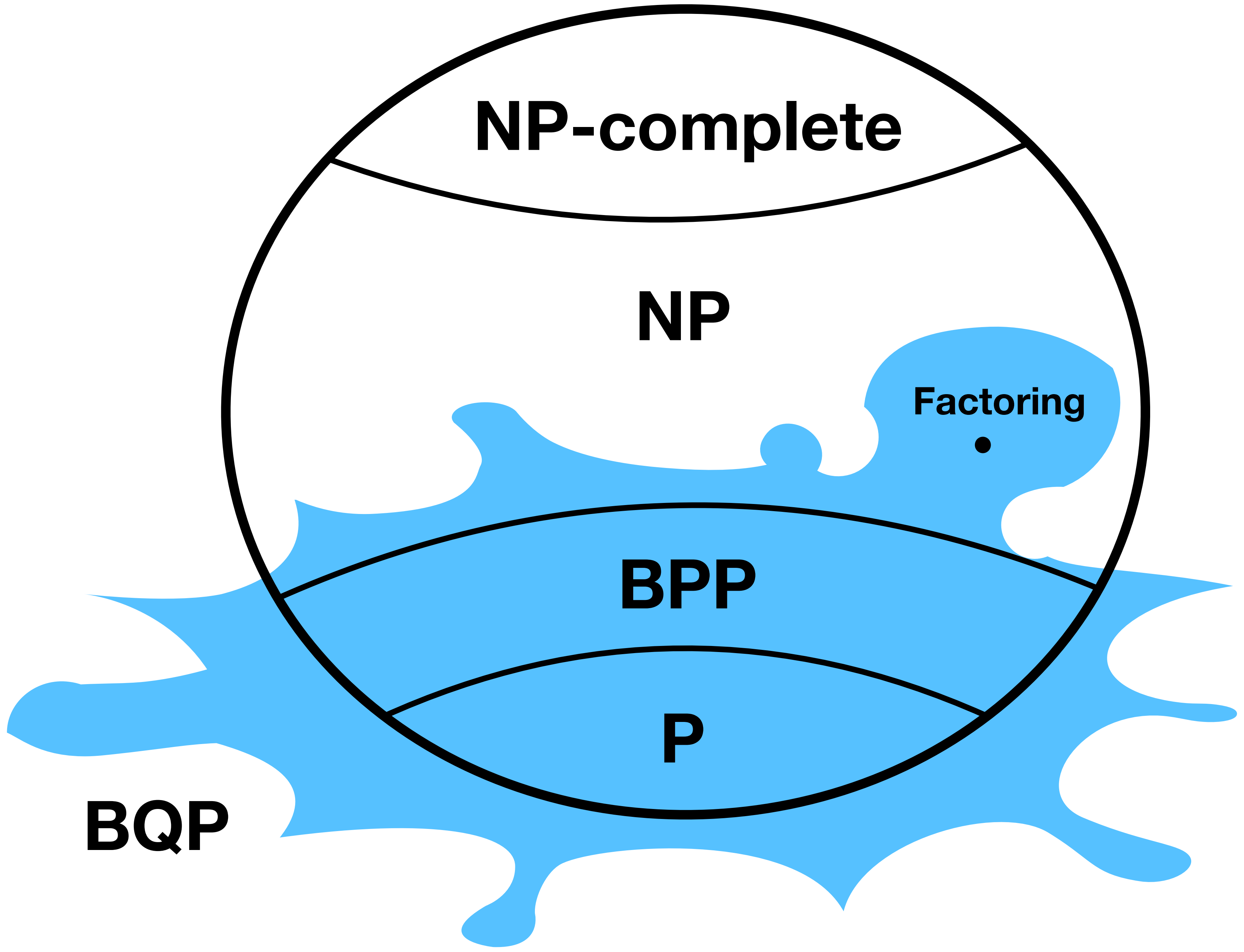

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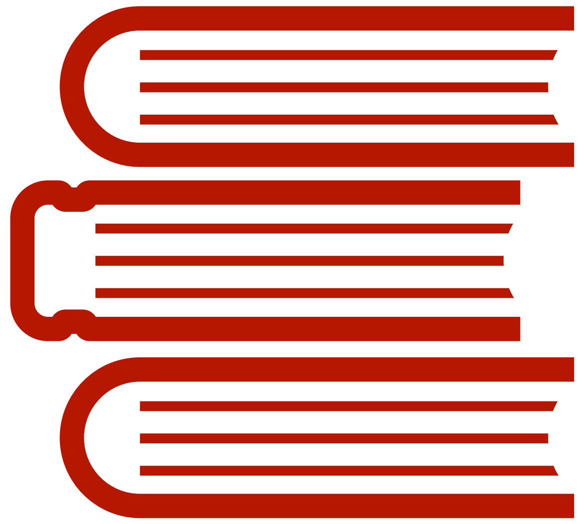

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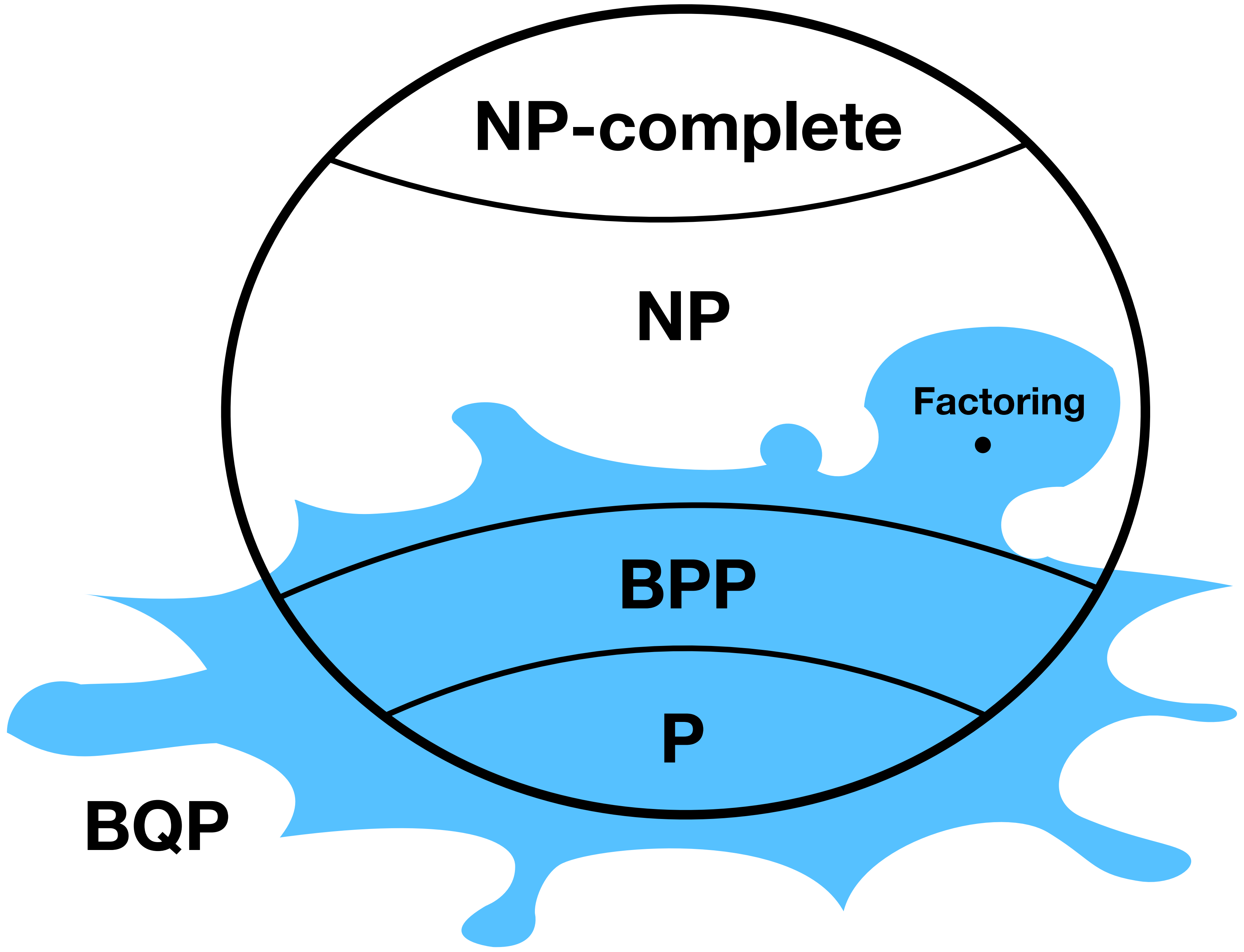

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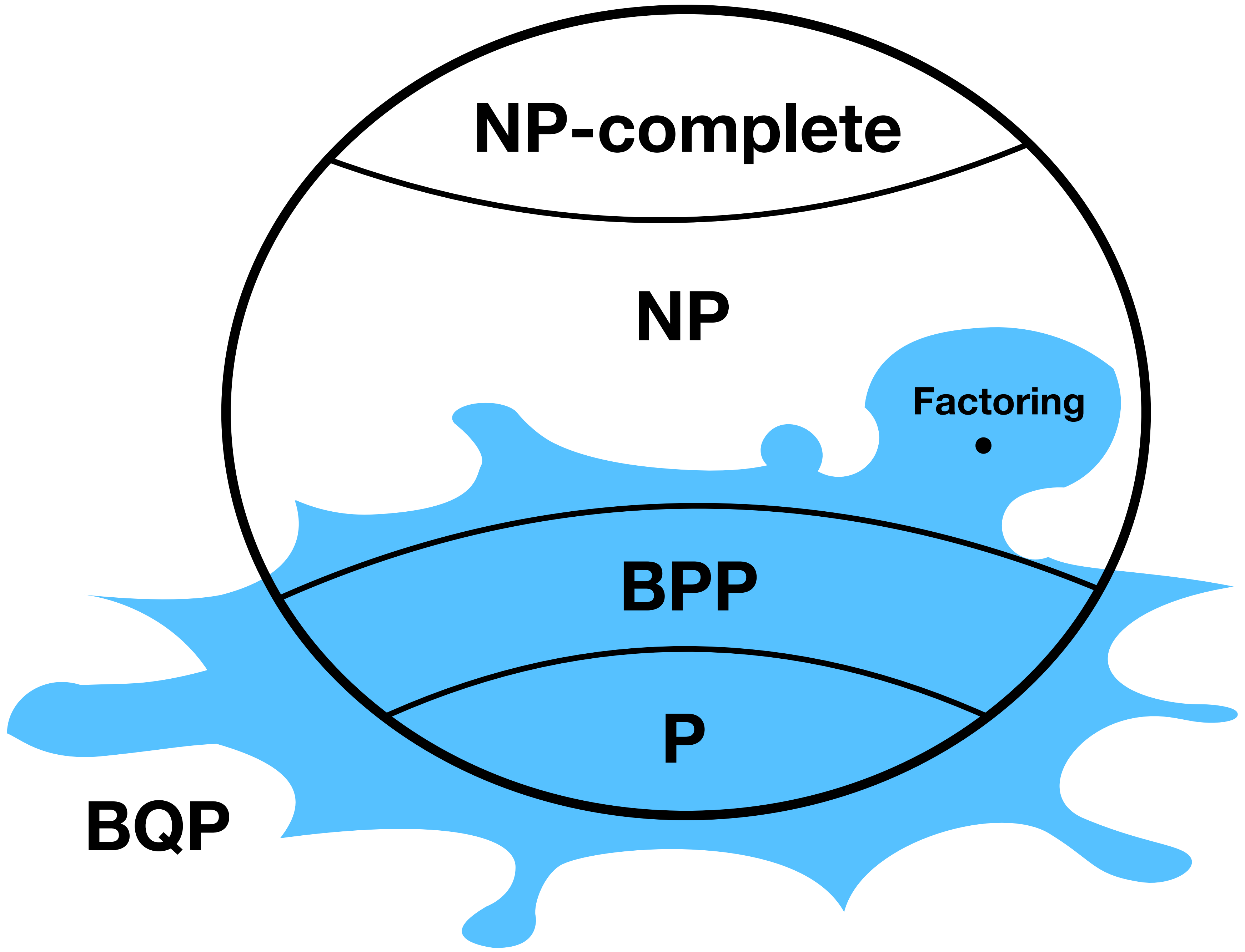
Q: Is BQP realizable? Does quantum computation break ECTT?

From Theory to the Real Physical World

[Shor 1994]: Quantum computer can solve **Factoring** in polynomial time!



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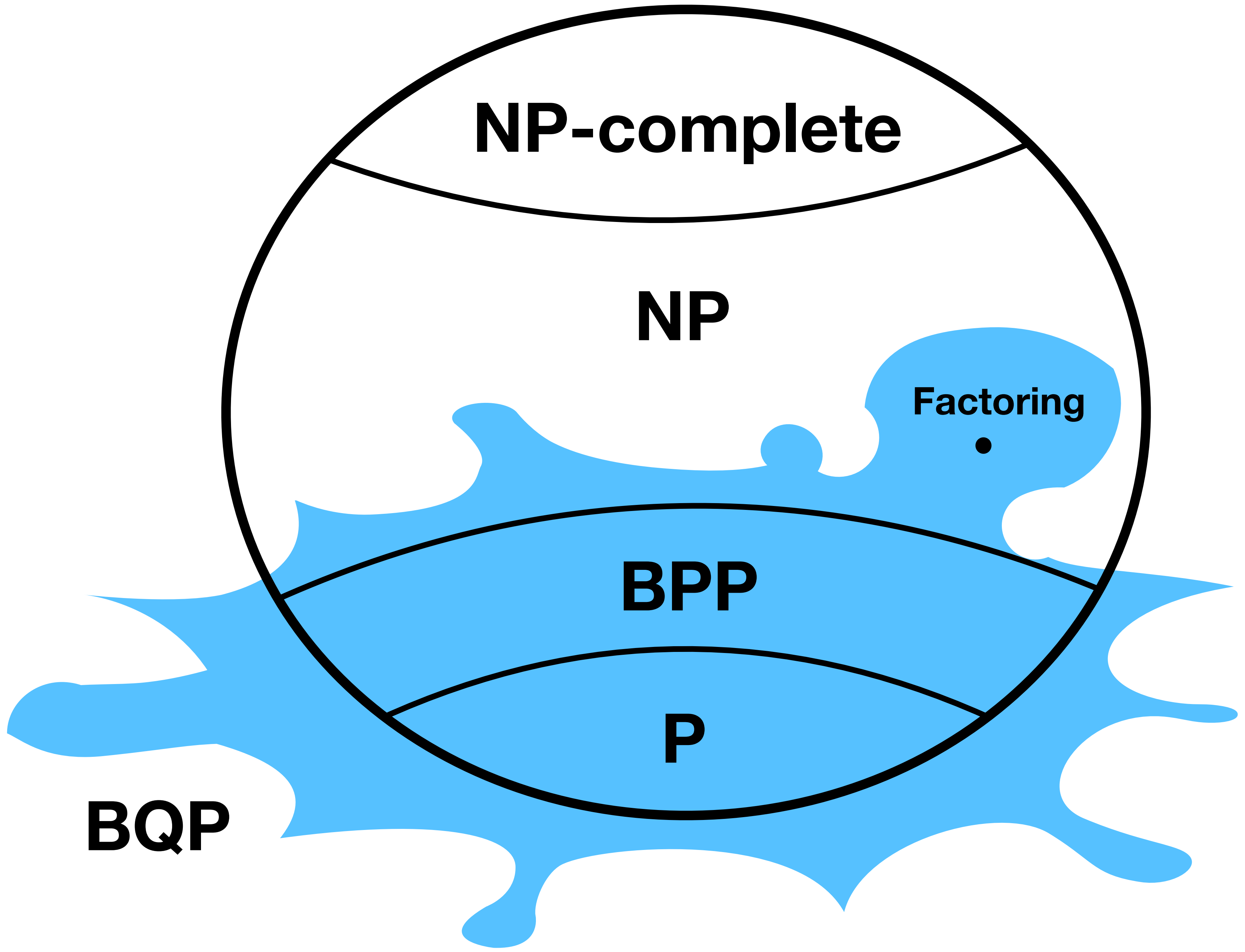

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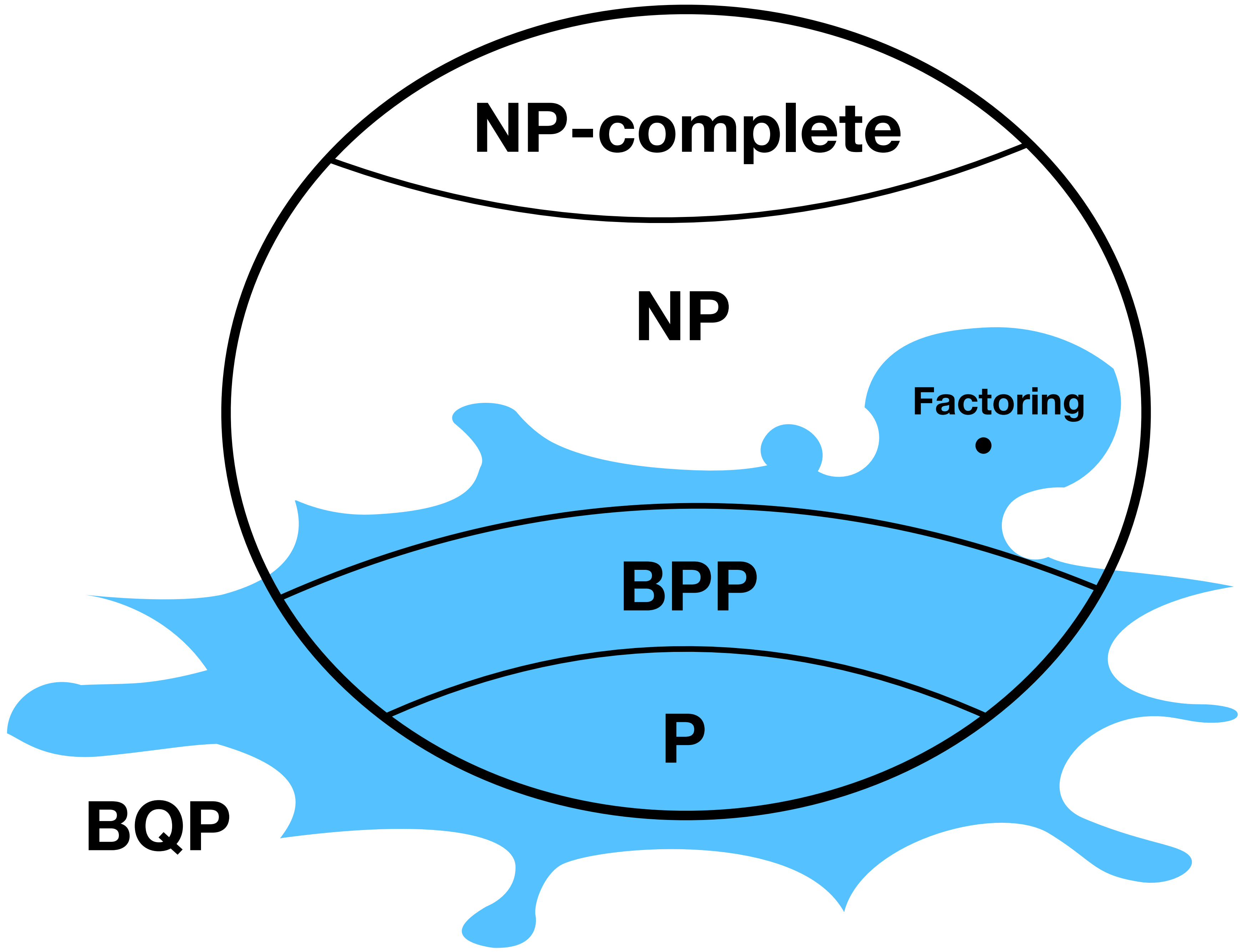

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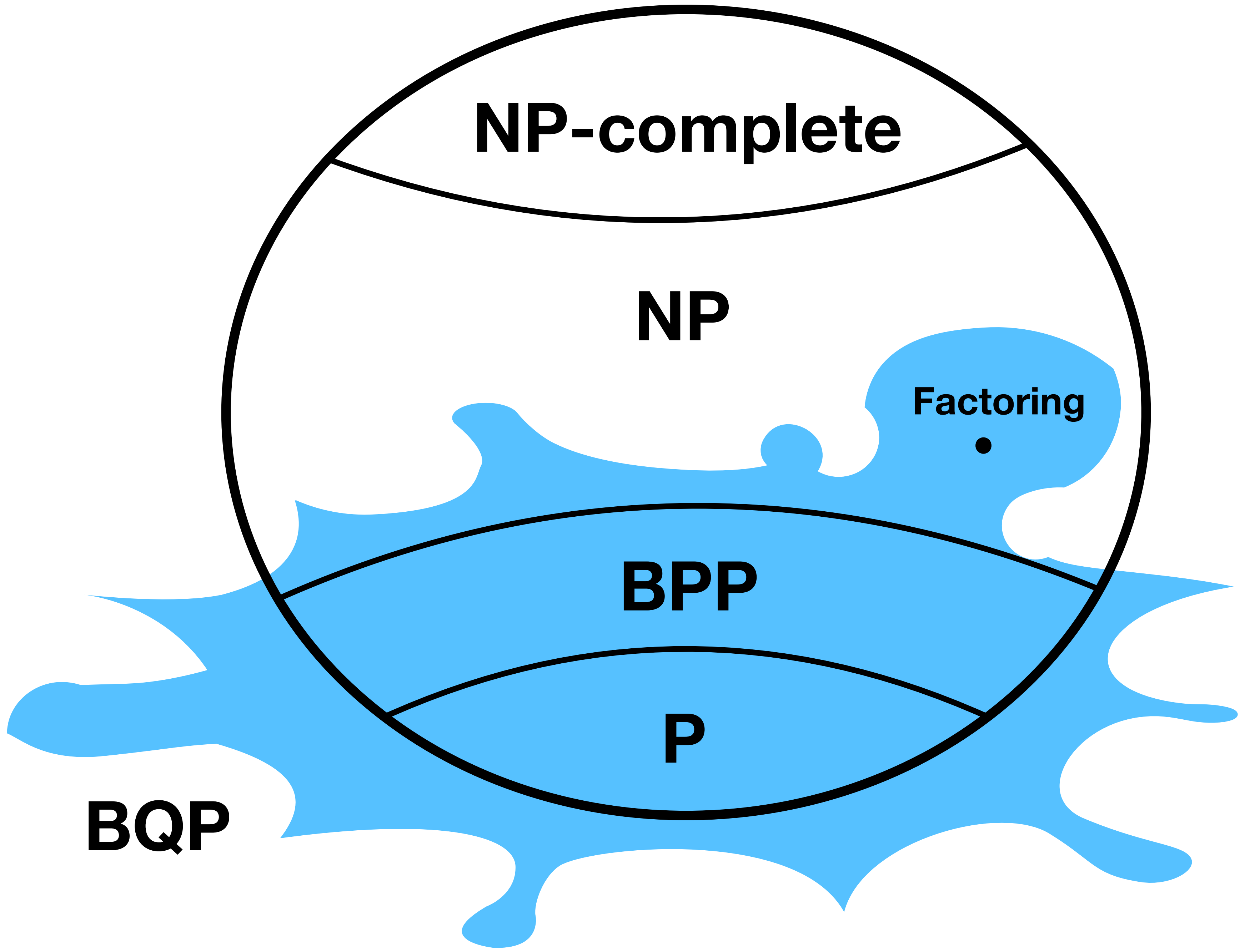

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Q: Can we refute ECTT with near-term technology?

Quantum Computational Supremacy

A compromise between theory and experiment

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Theory

Shor's algorithm

Grover's search

Simon's algorithm

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- Quantum states $|\psi\rangle$.
- Quantum gates U.
- Quantum circuits C.
- Output distribution q_C.

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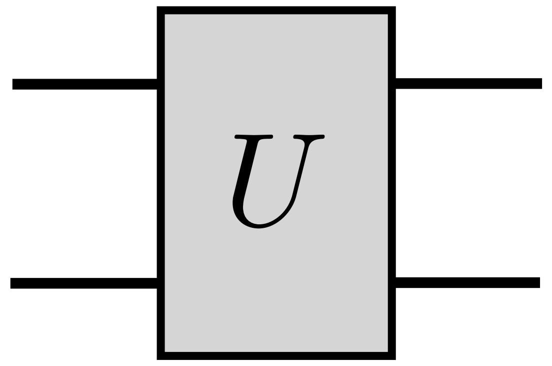

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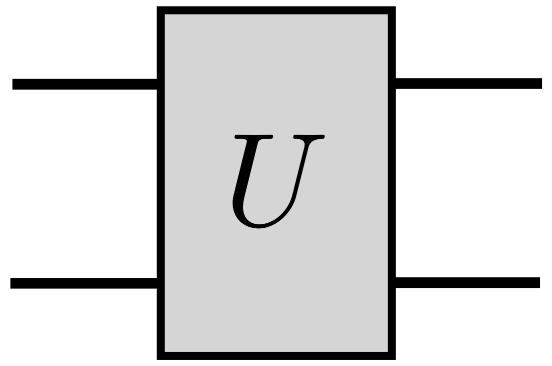

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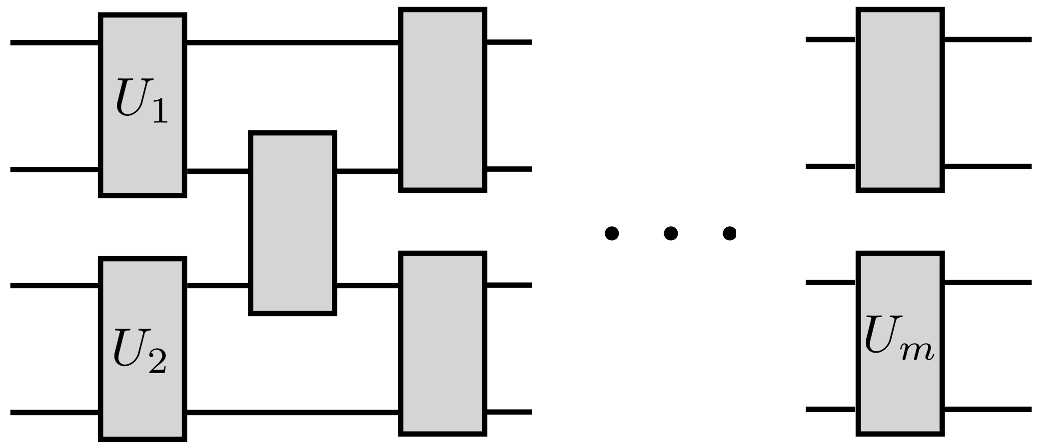

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circuit with 1- and 2-qubit gates — 2^n by 2^n unitary matrix

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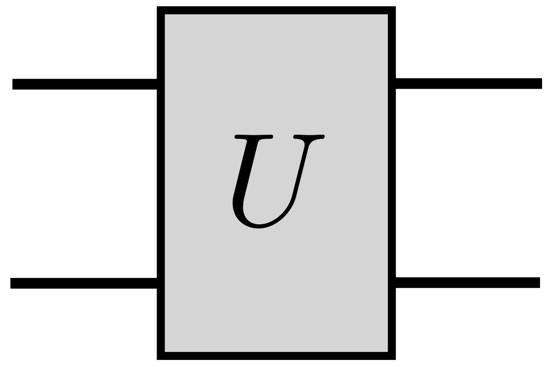

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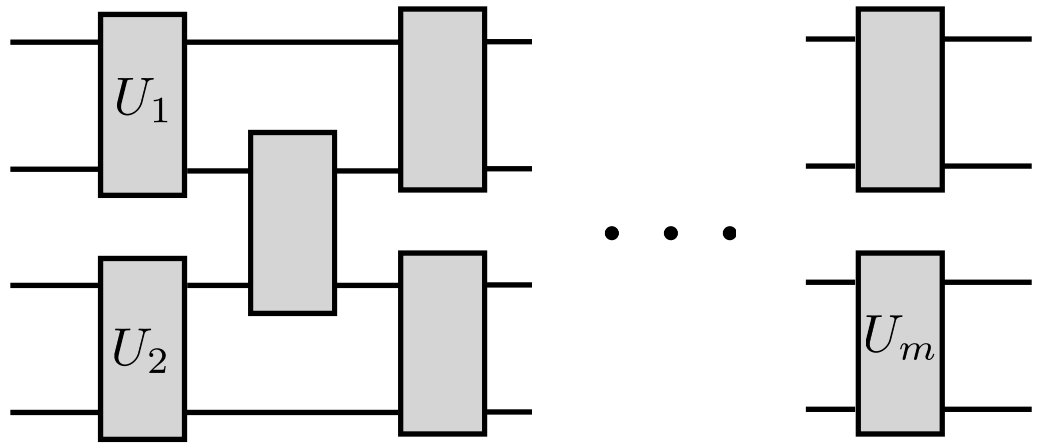

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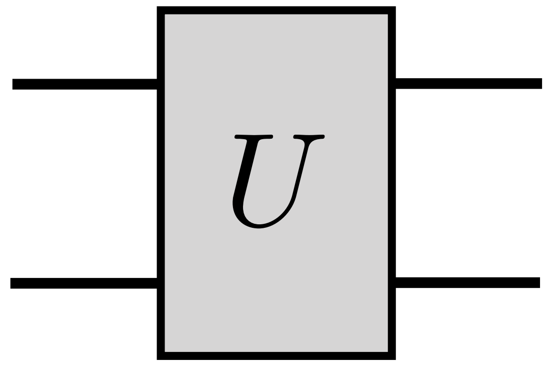

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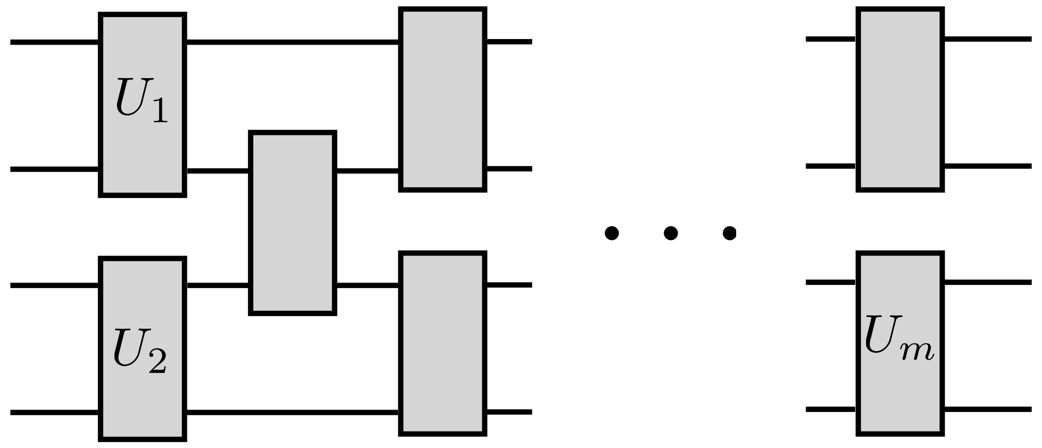

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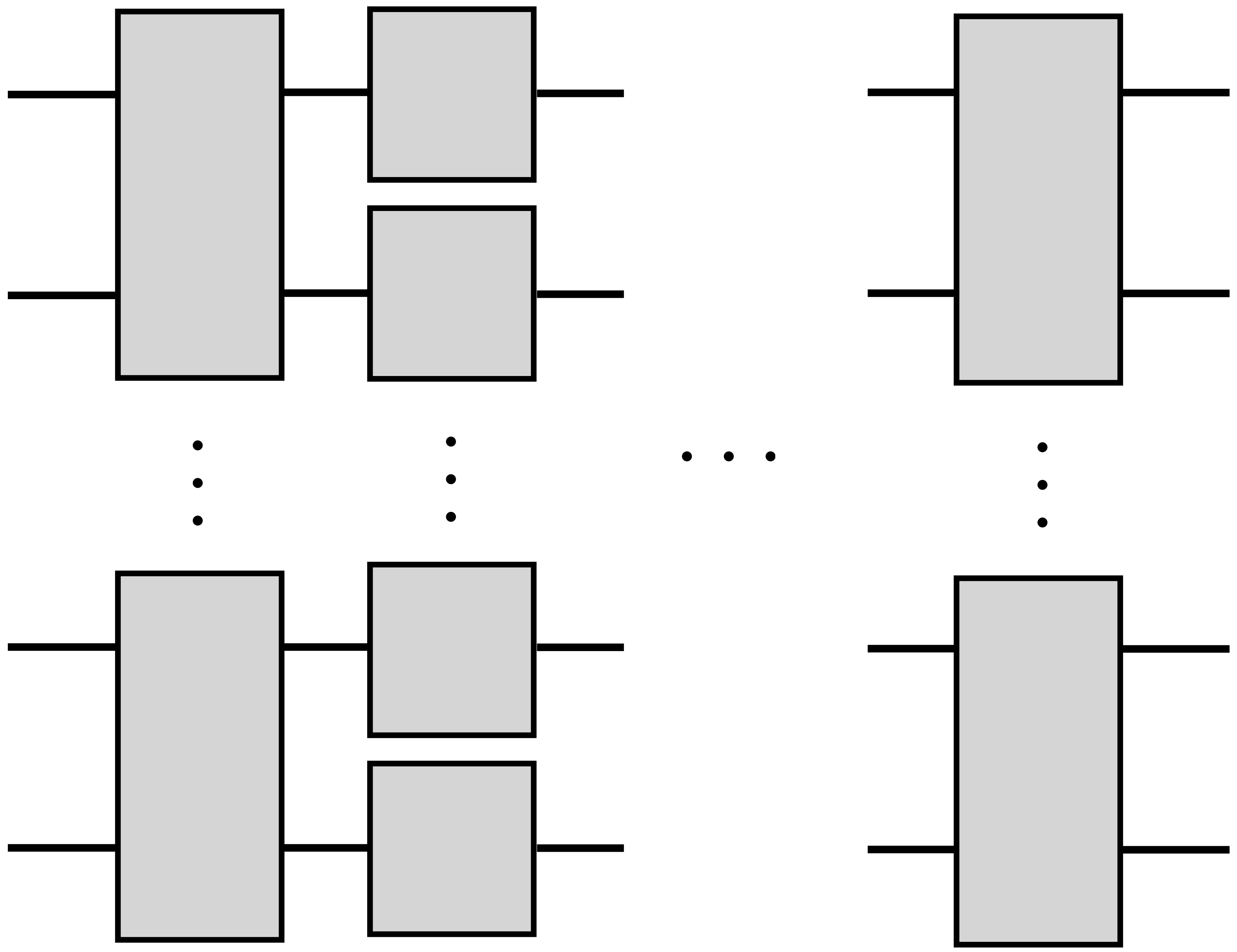
Random Circuit Sampling

The lead-candidate used by Google's Sycamore



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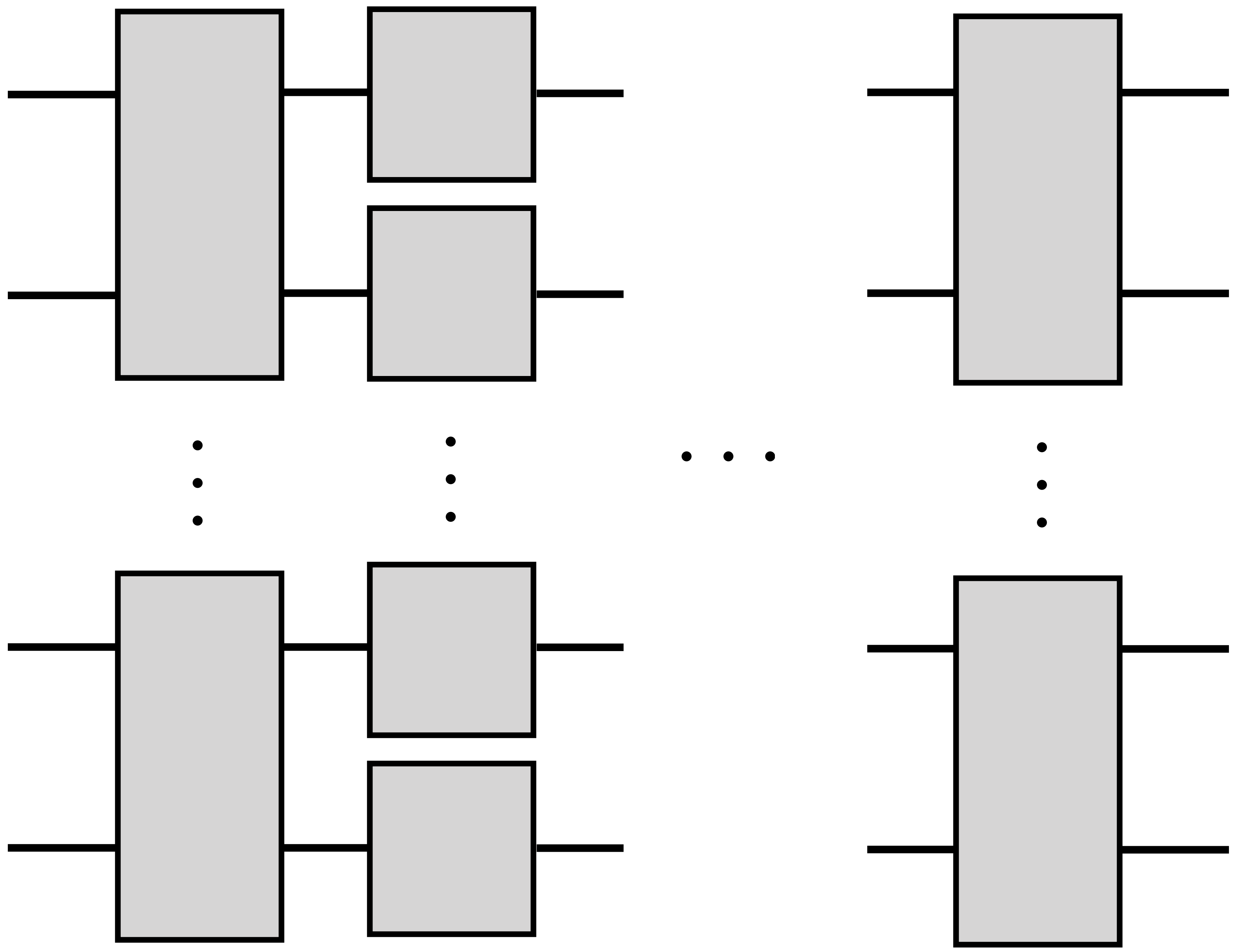

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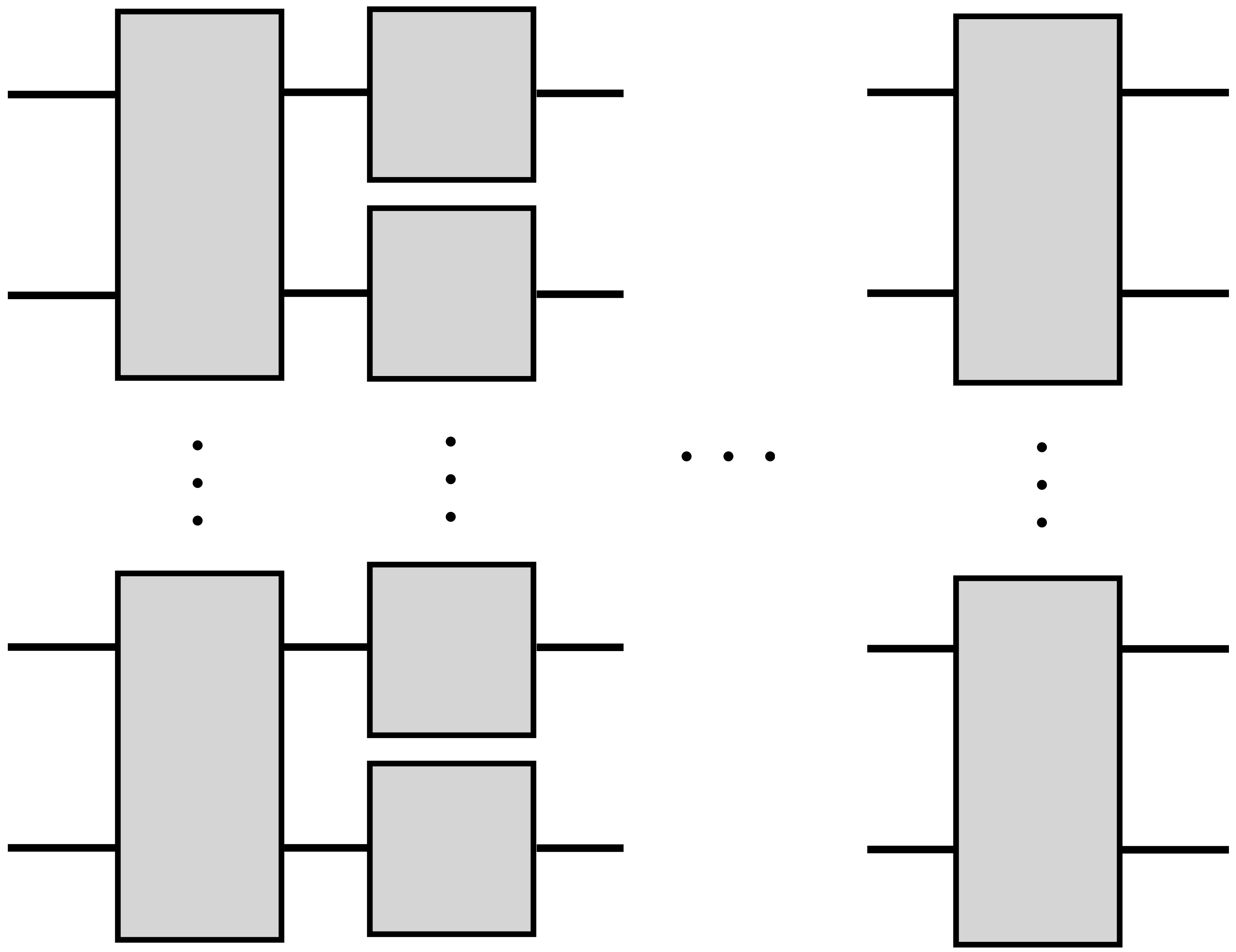

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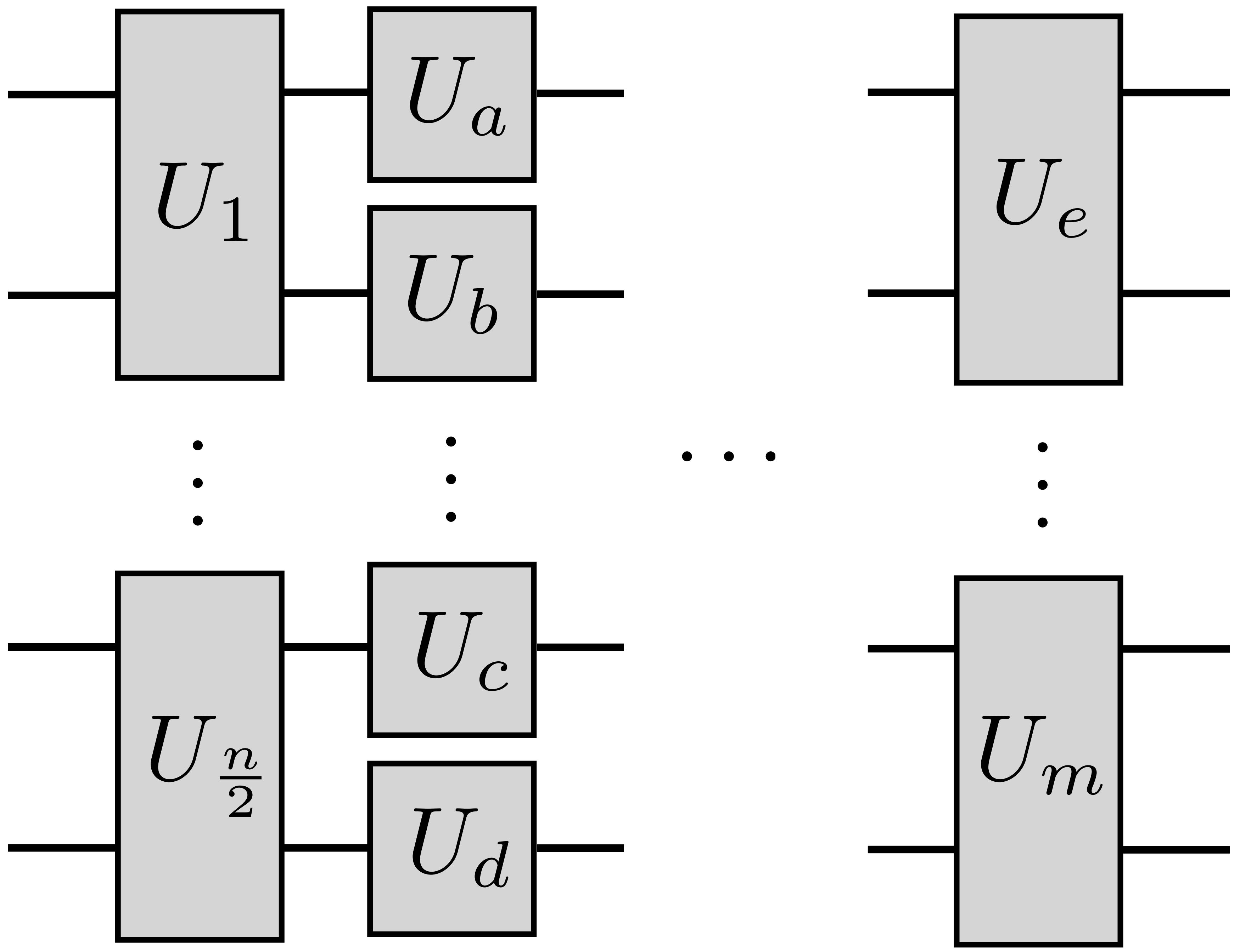

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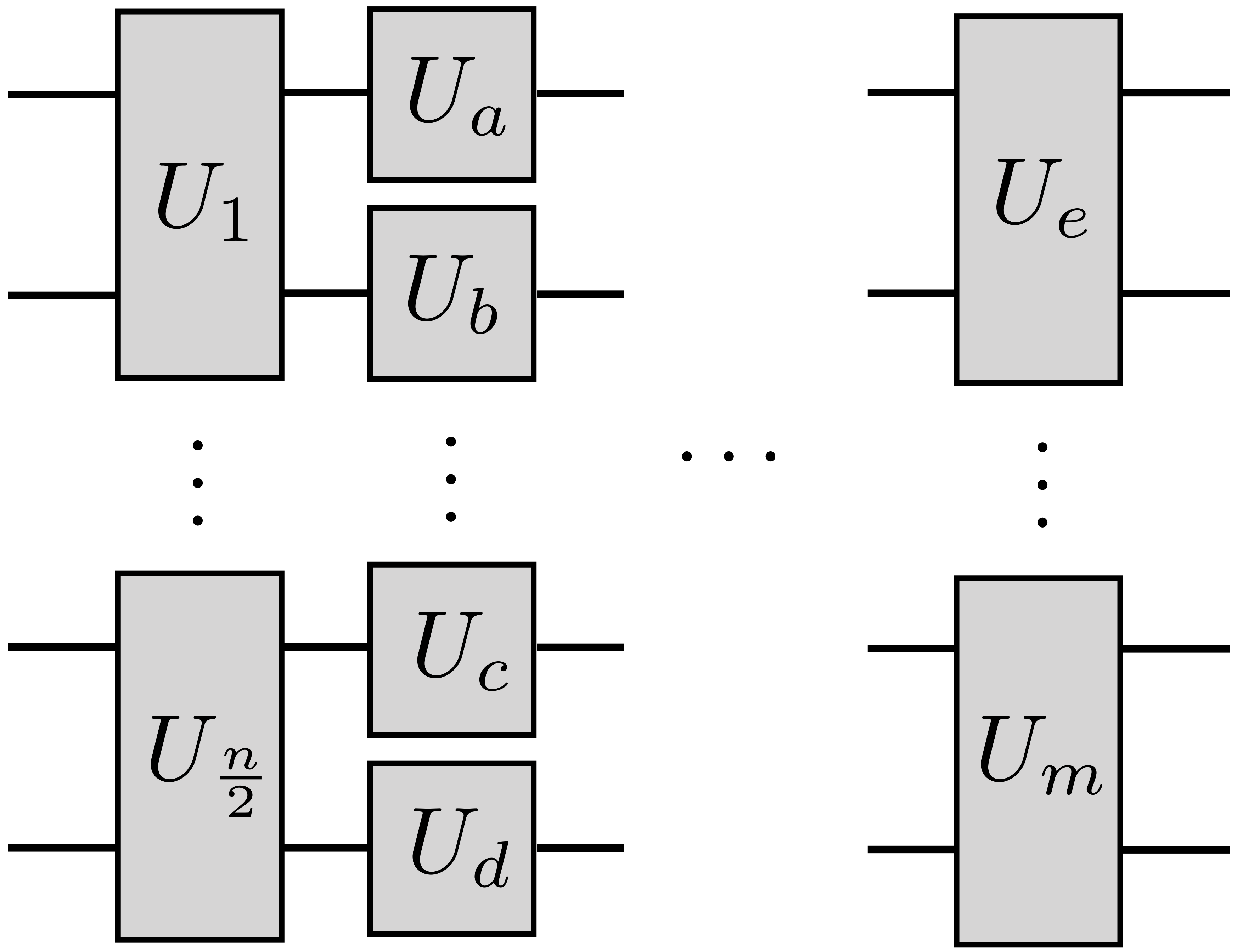

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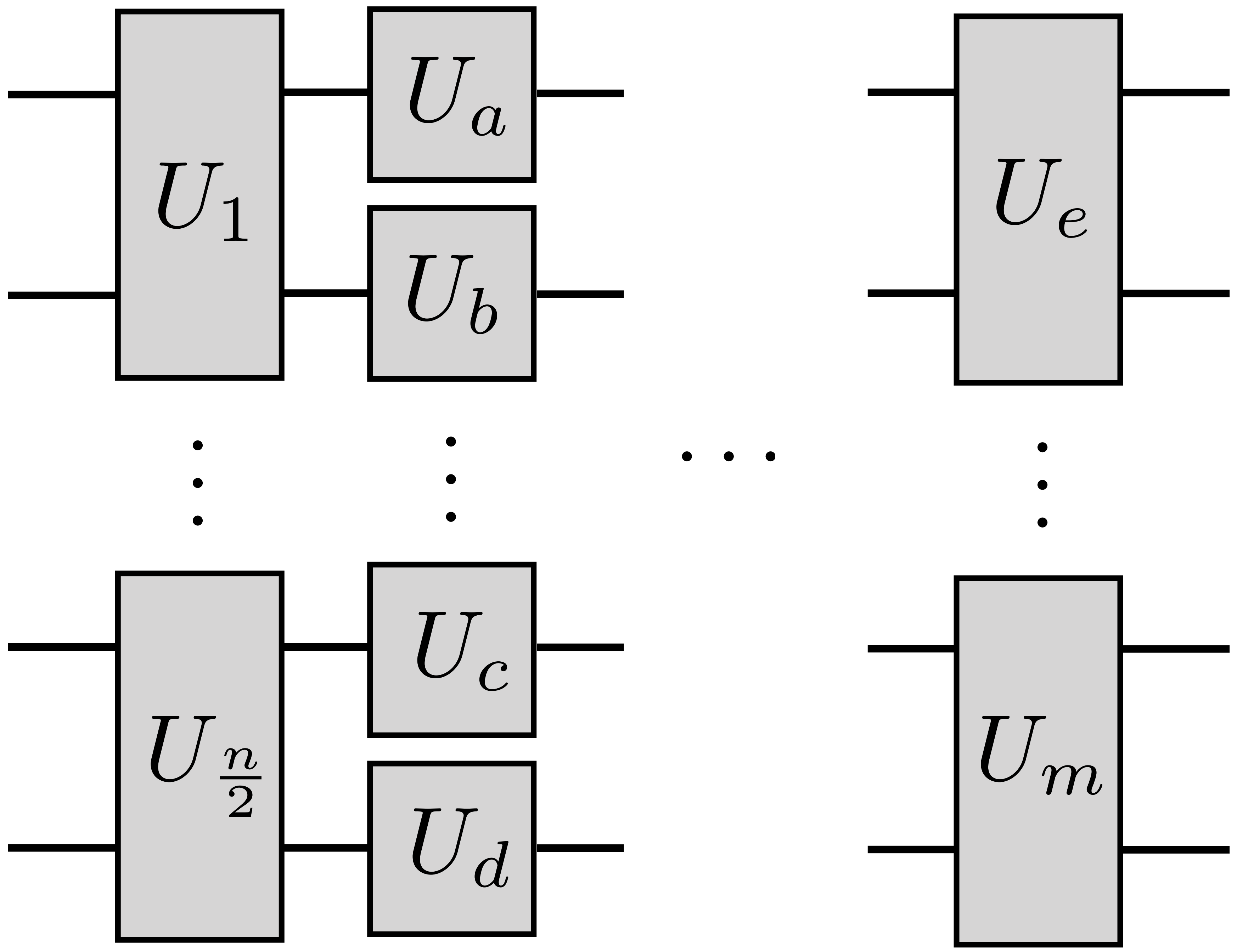

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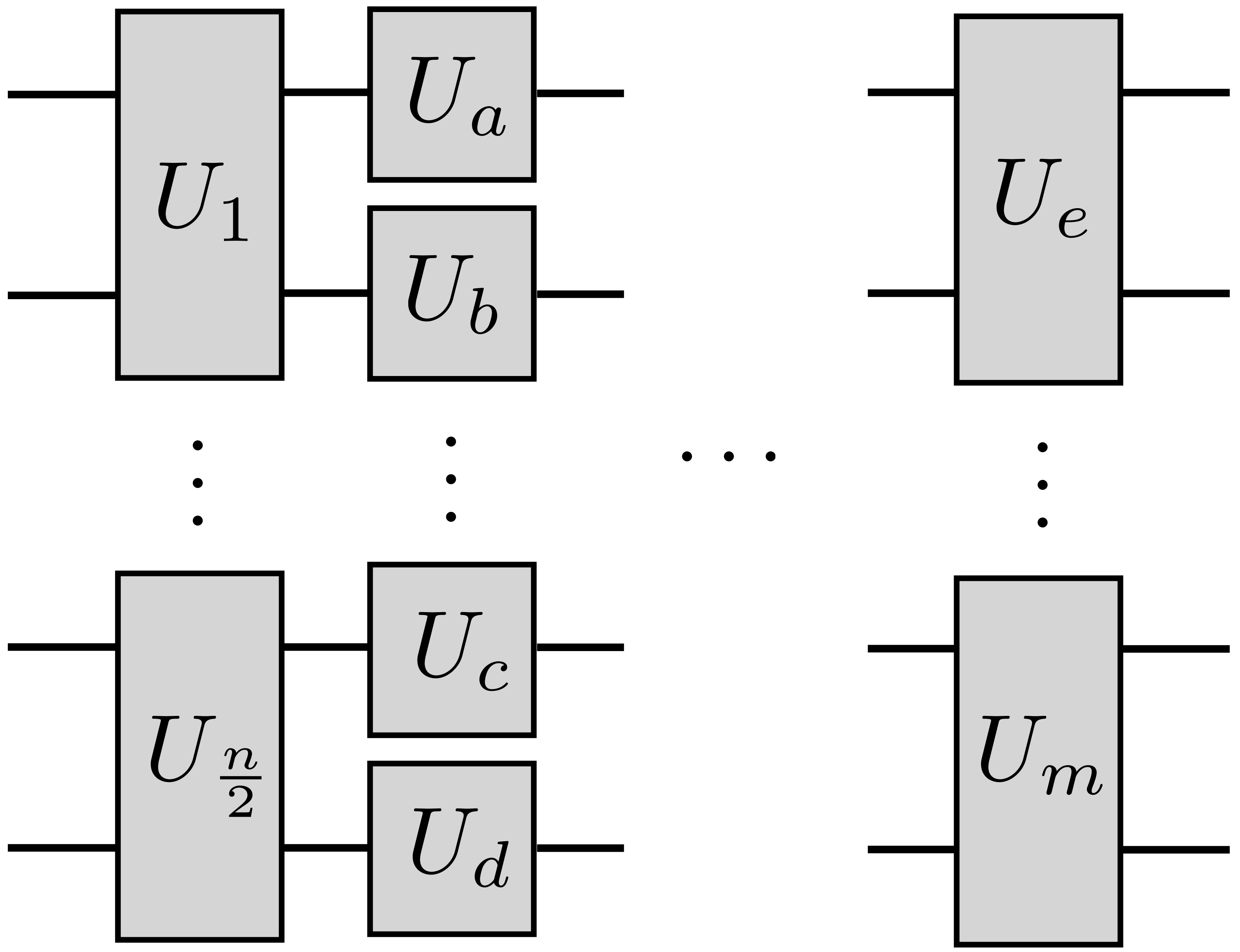

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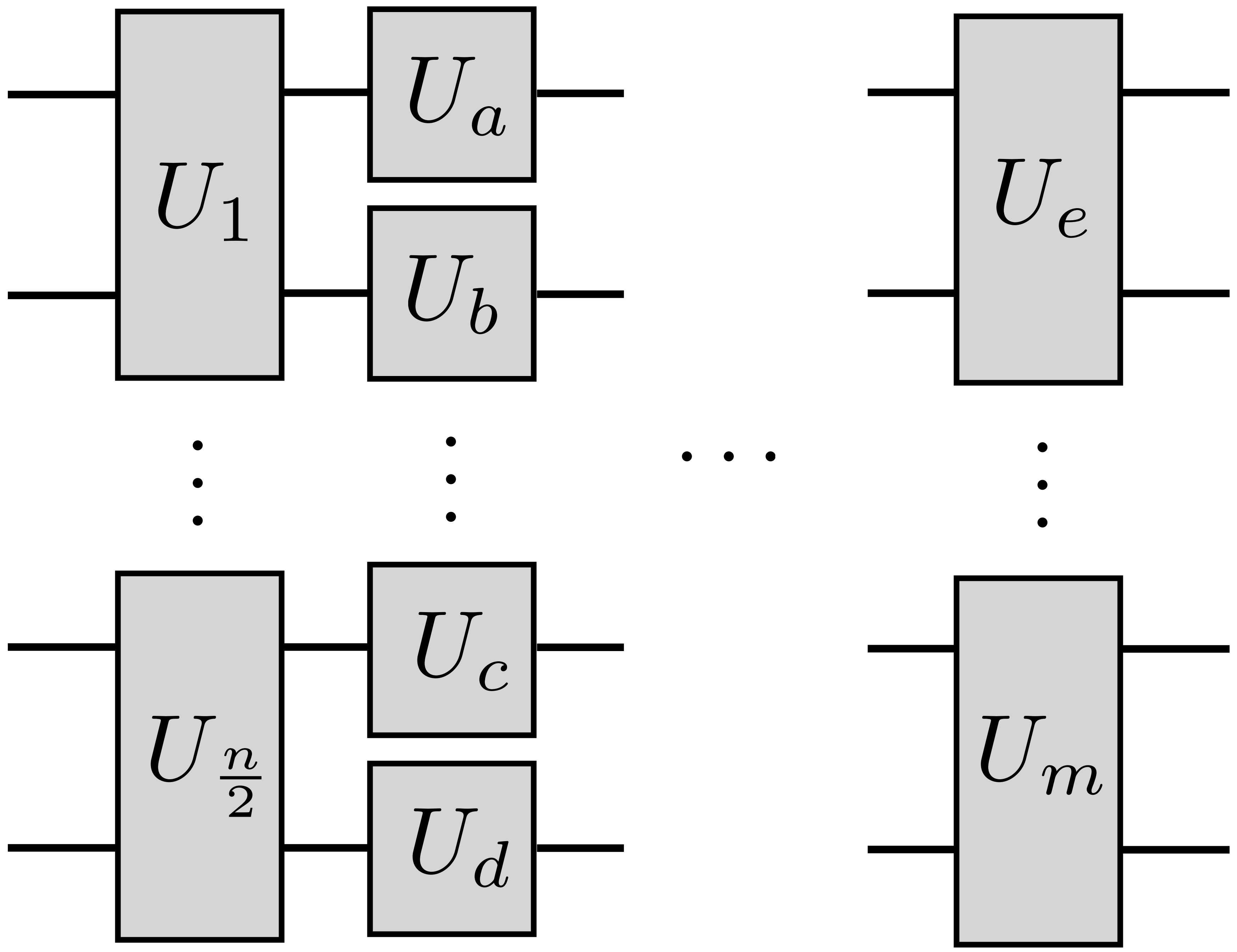

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Intuition: Without quantumness, the prover requires exponential time!?

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- **Soundness:** If the distribution came from a classical device, then reject w.h.p.

Linear Cross-Entropy Benchmarking

A statistic for verifying RCS-based quantum supremacy

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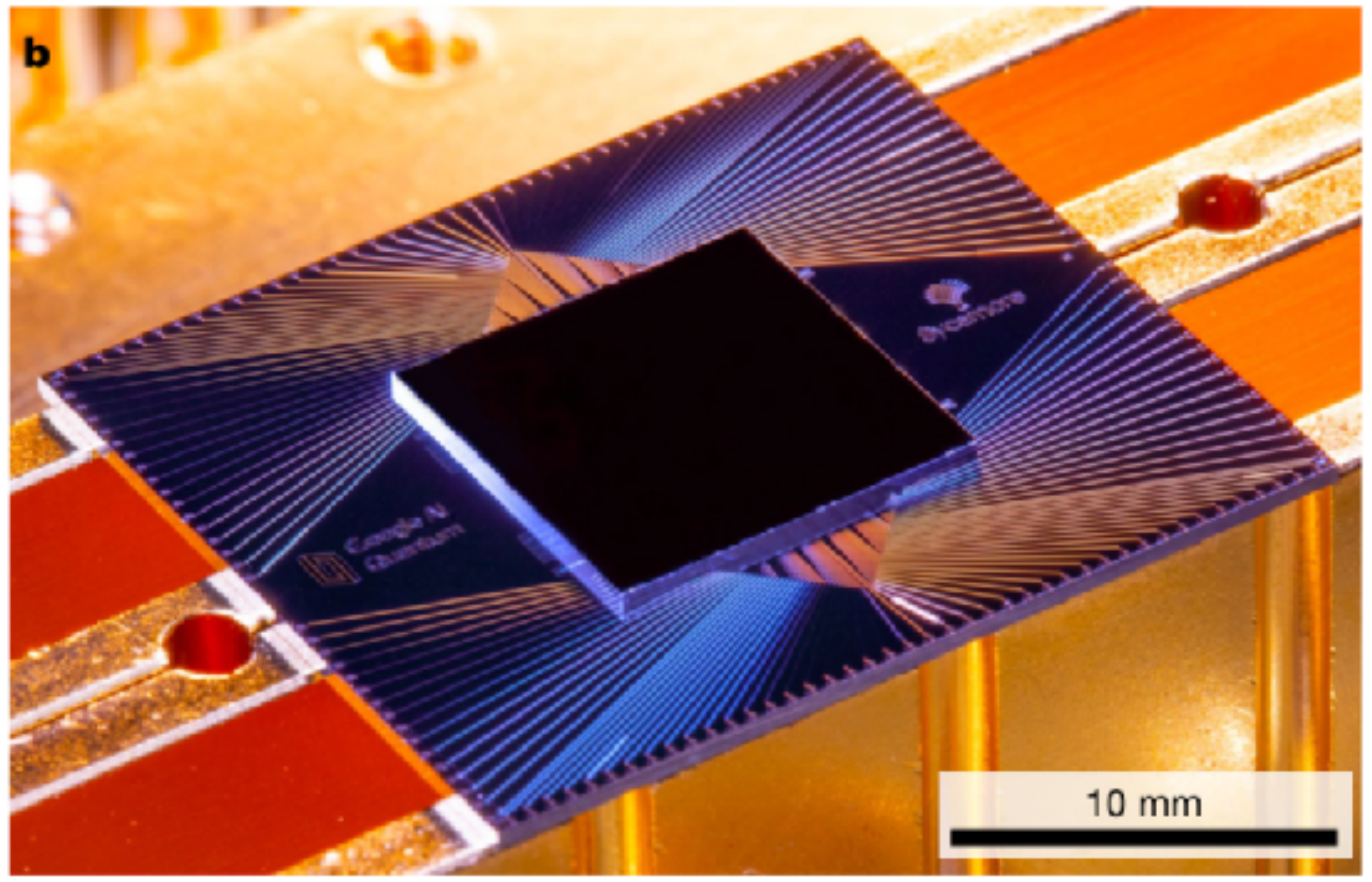

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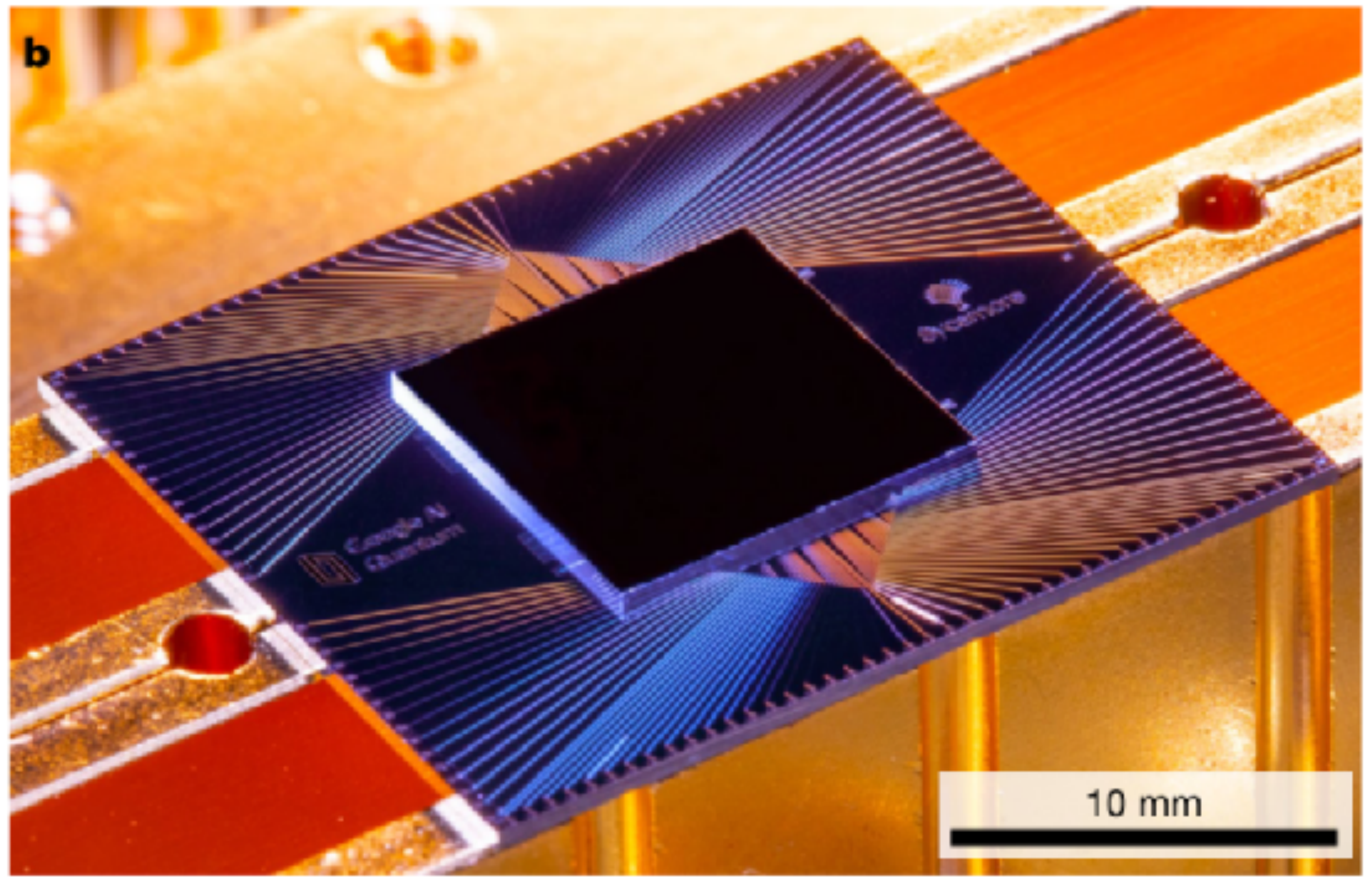

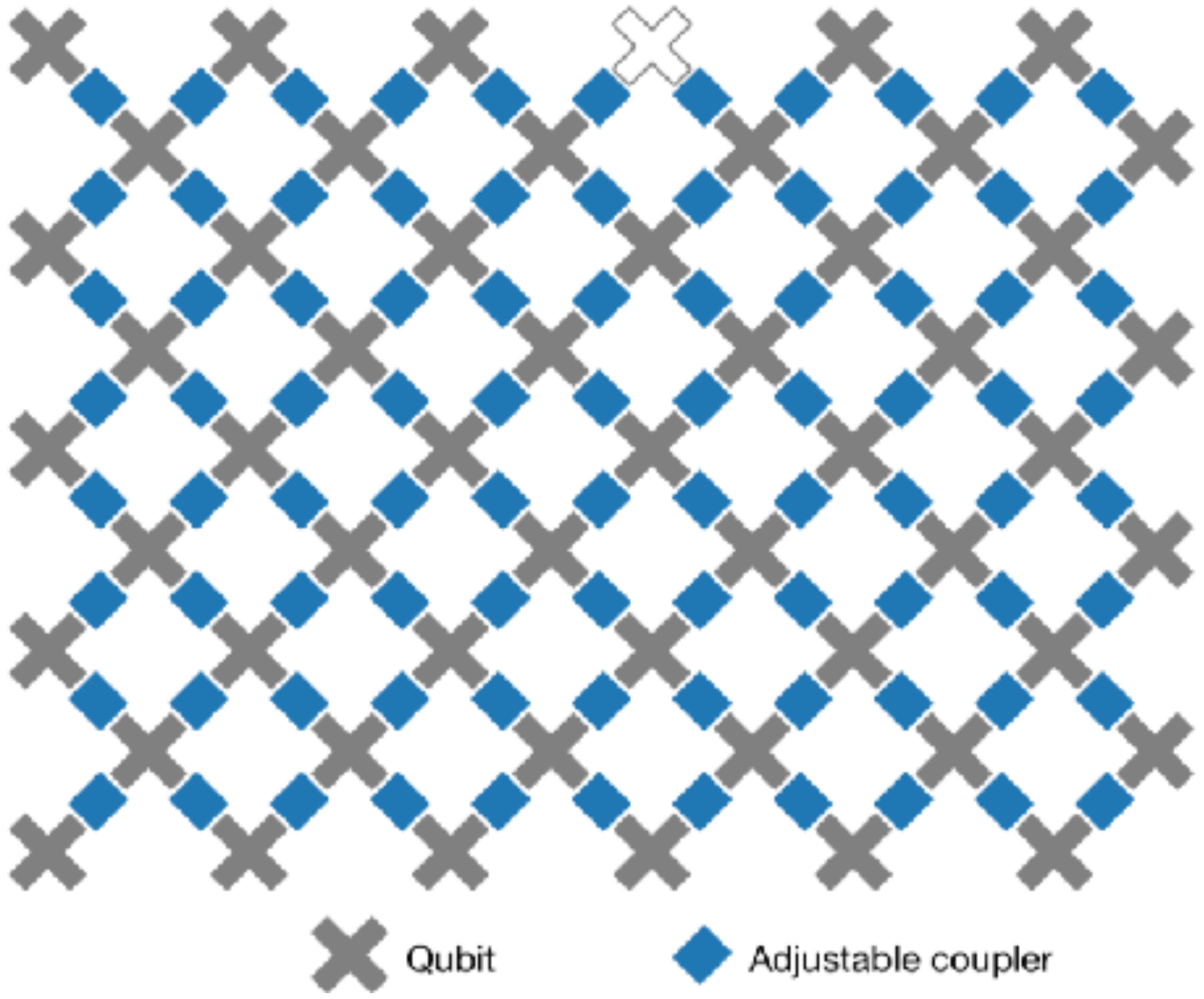

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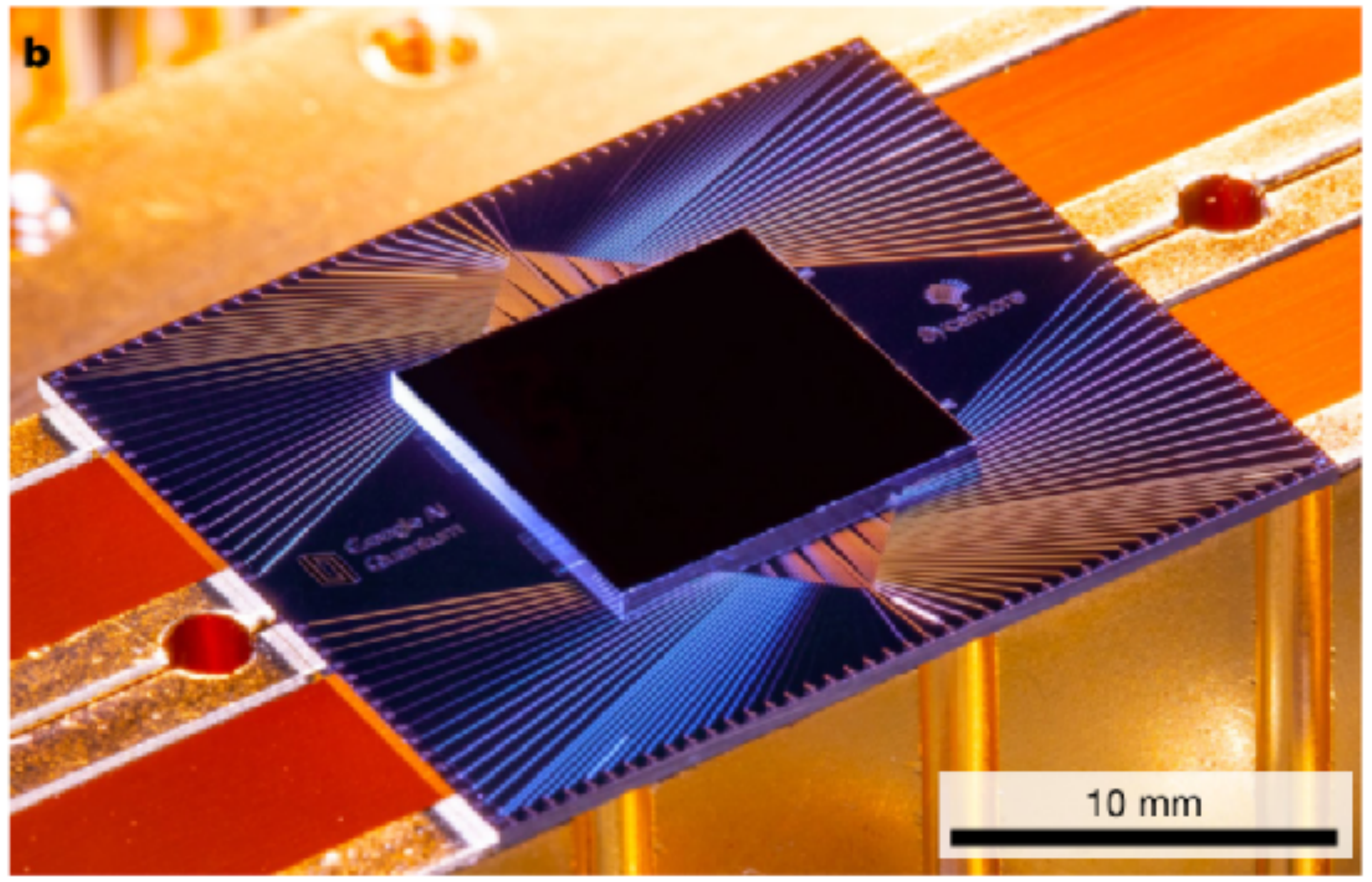

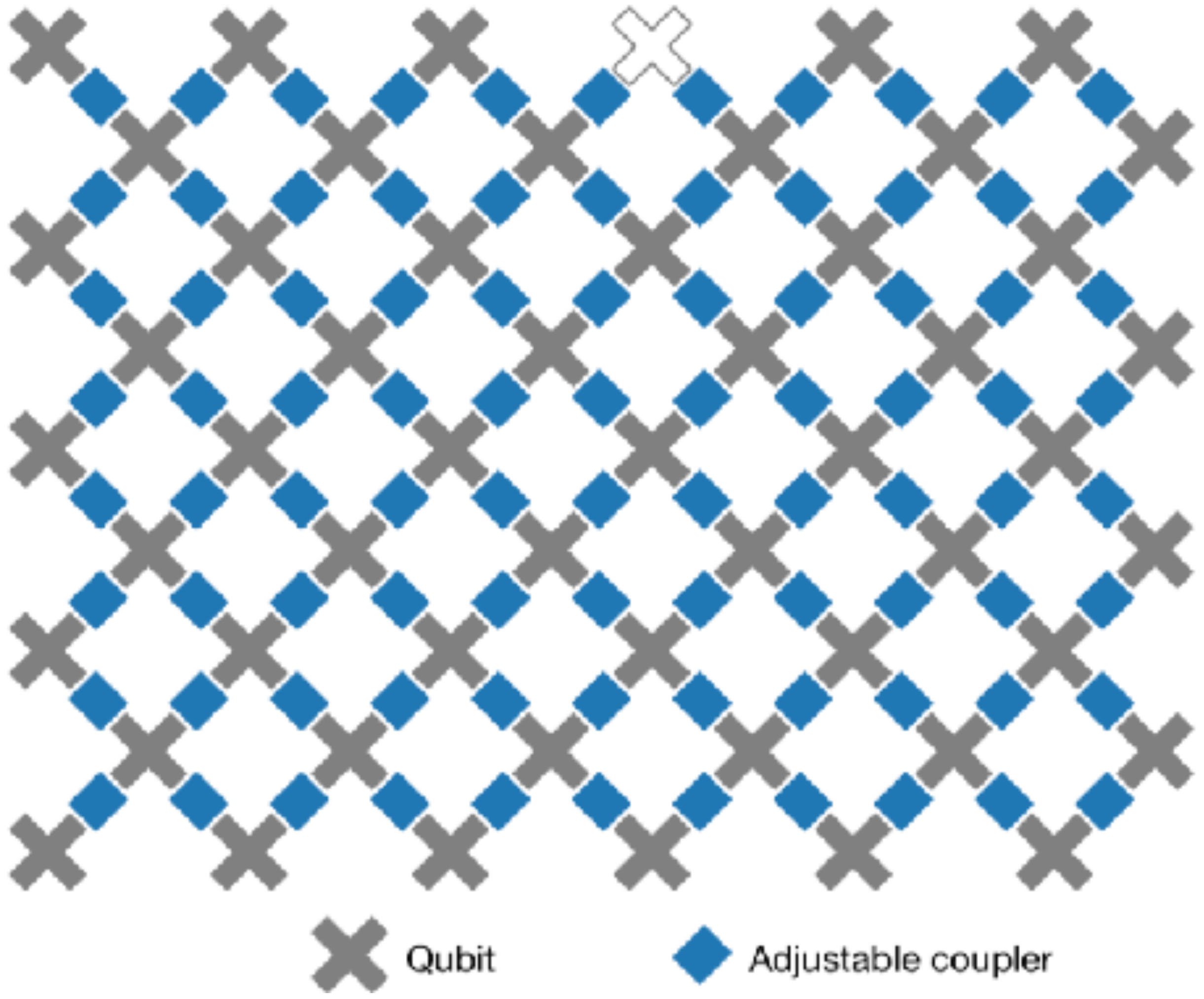

- 2D nearest neighbors circuit.

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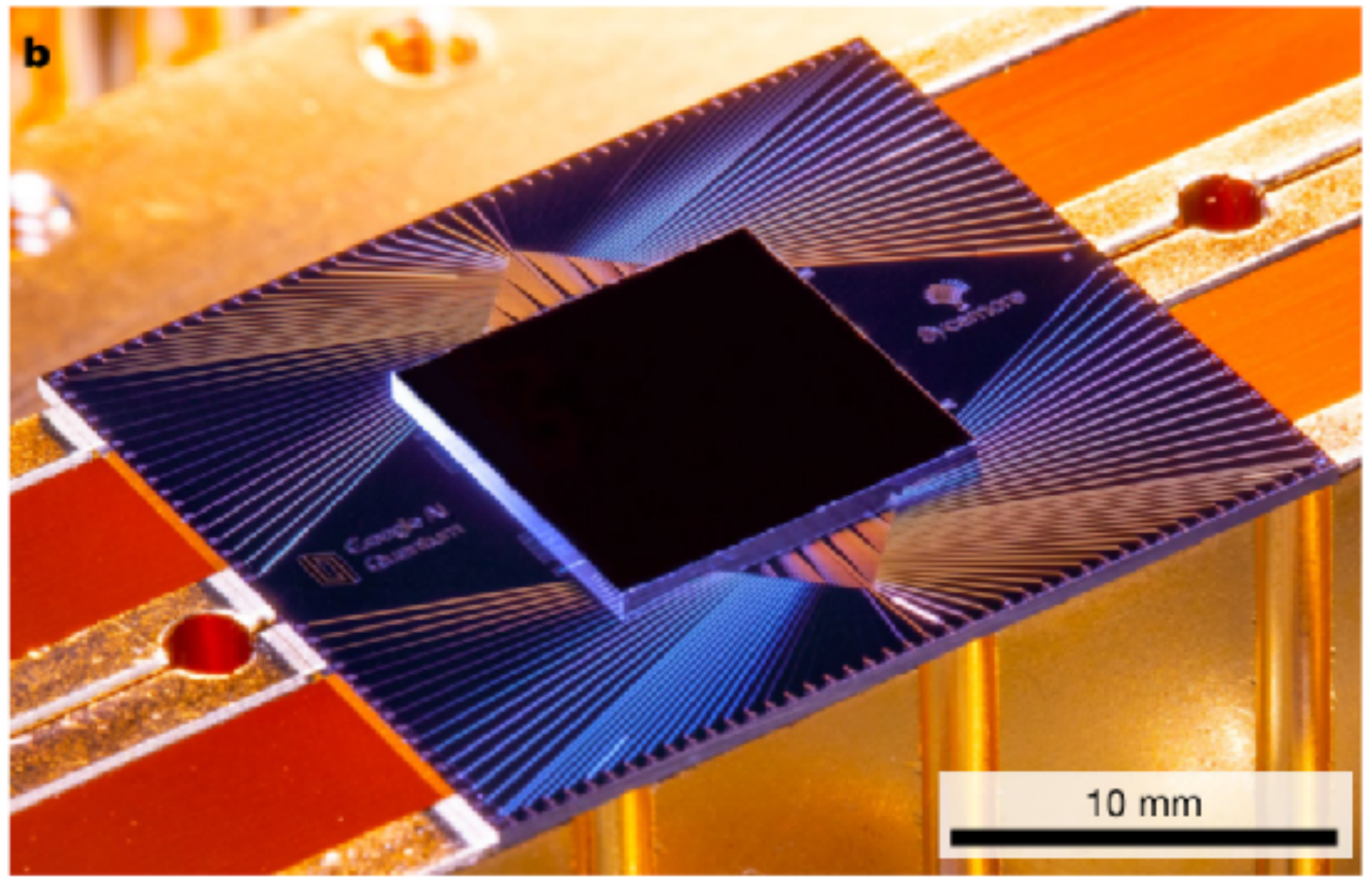

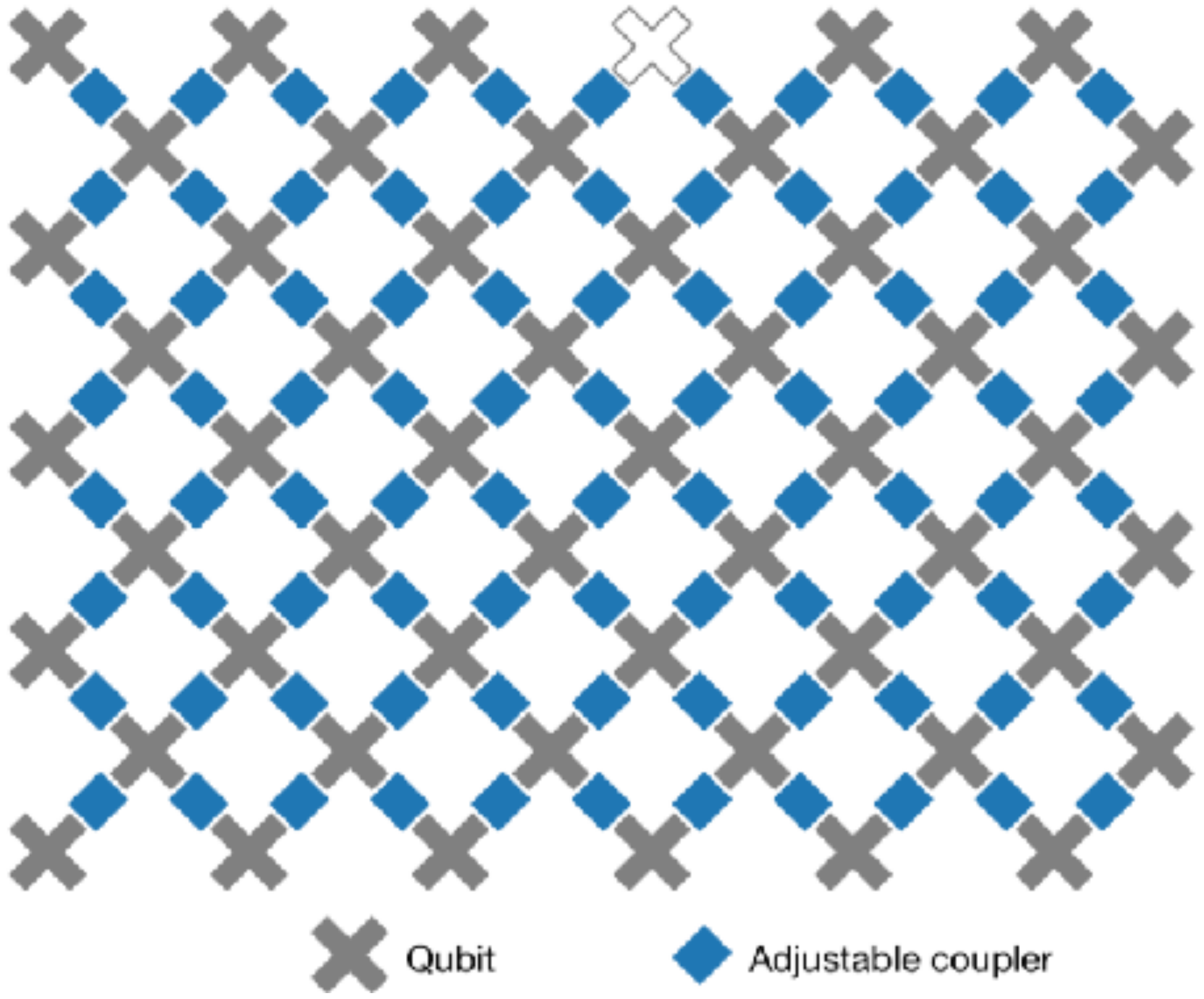

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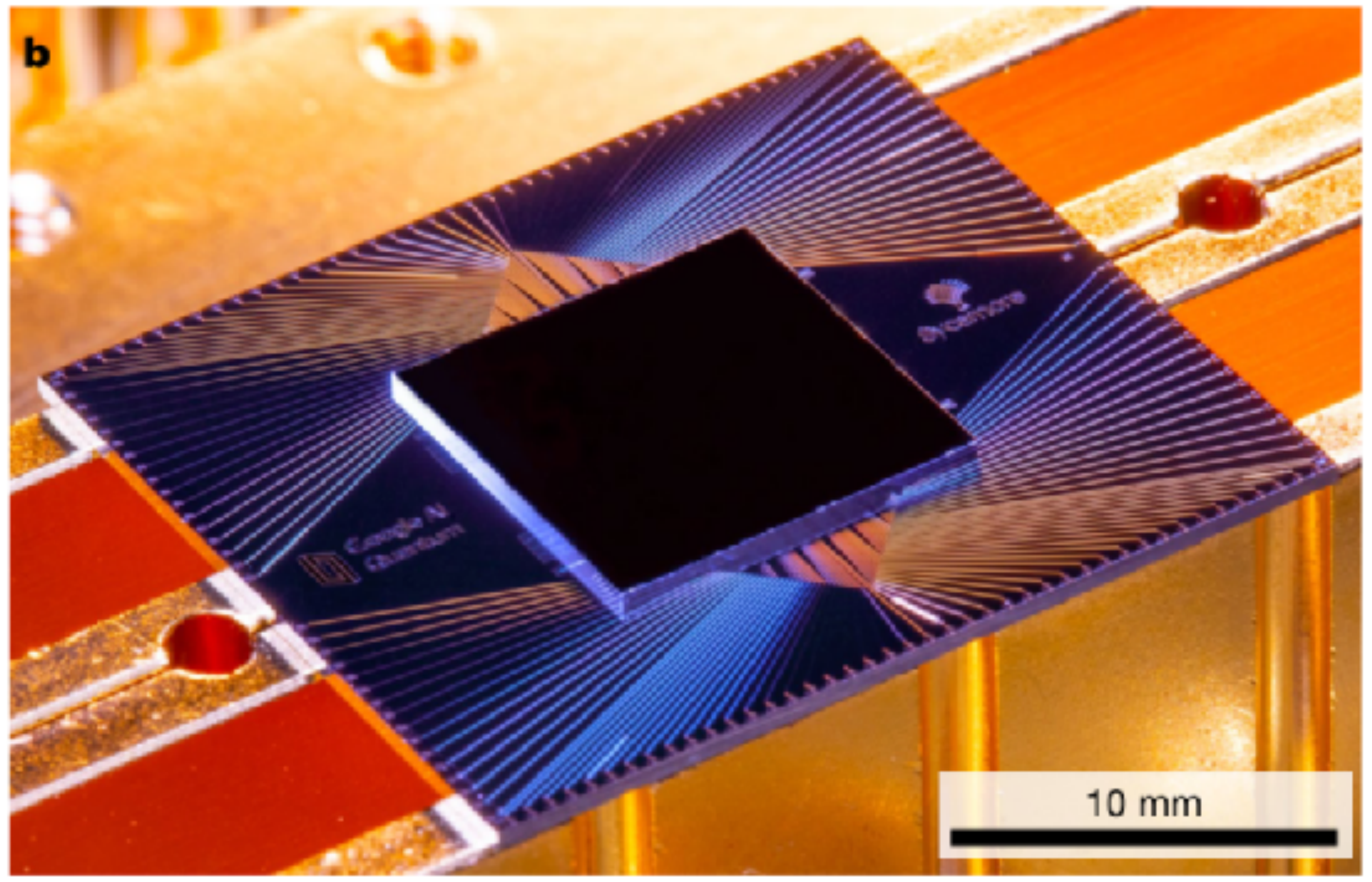

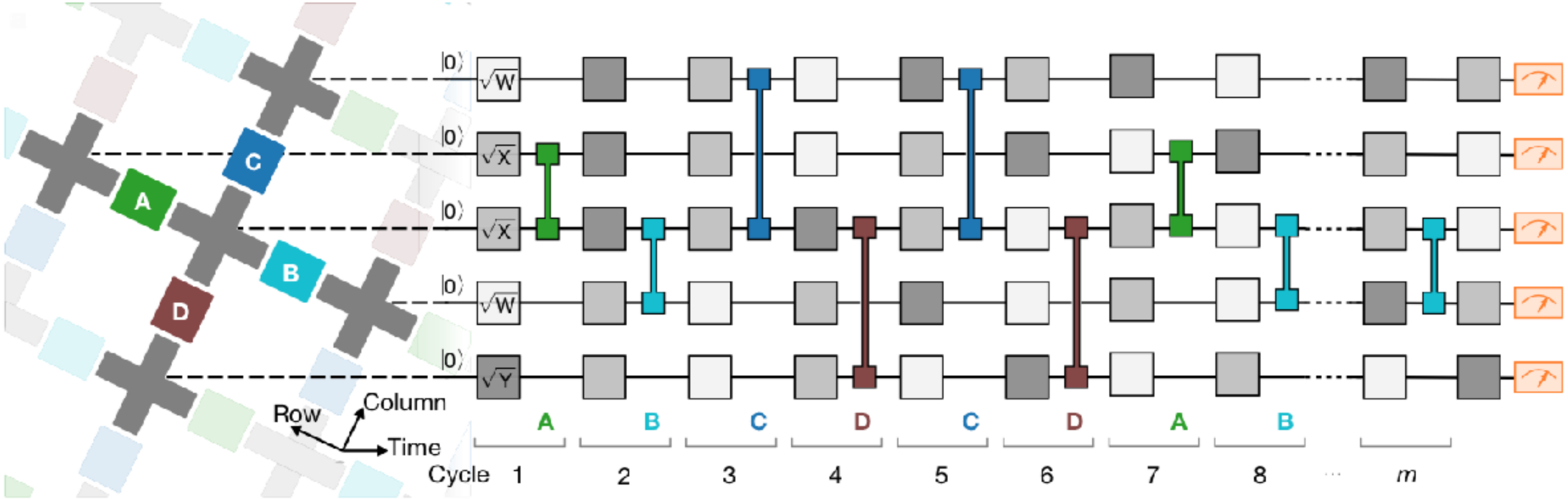

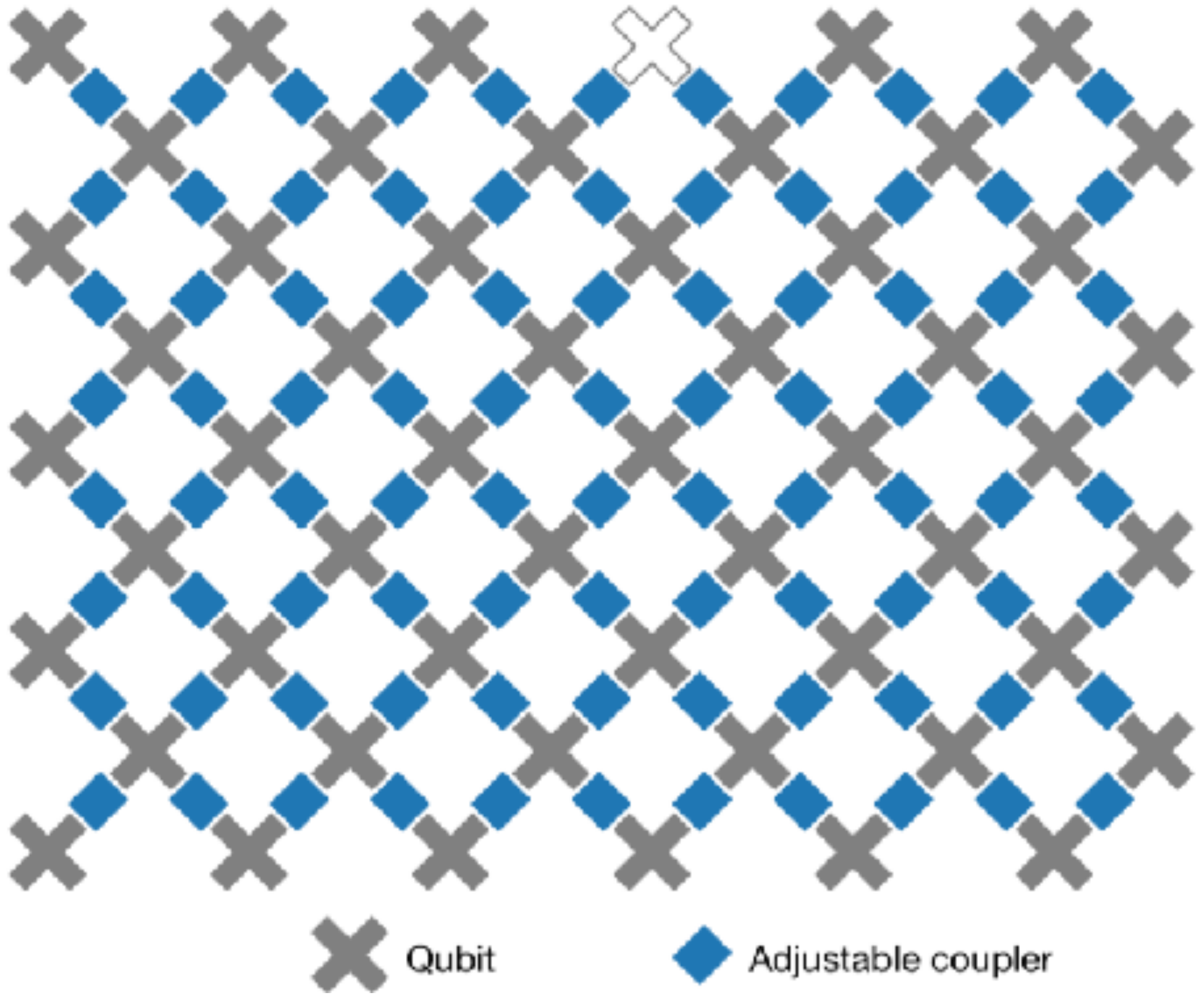

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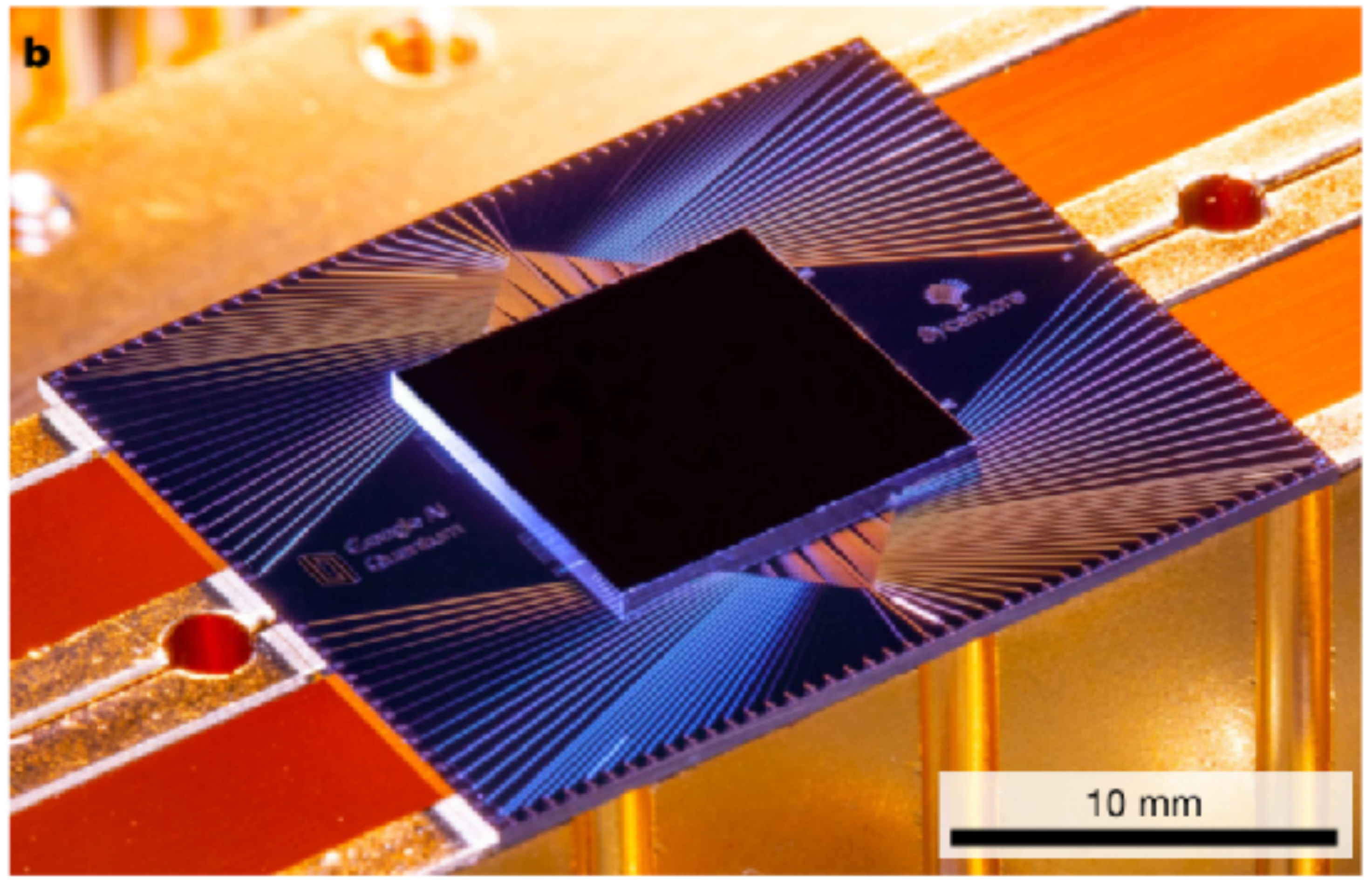

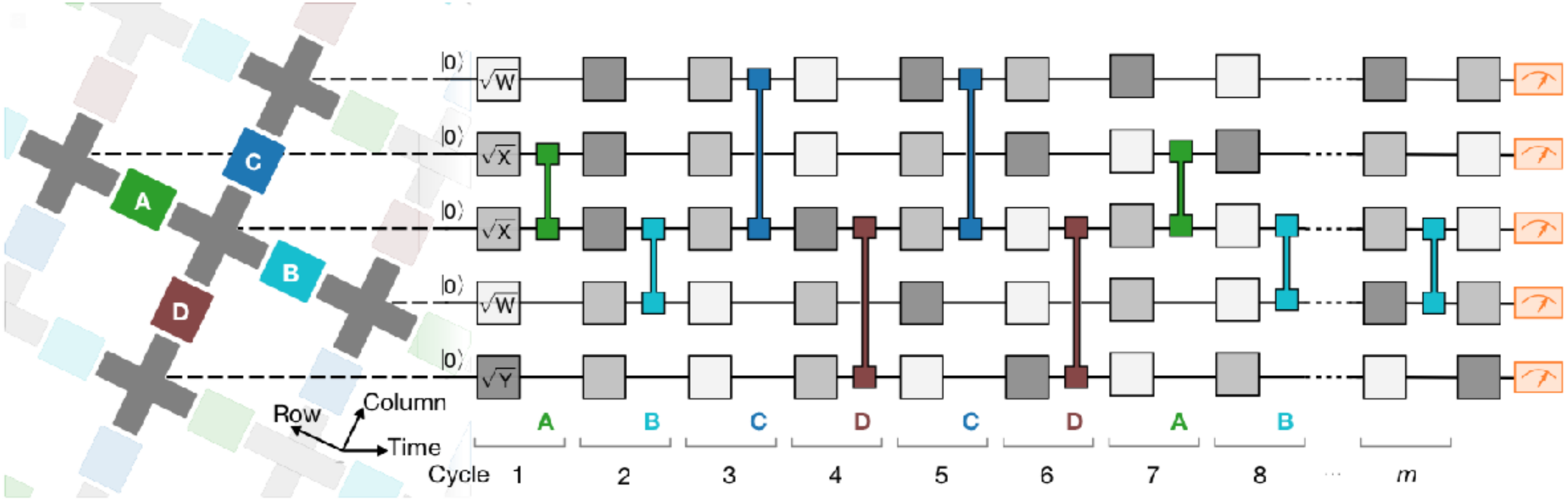

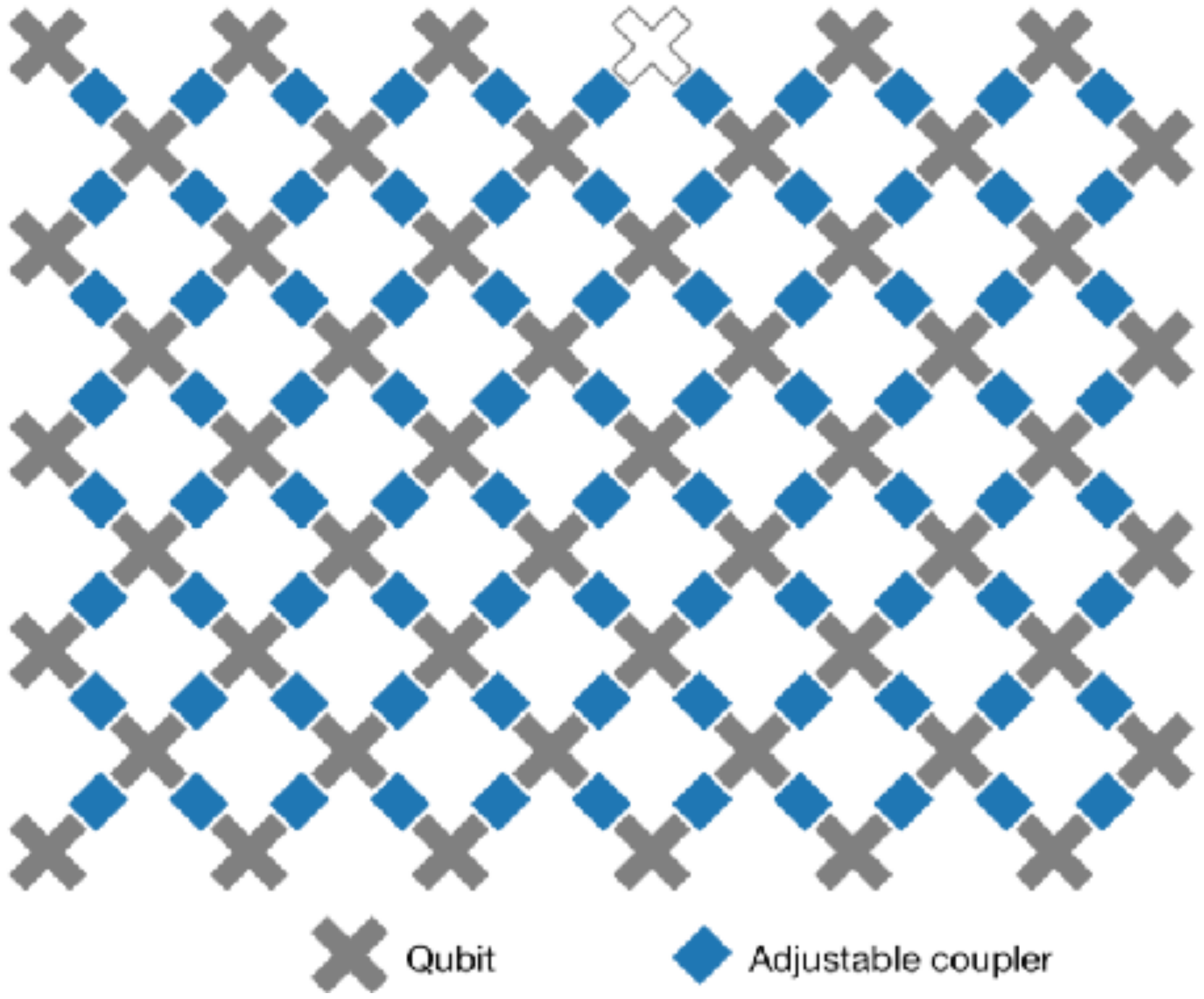

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- Depth: from 14 to 20.

* We use *m* for # gates but in Google's paper *m* denotes depth.

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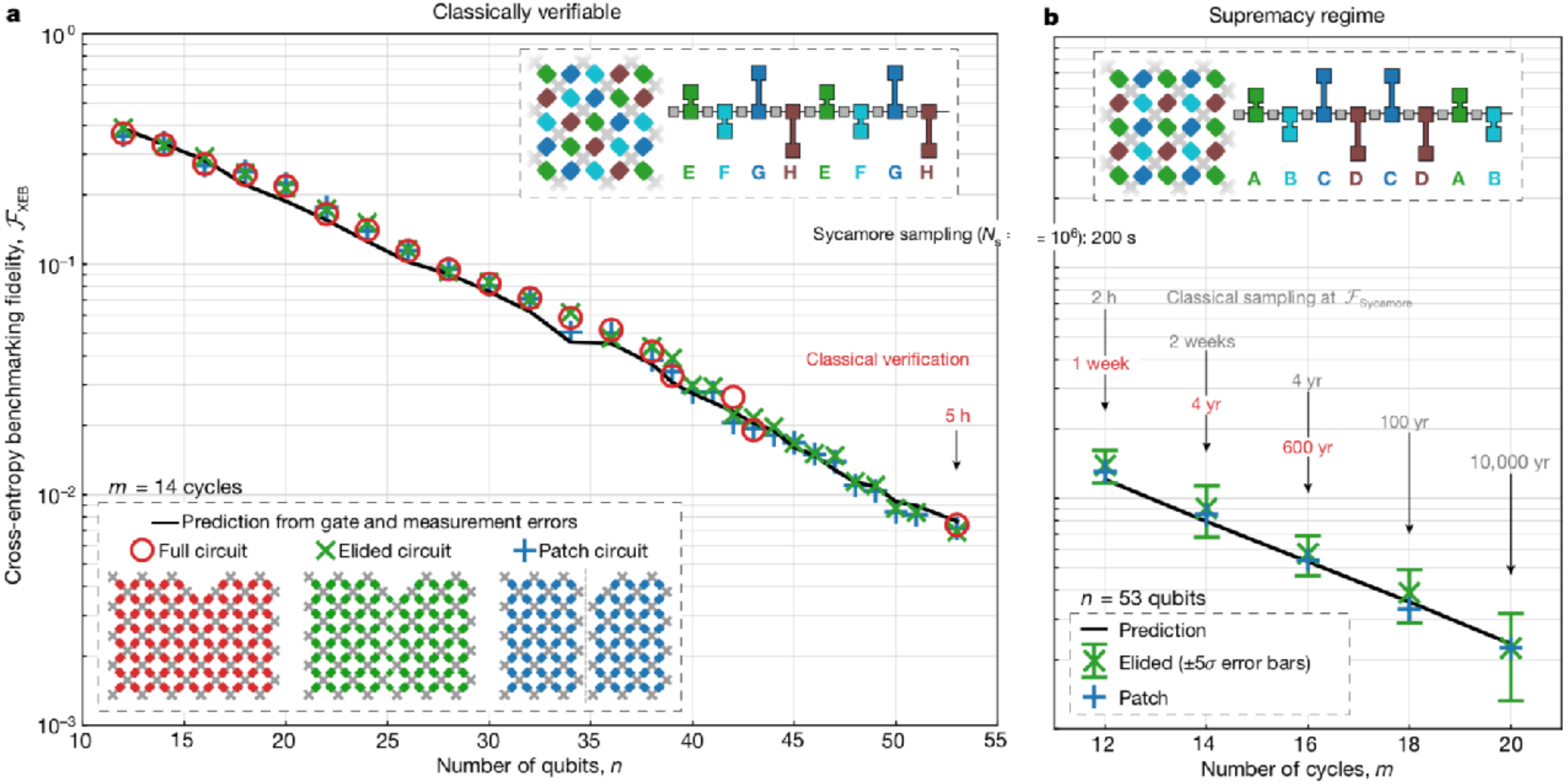
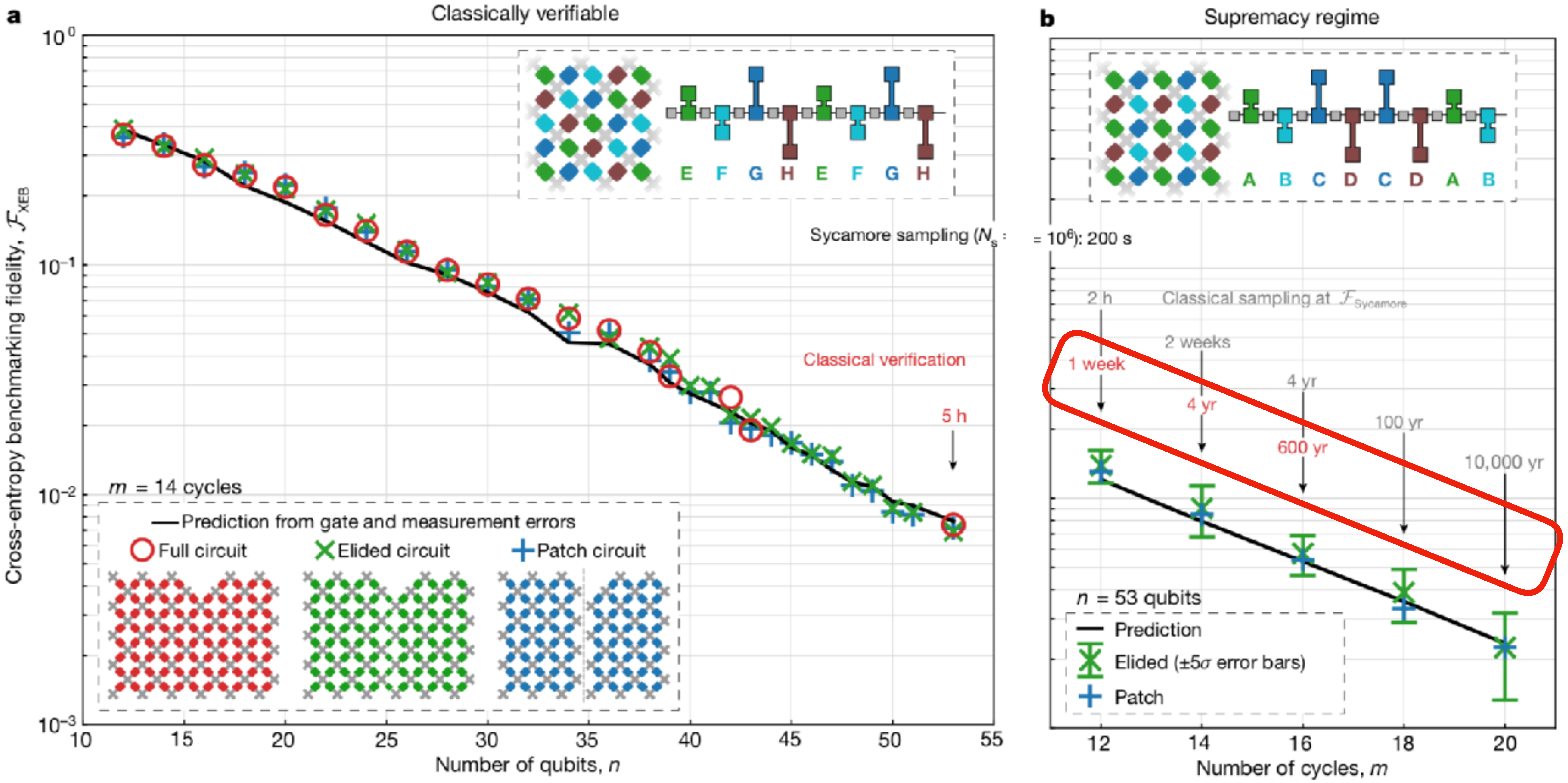


Classically verifiable Extrapolation

Google's Quantum Supremacy



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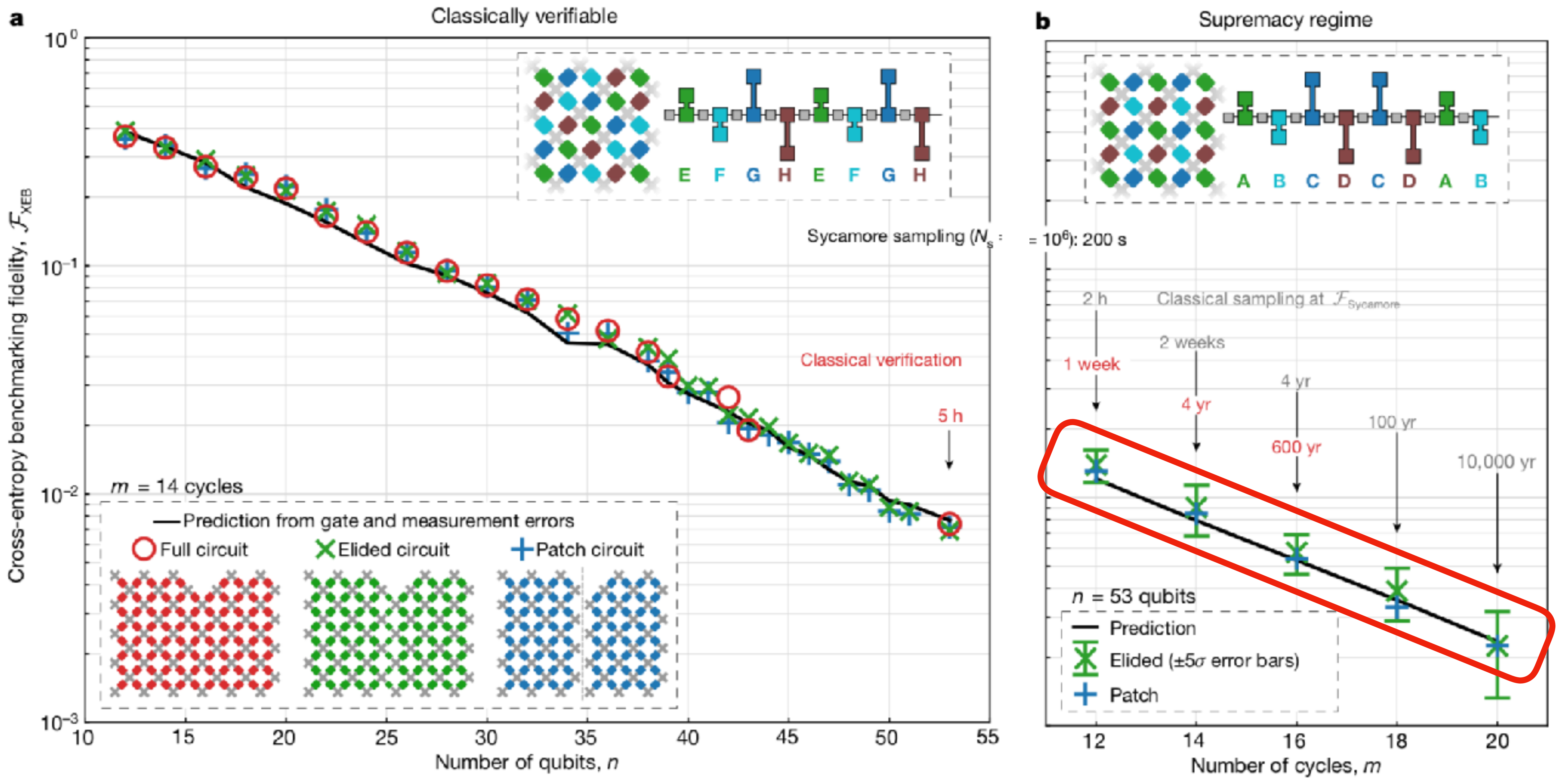

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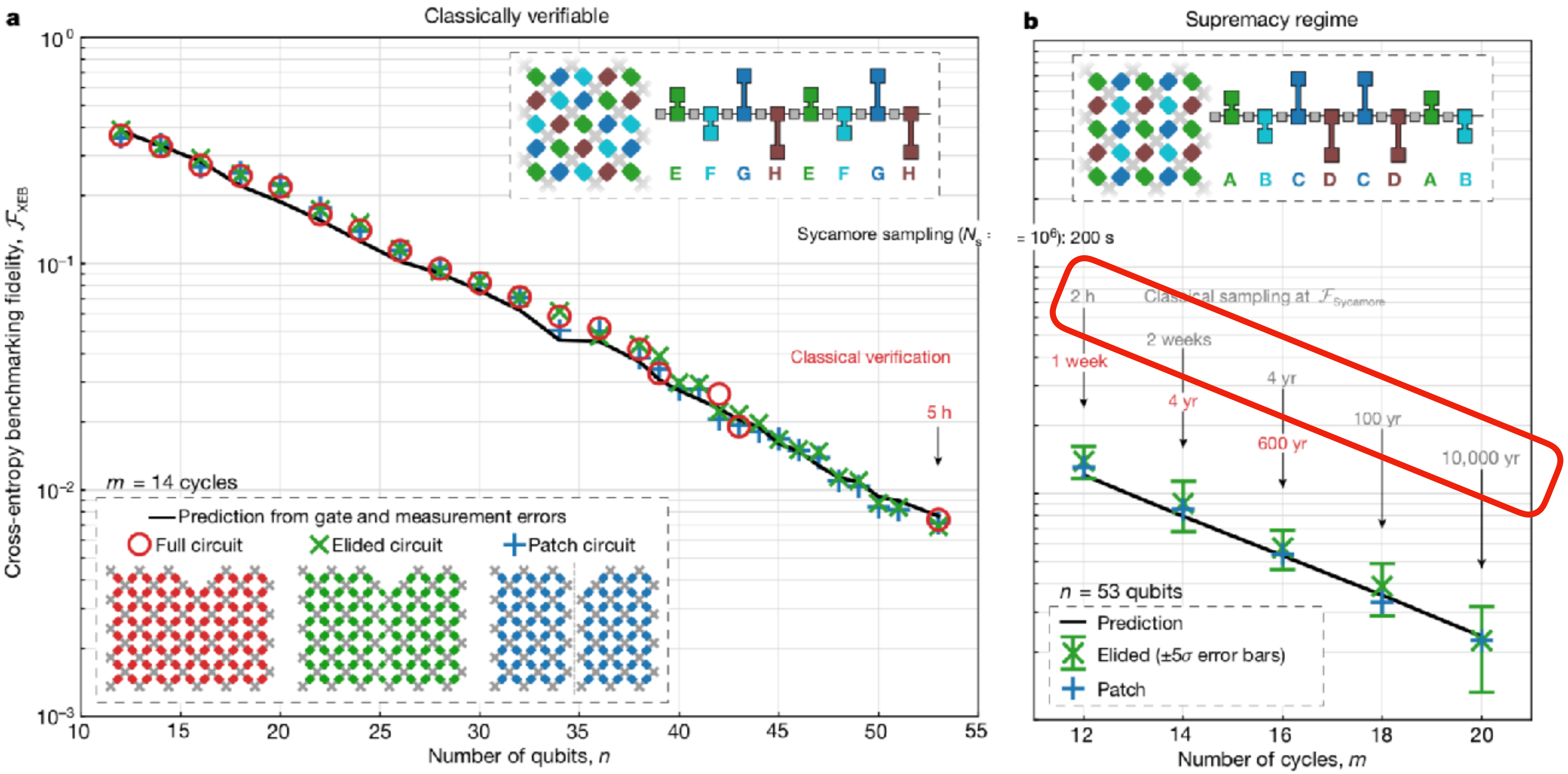

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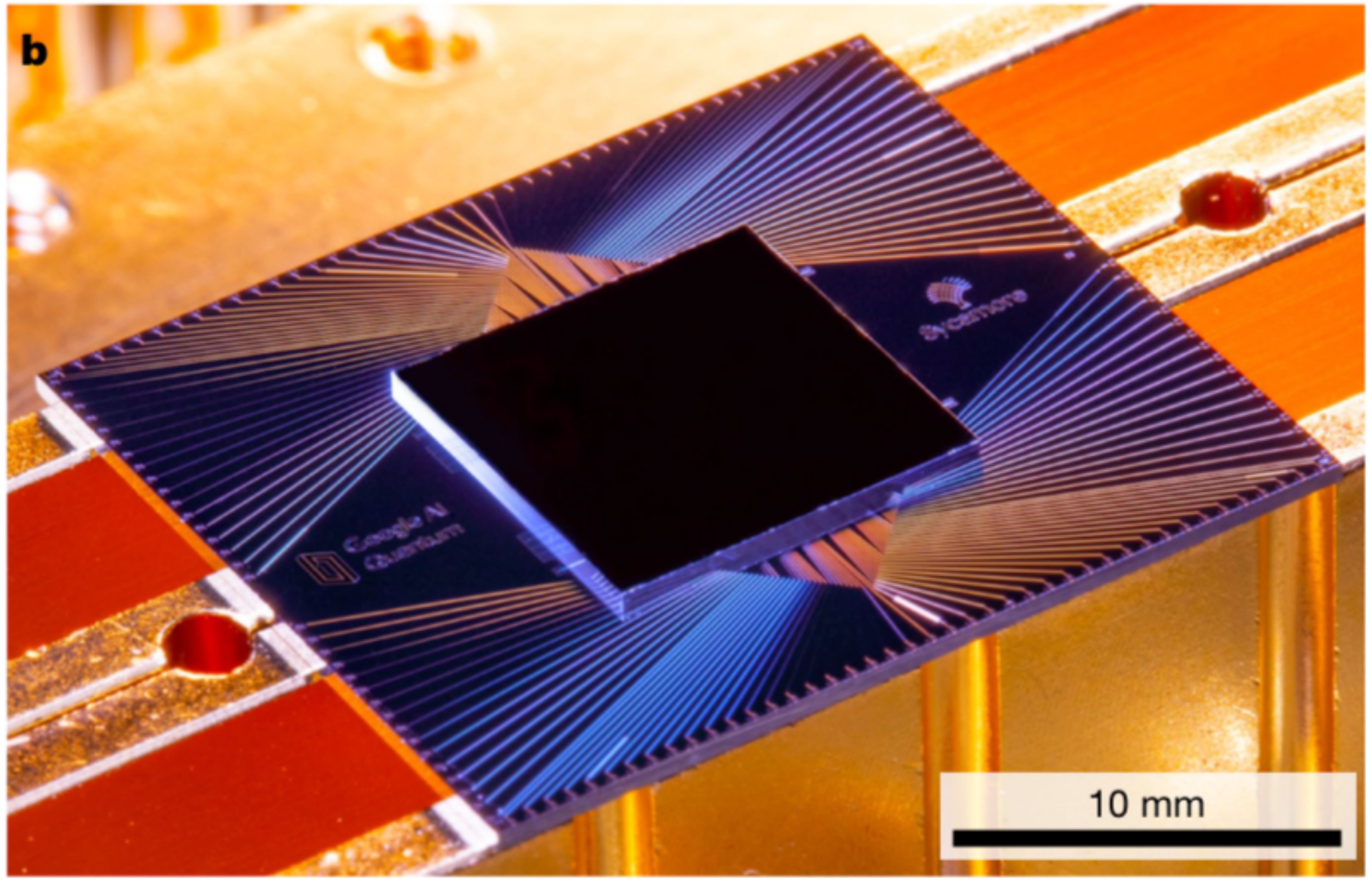
- Achieve $(2.24 \pm 0.21) \times 10^{-3}$ linear XEB when 53-qubit and depth-20 in few minutes.
- They conjectured classical sampling takes 10,000 years.

Does Google refute ECTT?

Google indeed had made significant progress, but…



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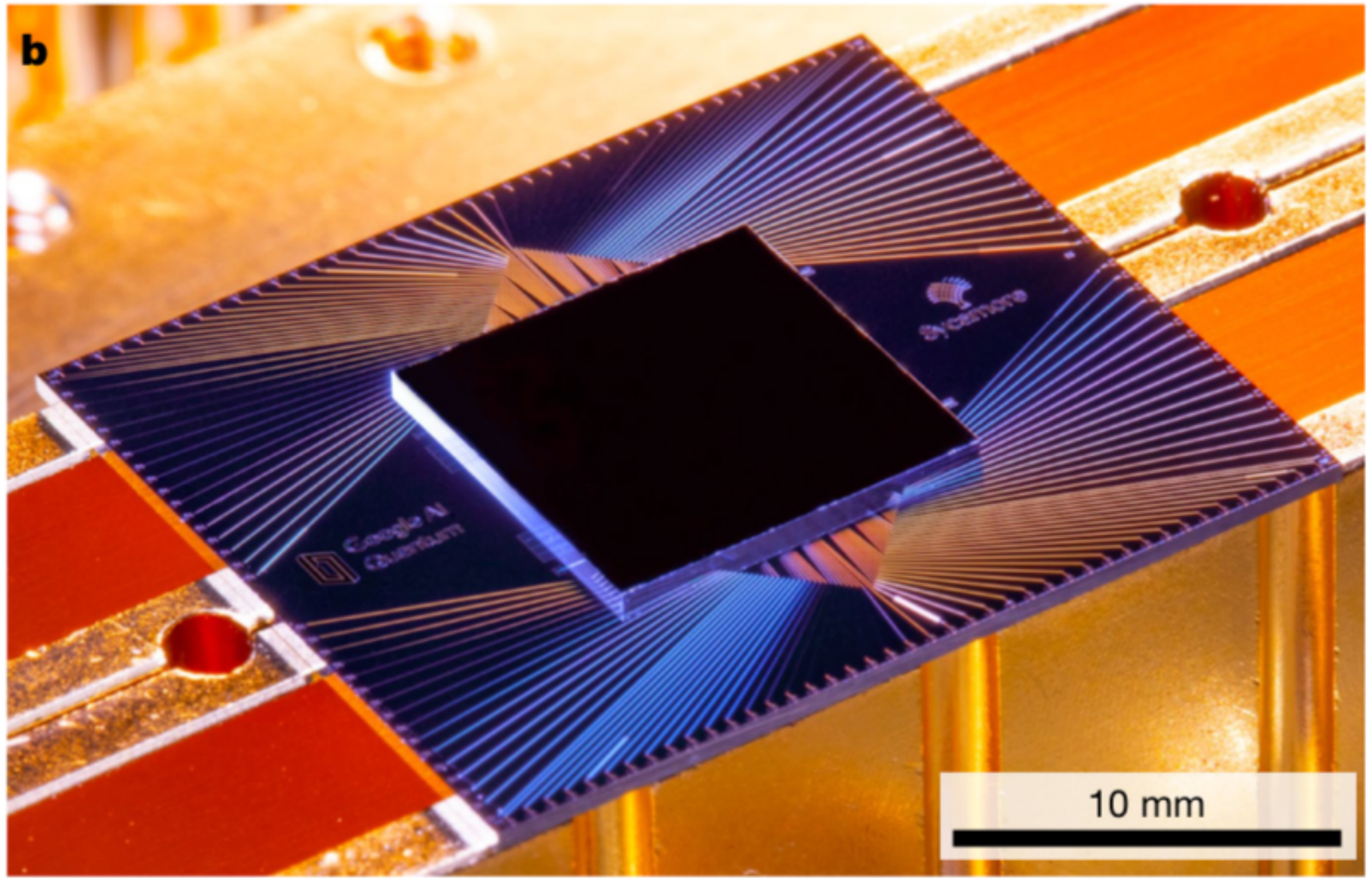

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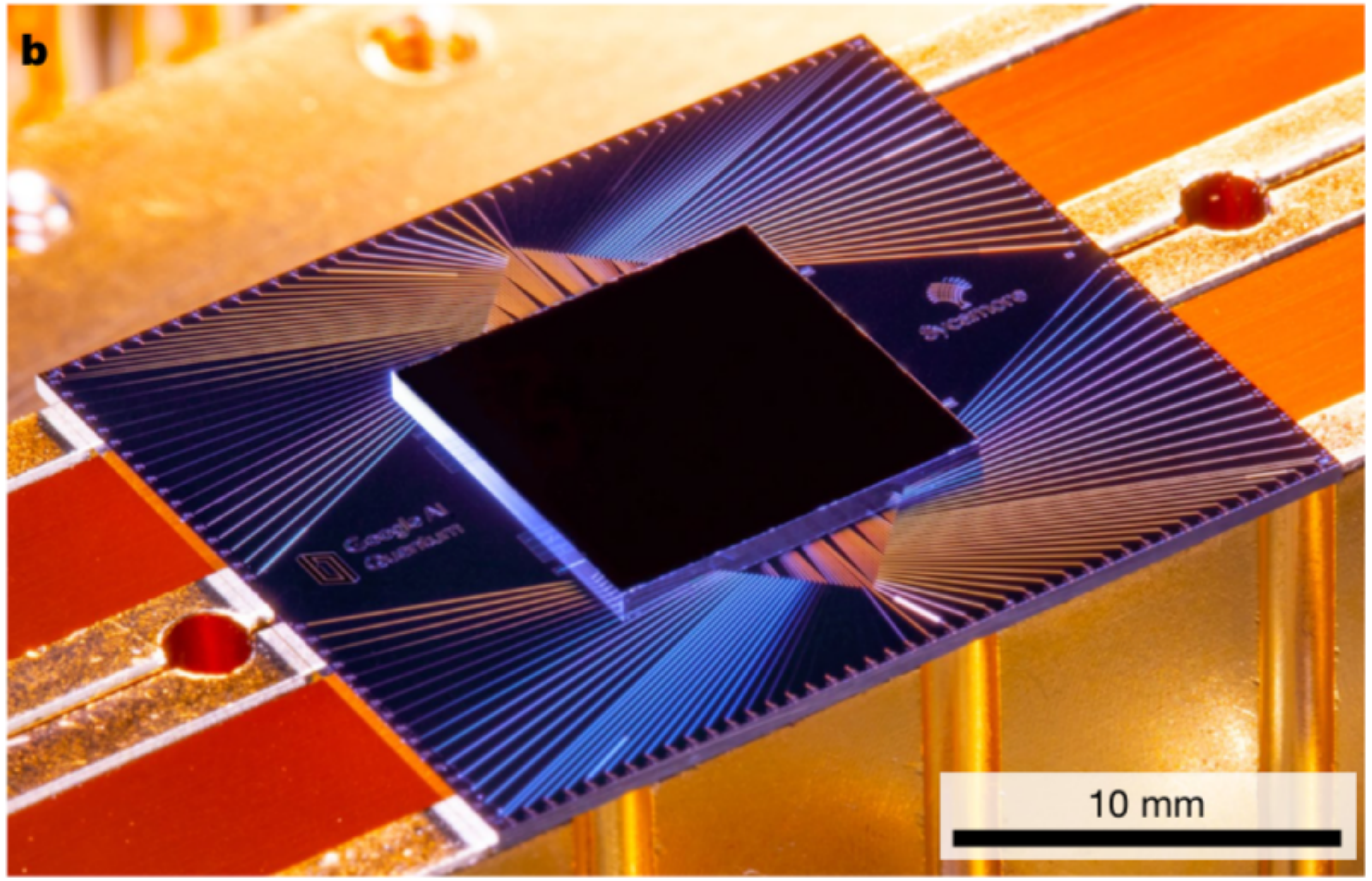

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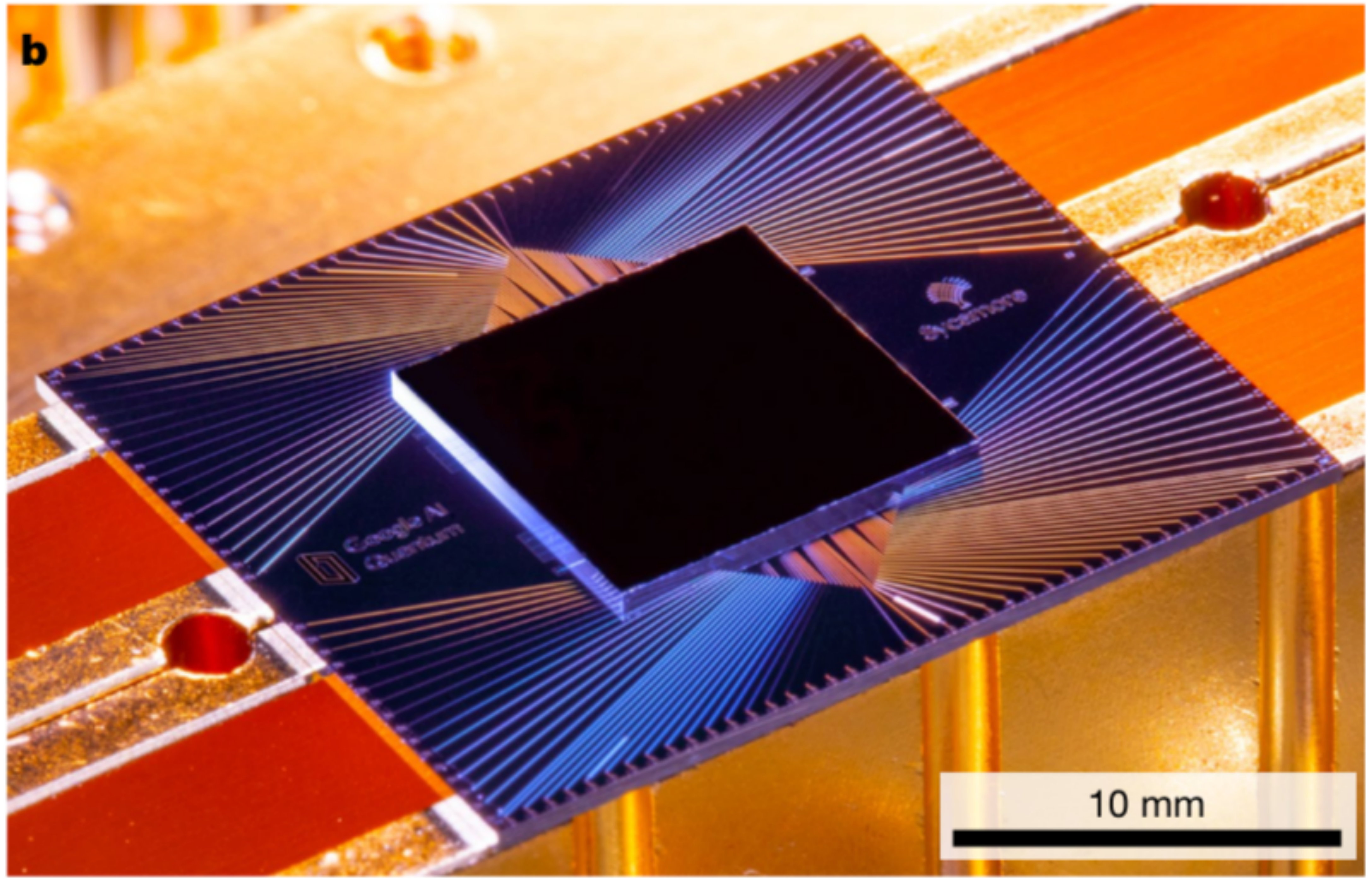

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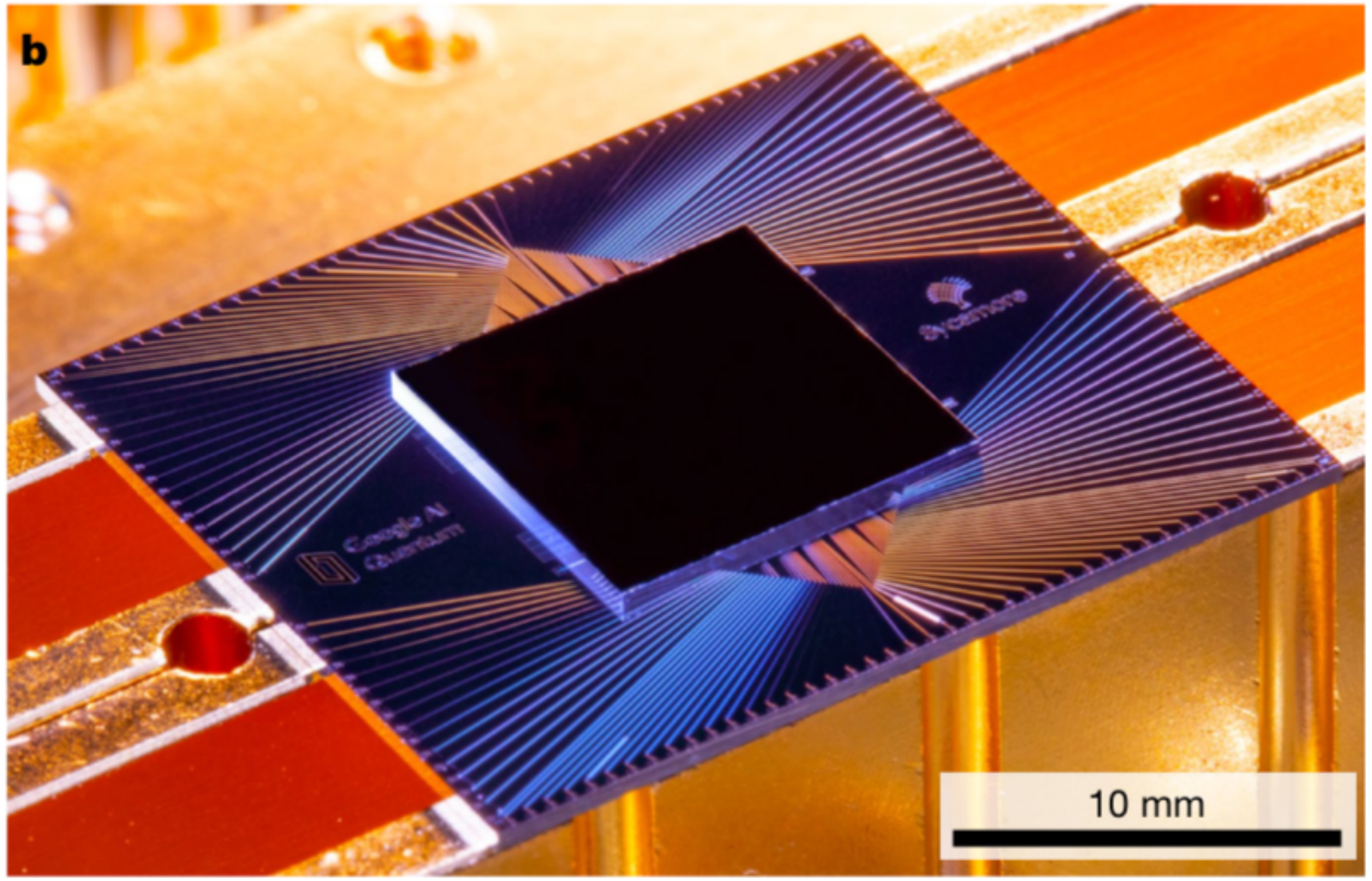

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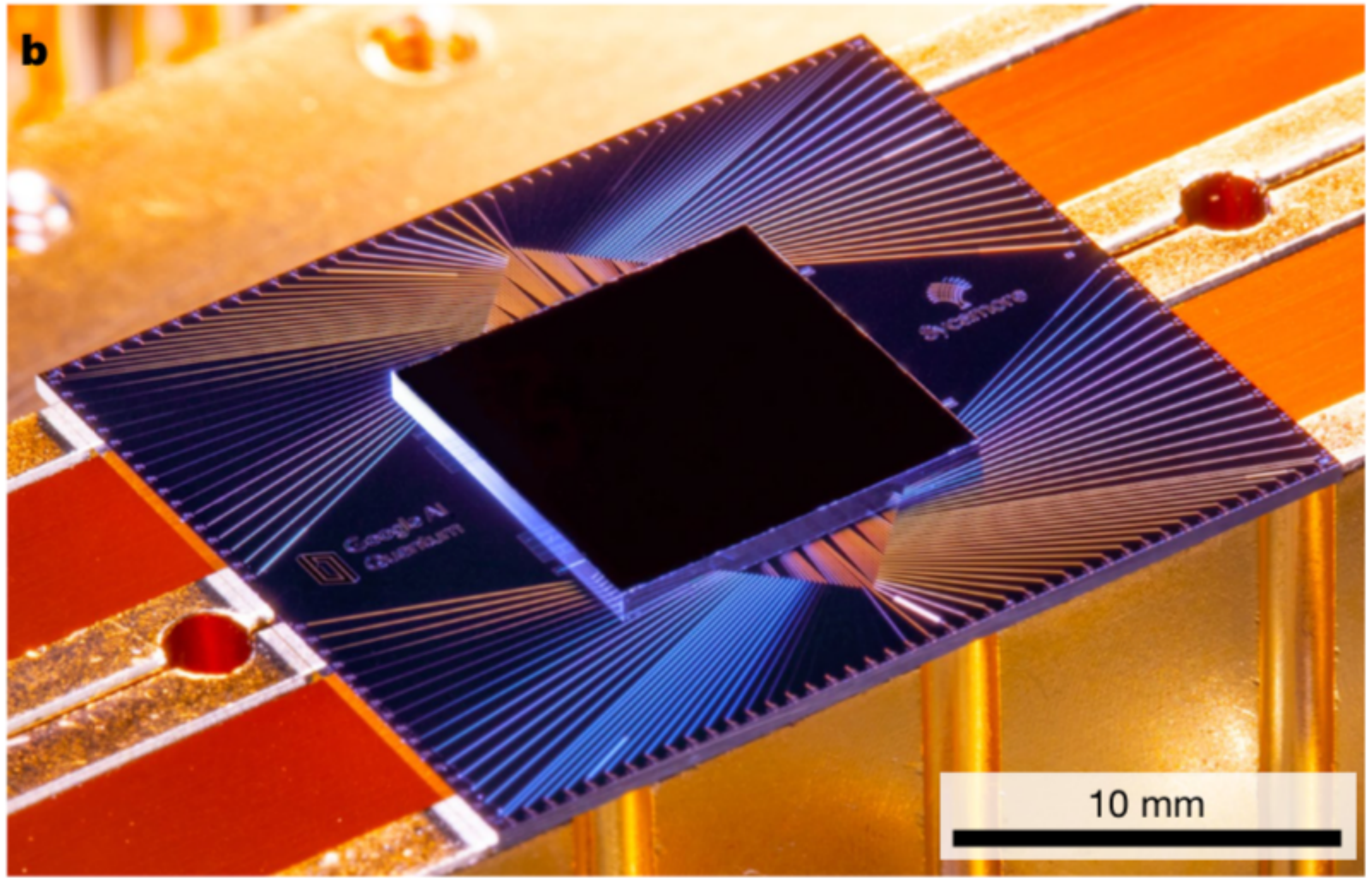

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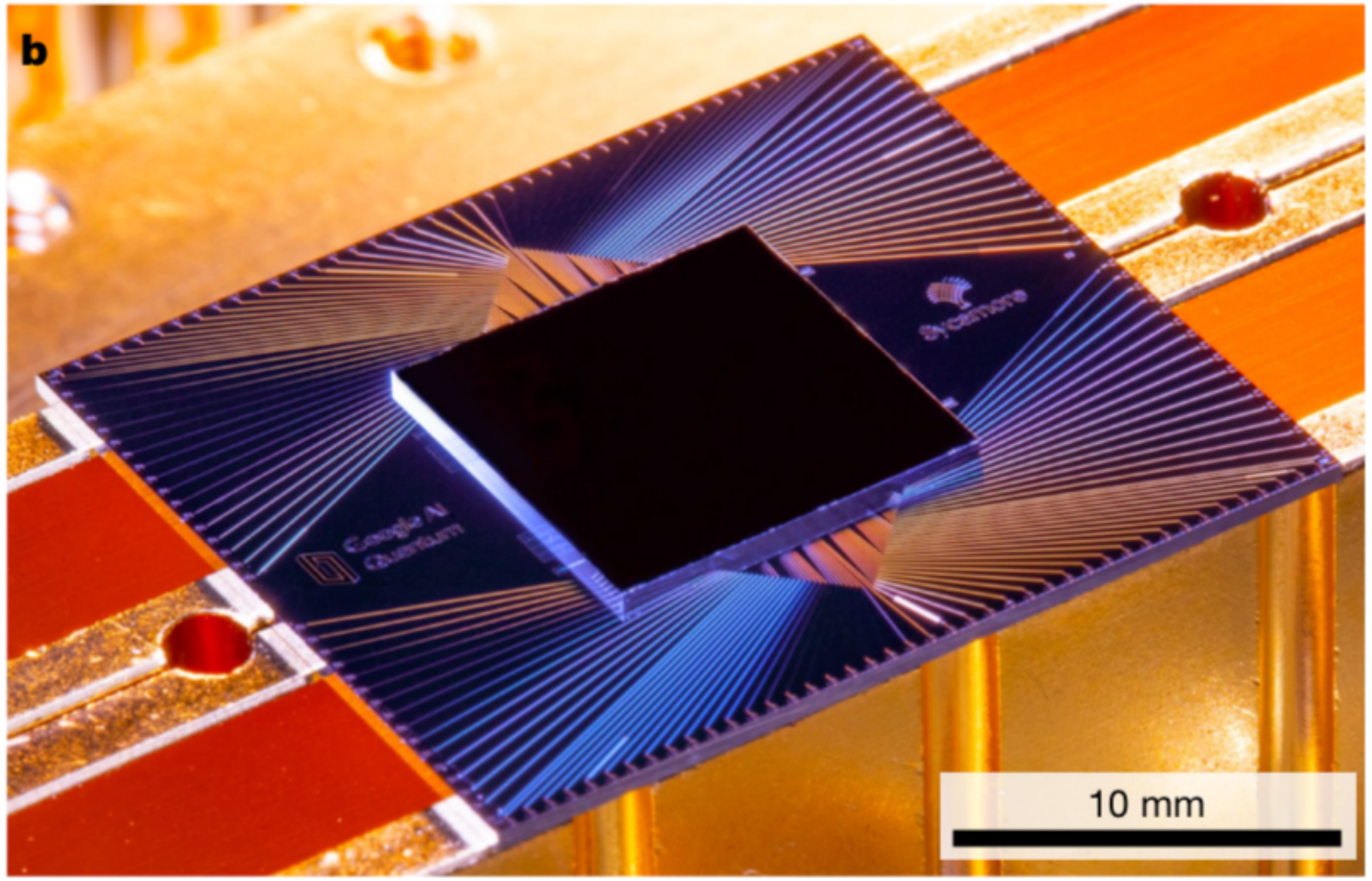

Spoofing Linear XEB!?

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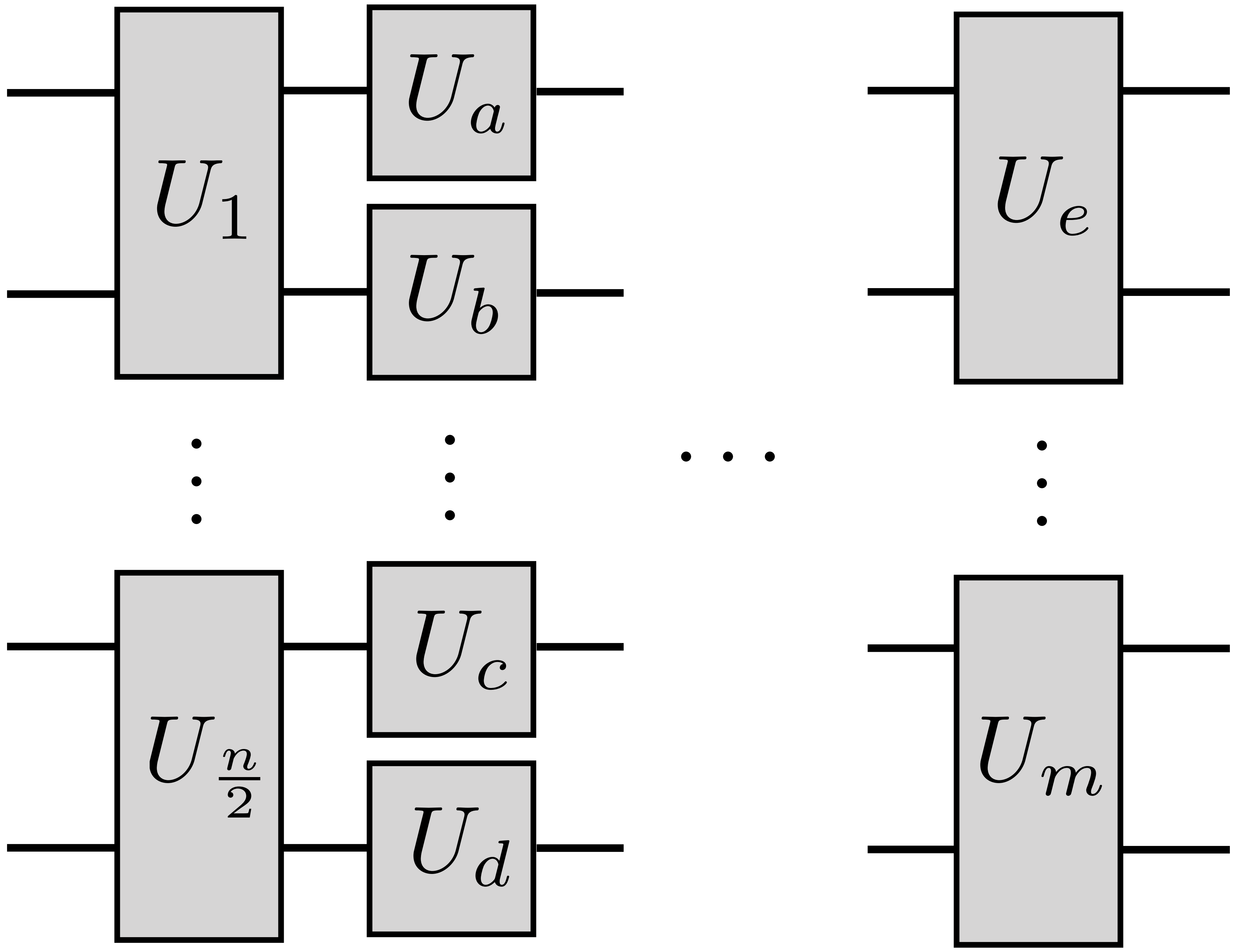

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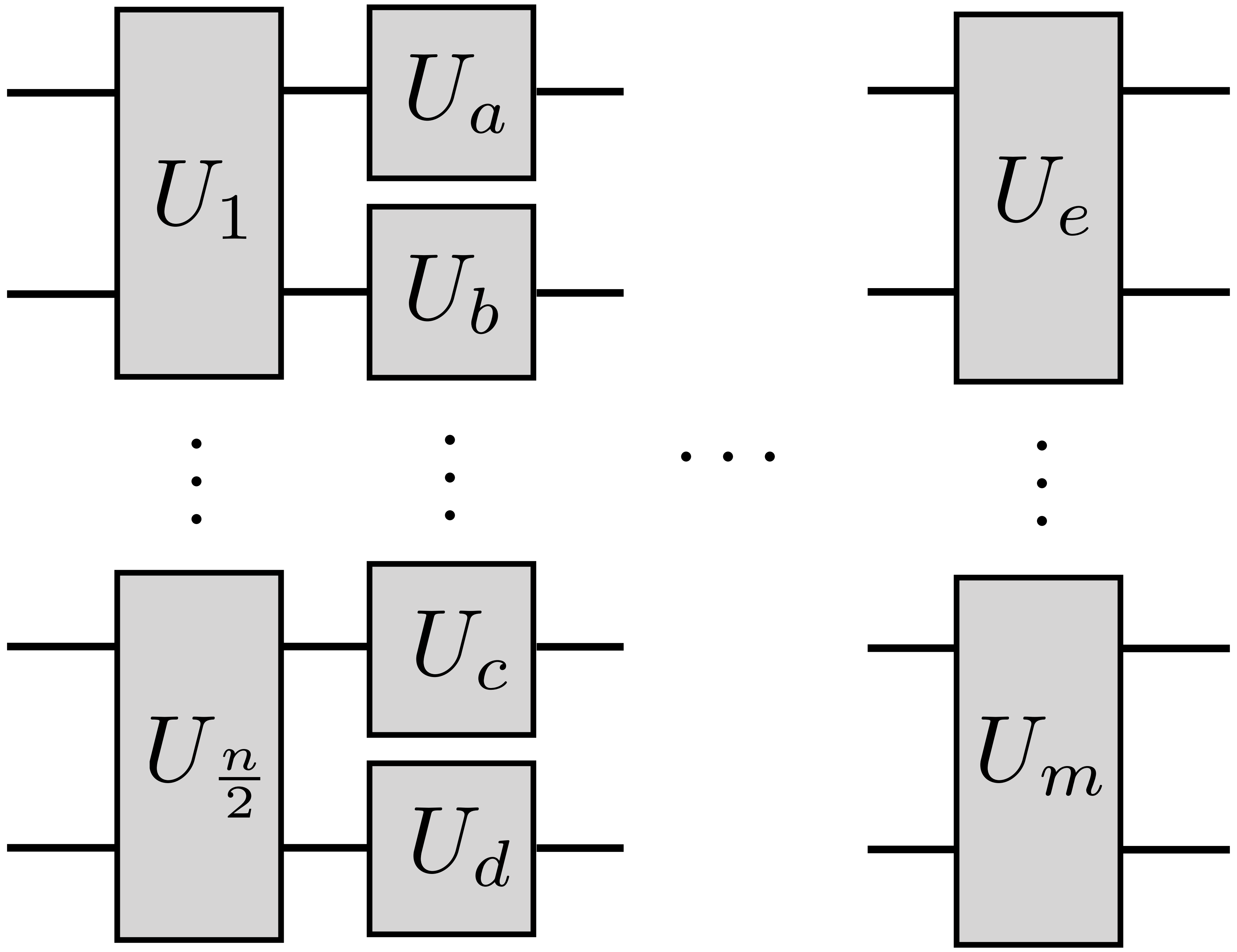

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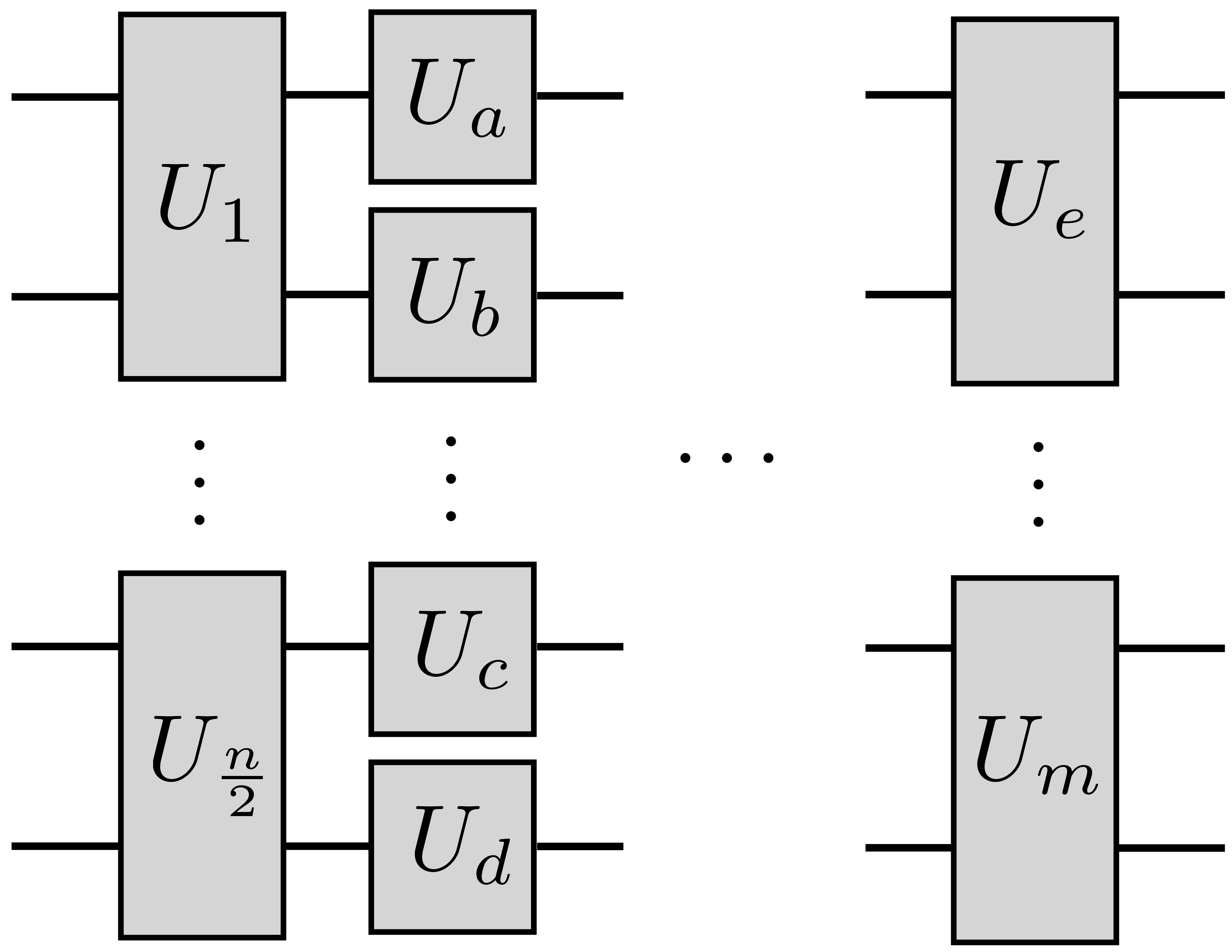

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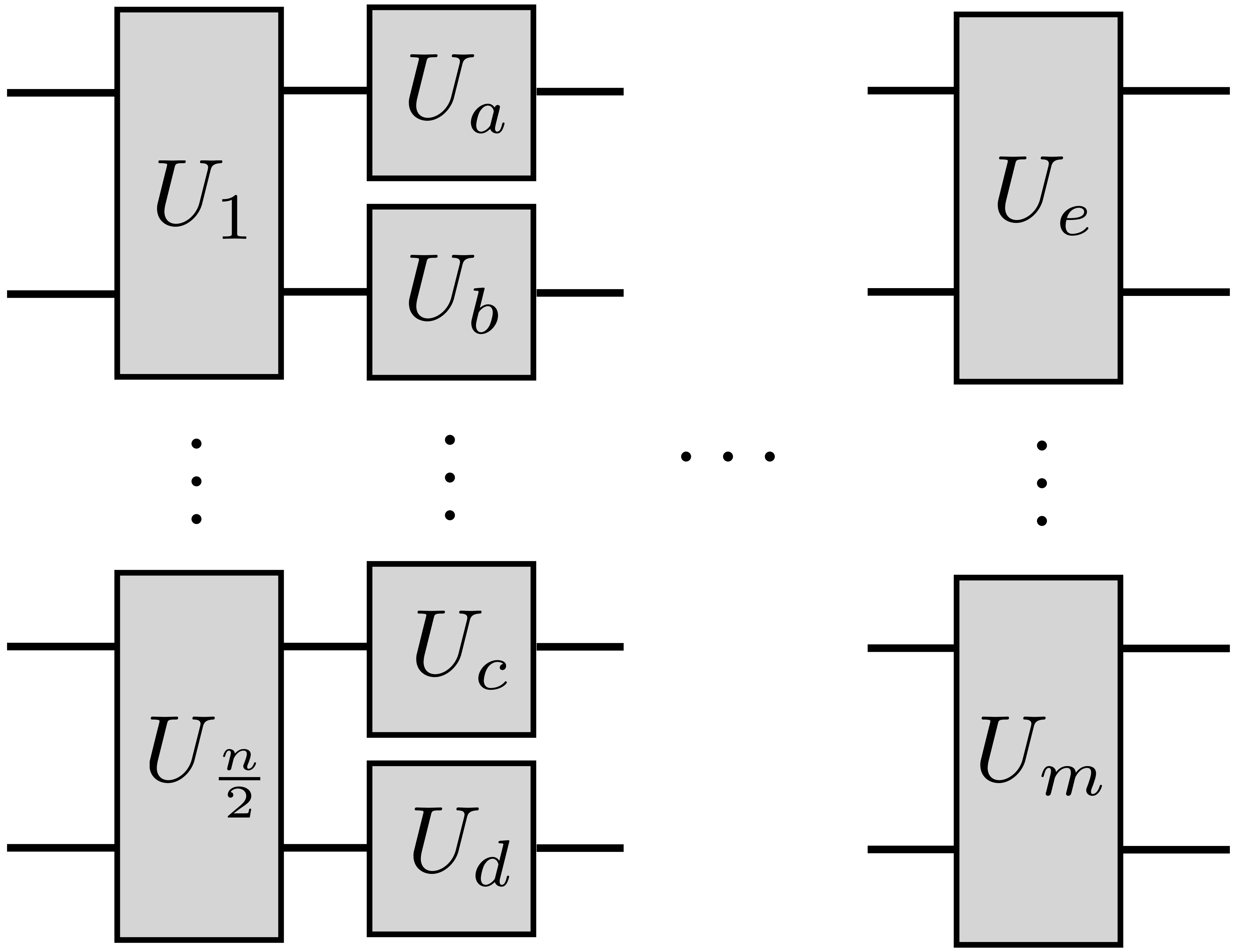

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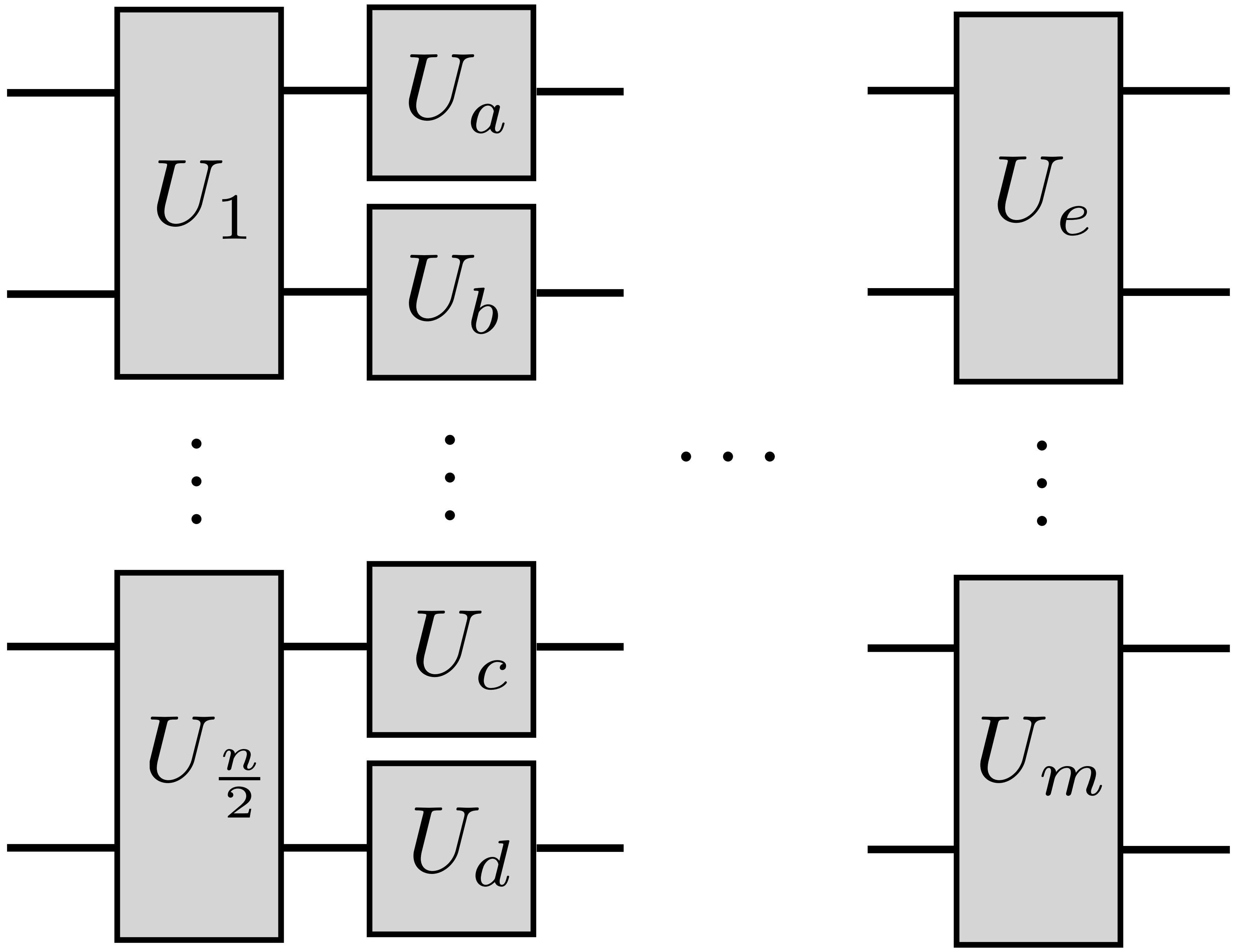

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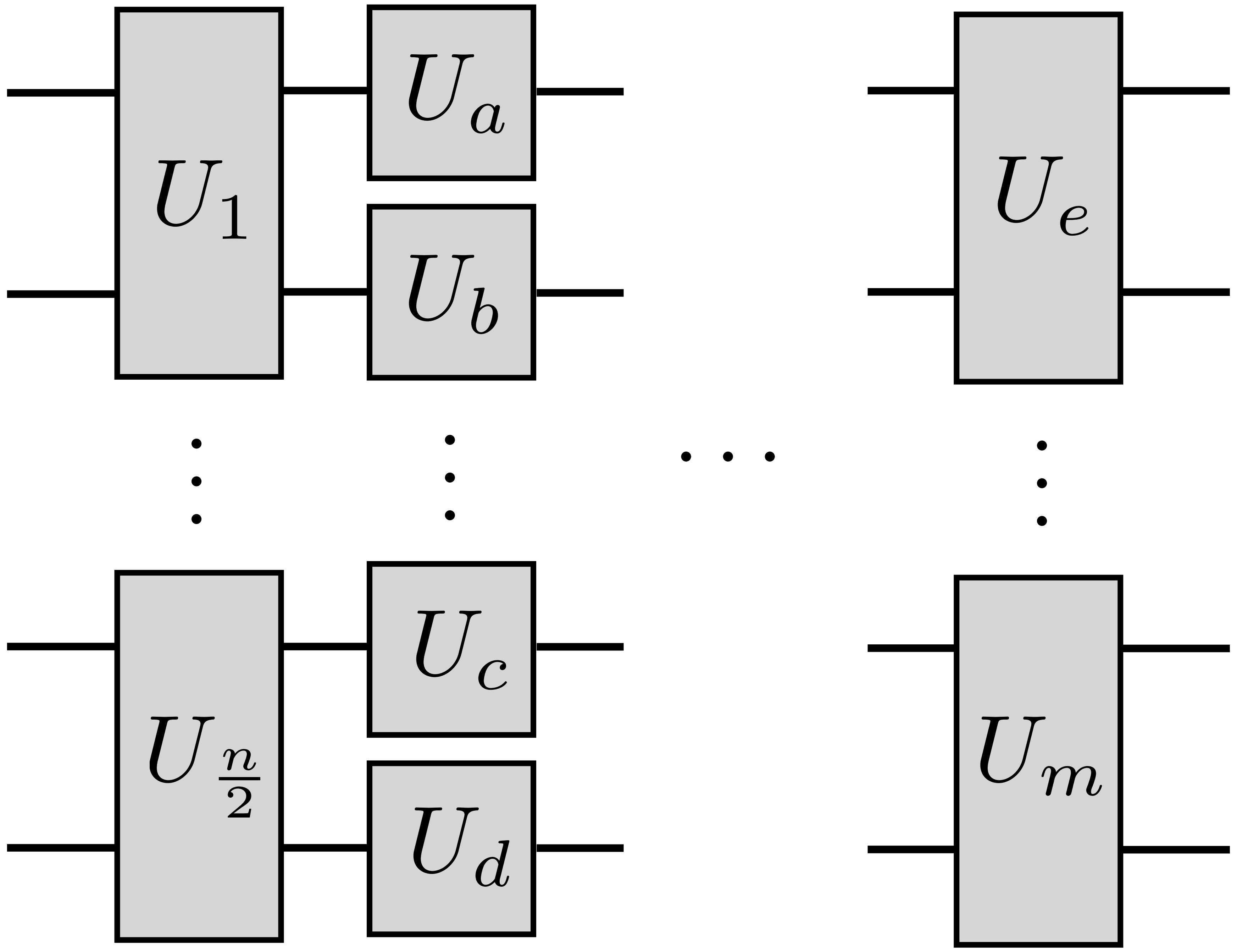

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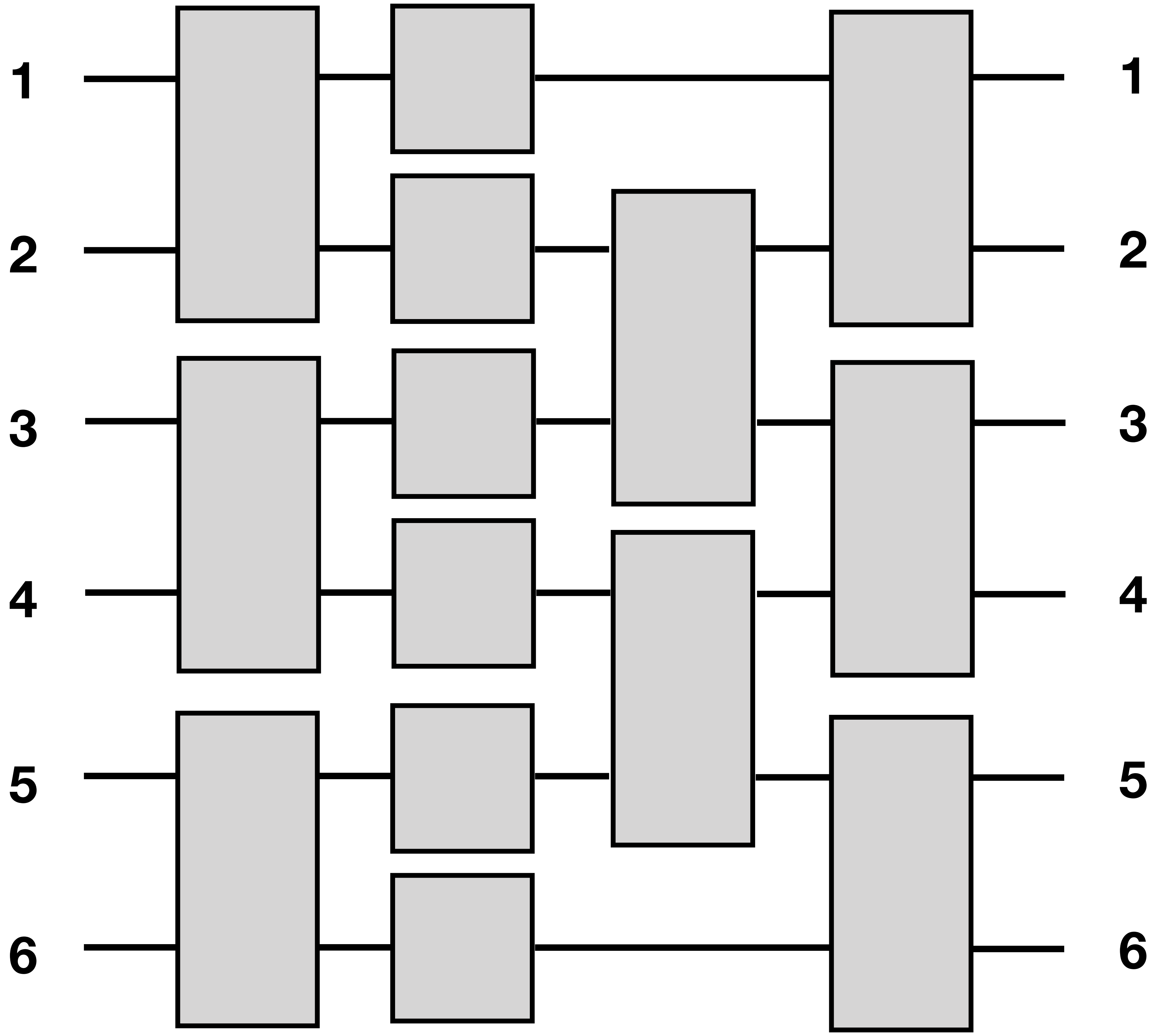
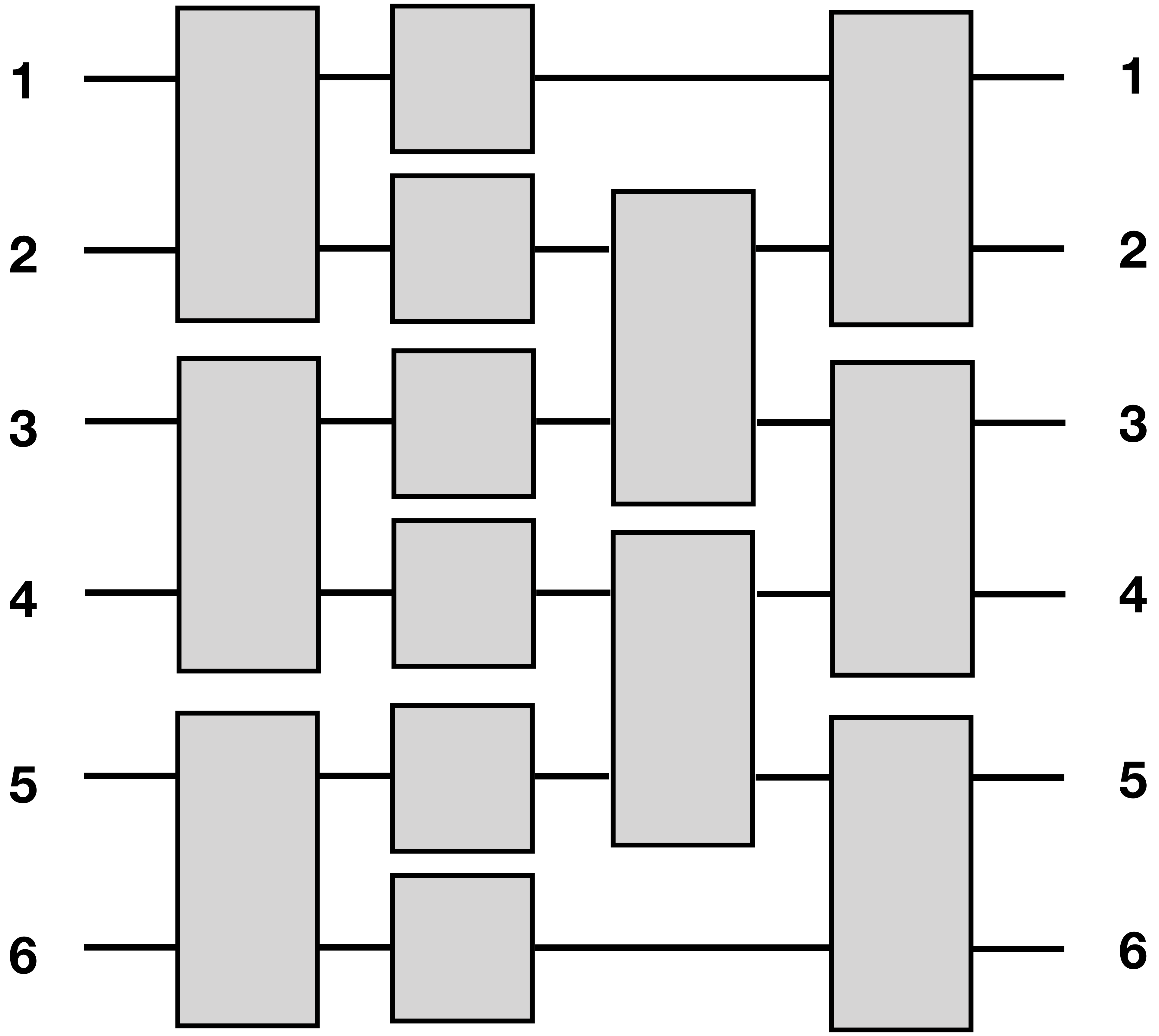
Spoofing Linear XEB in Shallow Circuits



Spoofing Linear XEB in Shallow Circuits

Observation: The marginal of an output qubit only depends on its *lightcone*!



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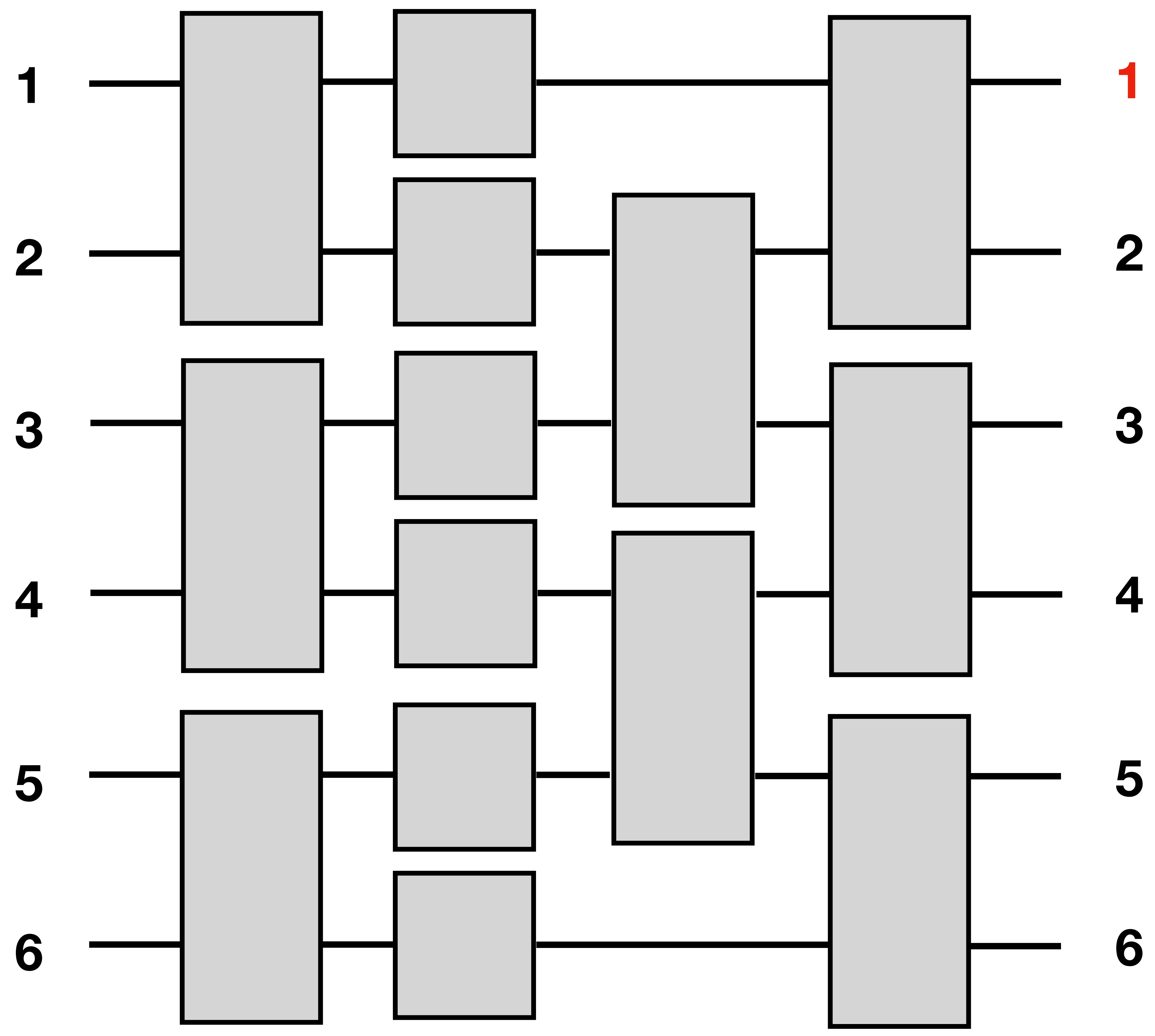

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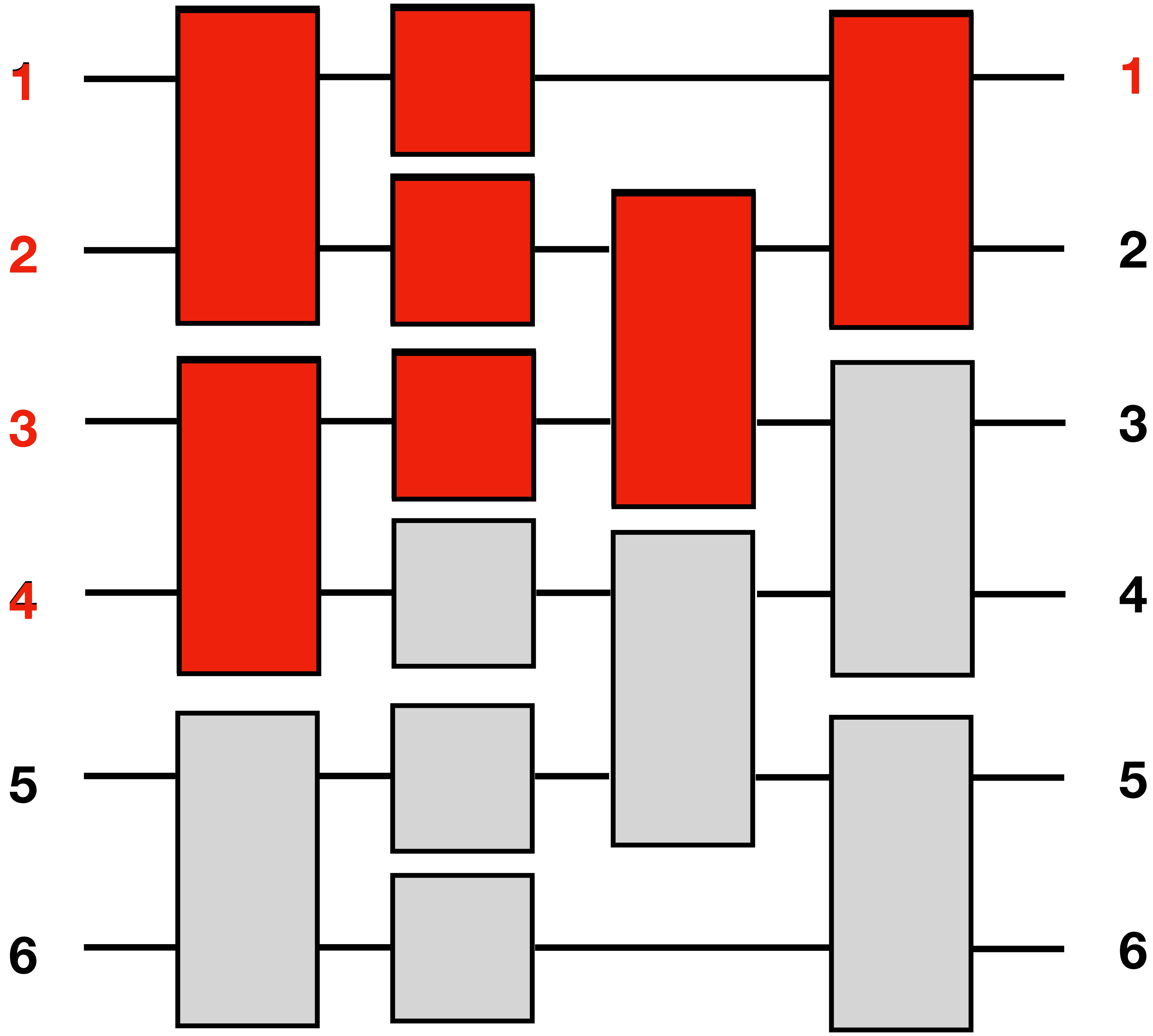

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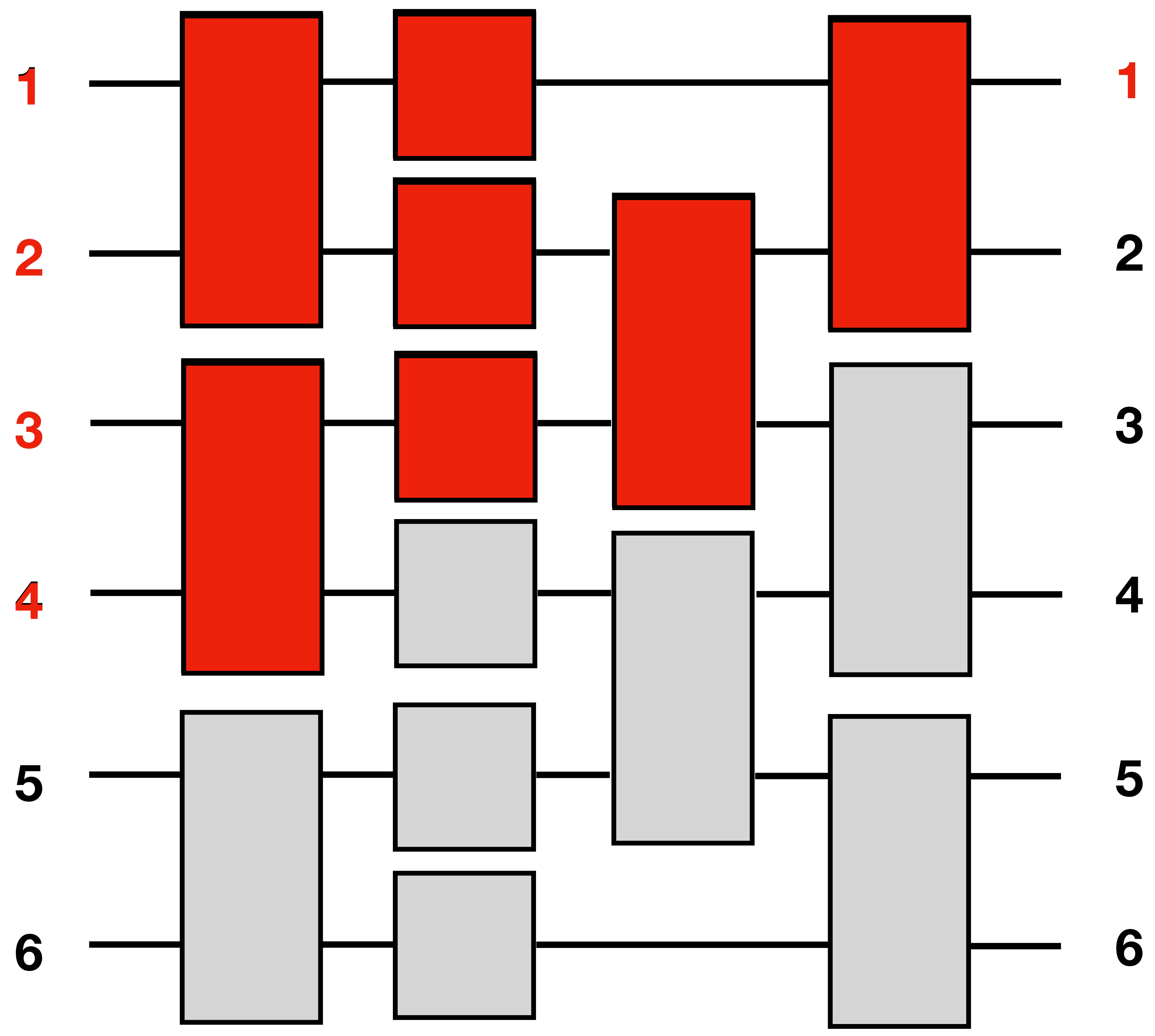

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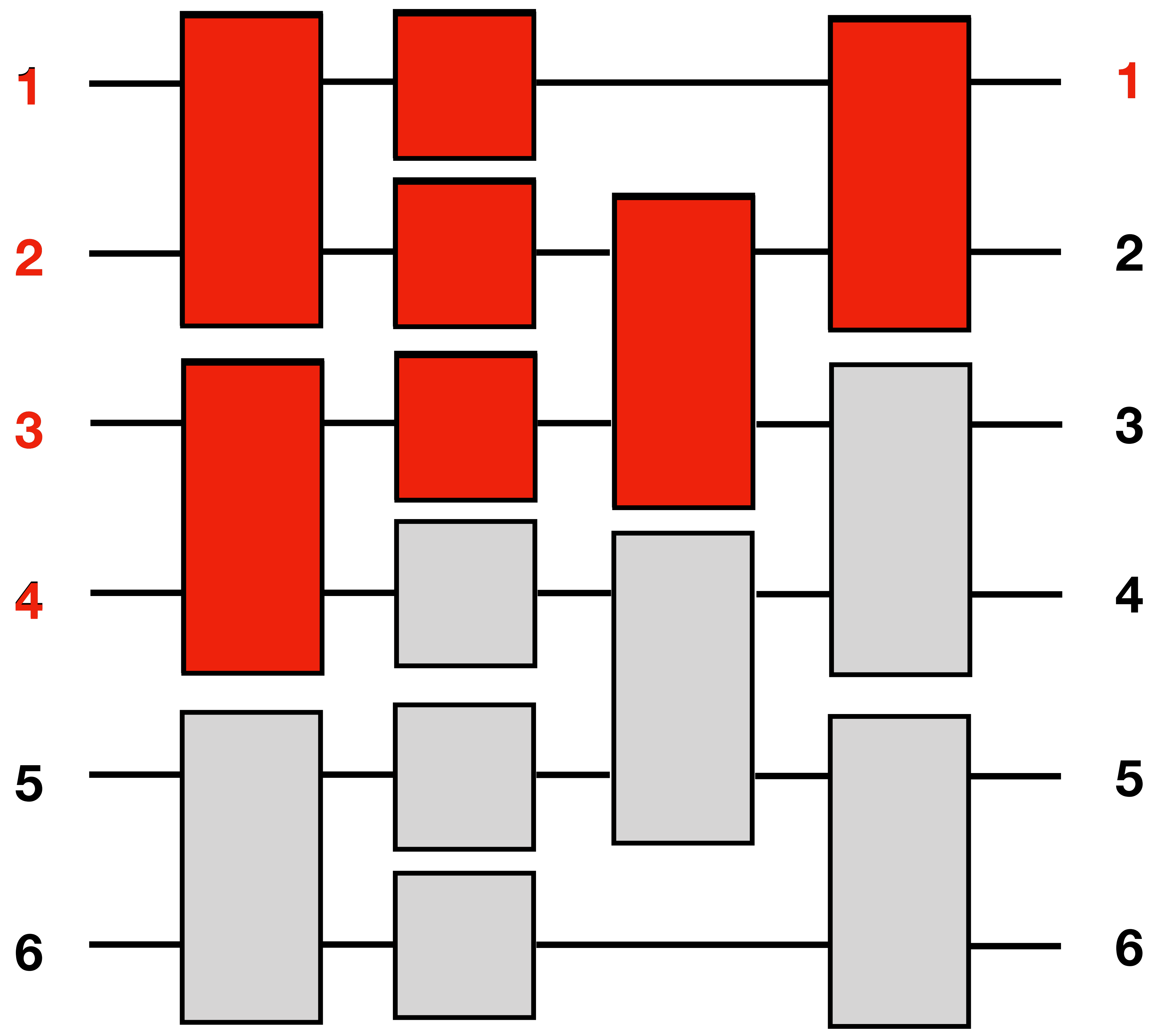

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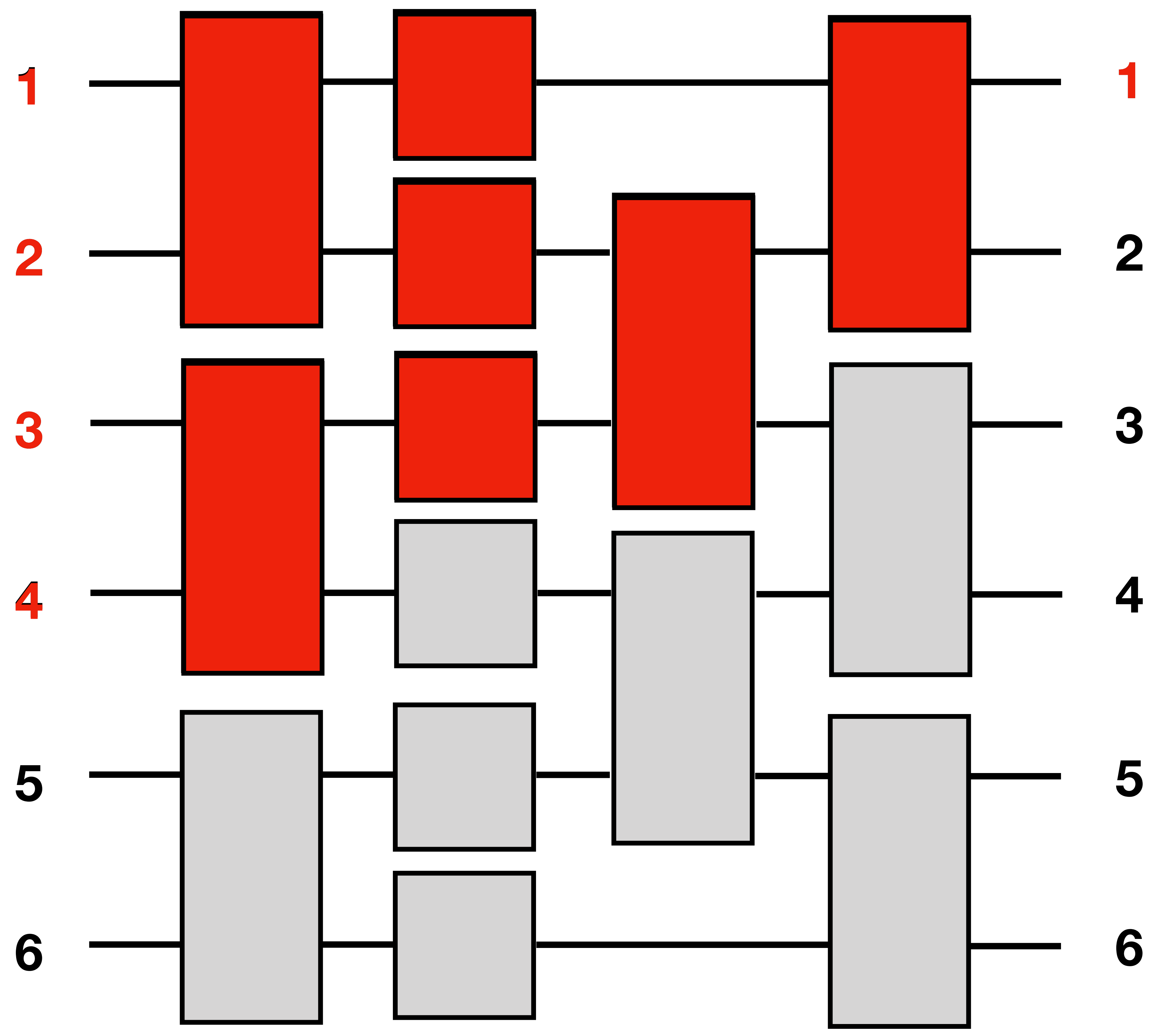

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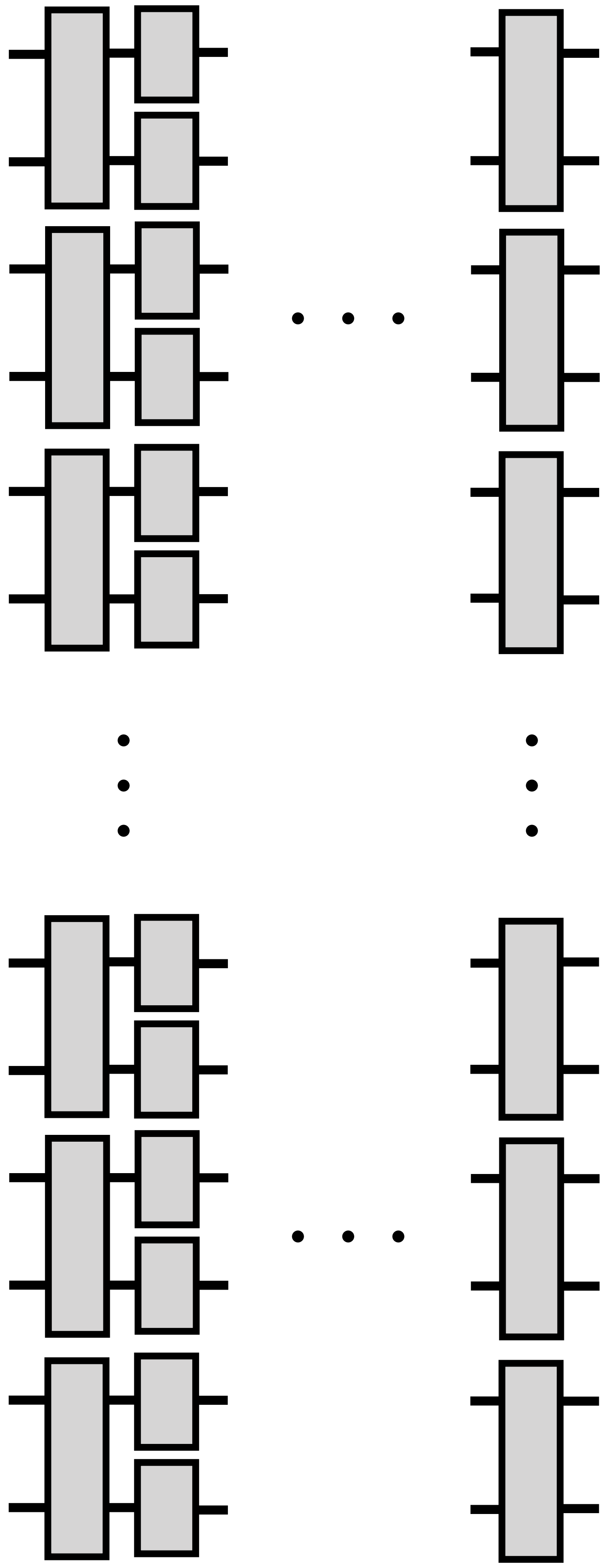
Idea: Use the marginal of each output qubit to perform biased sampling!

A Classical Algorithm Spoofing Linear XEB Using Lightcone



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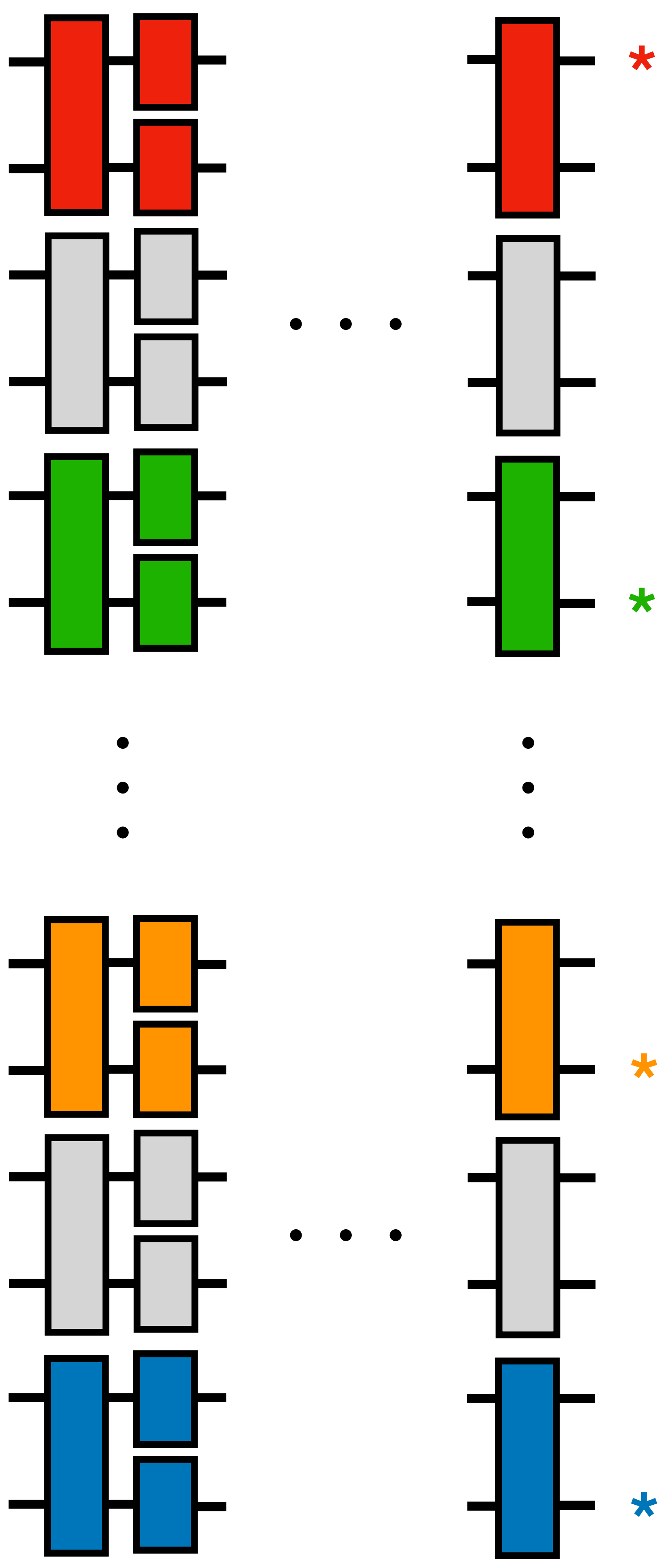

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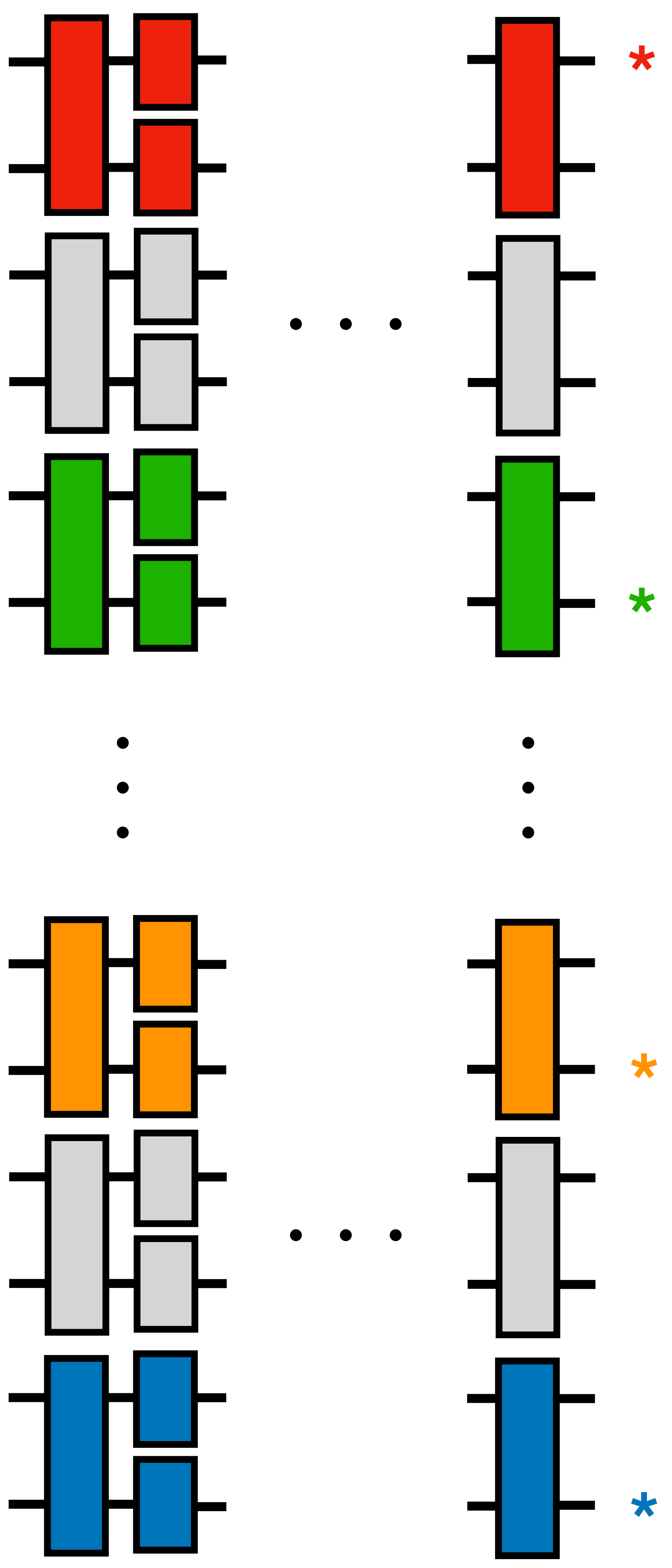

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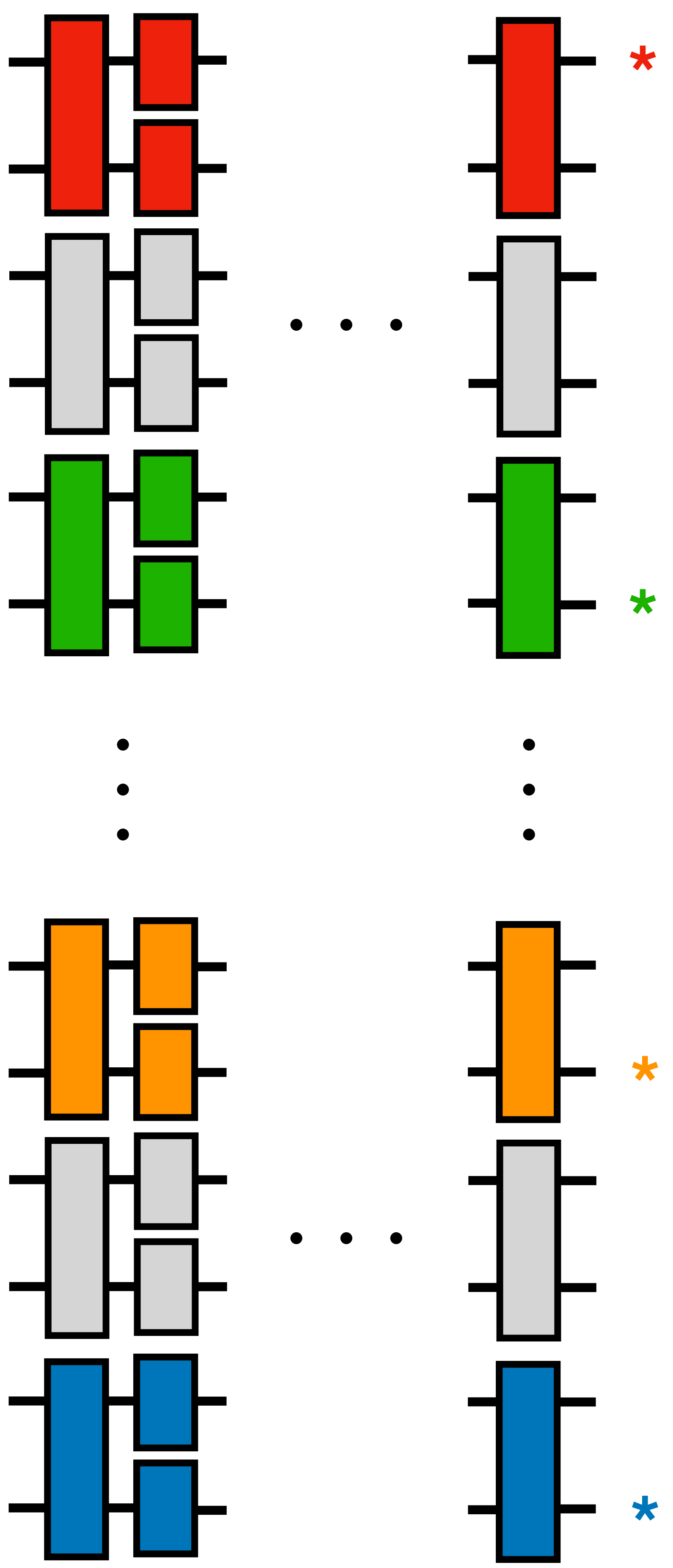

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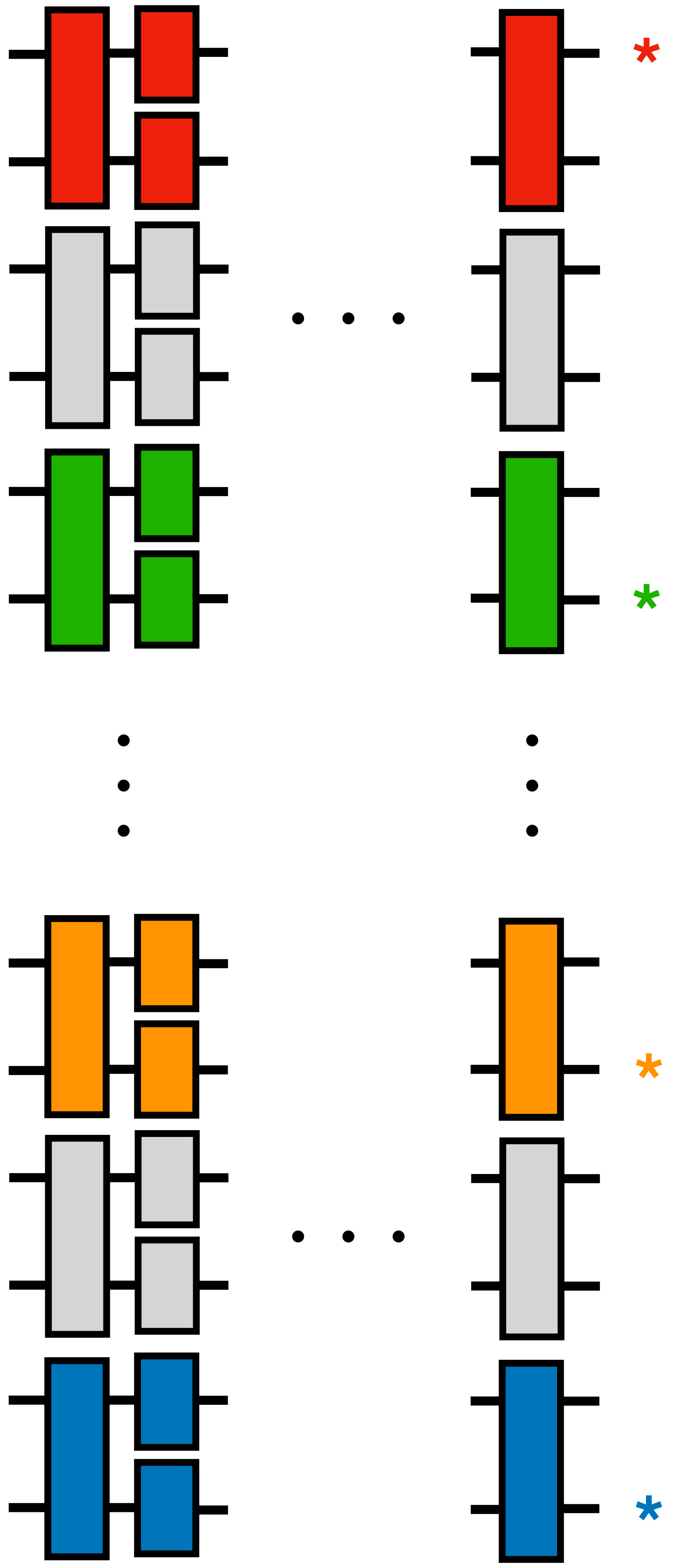

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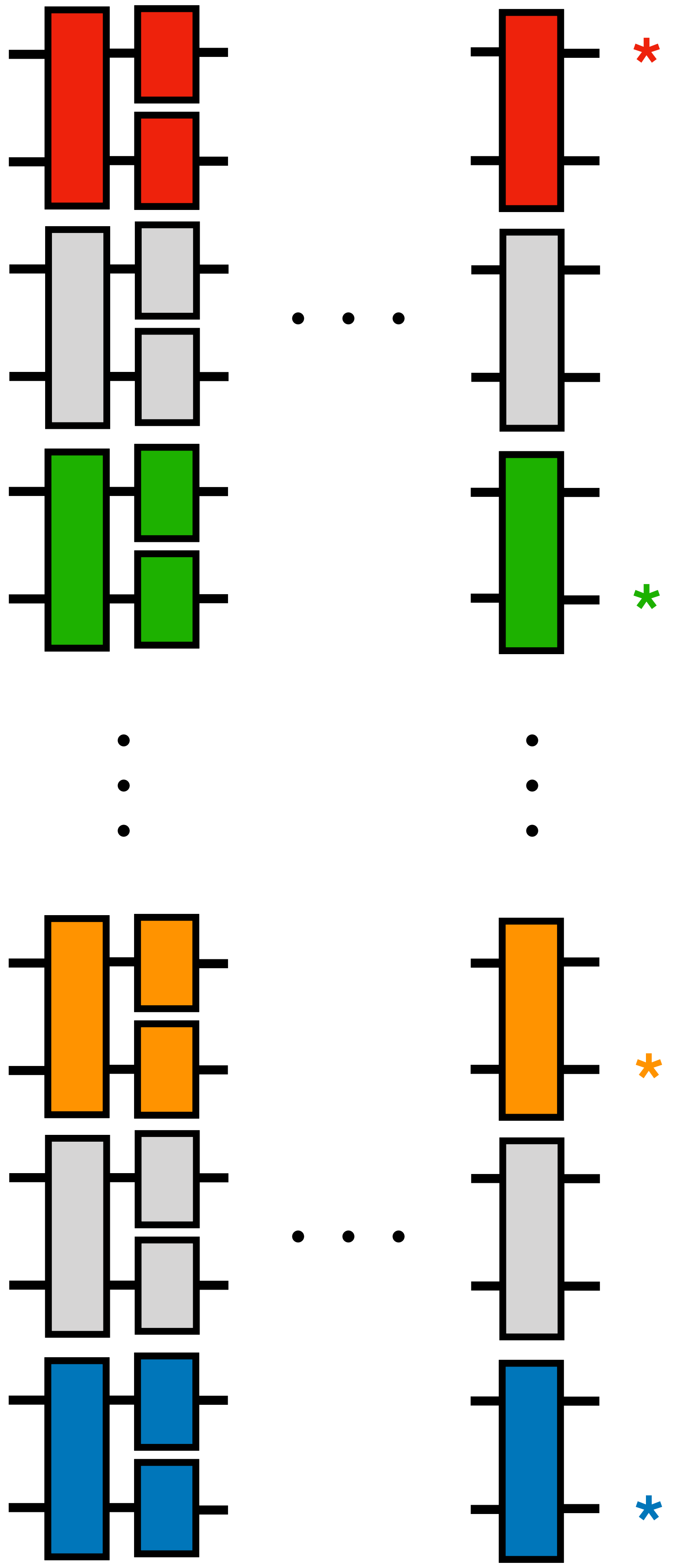

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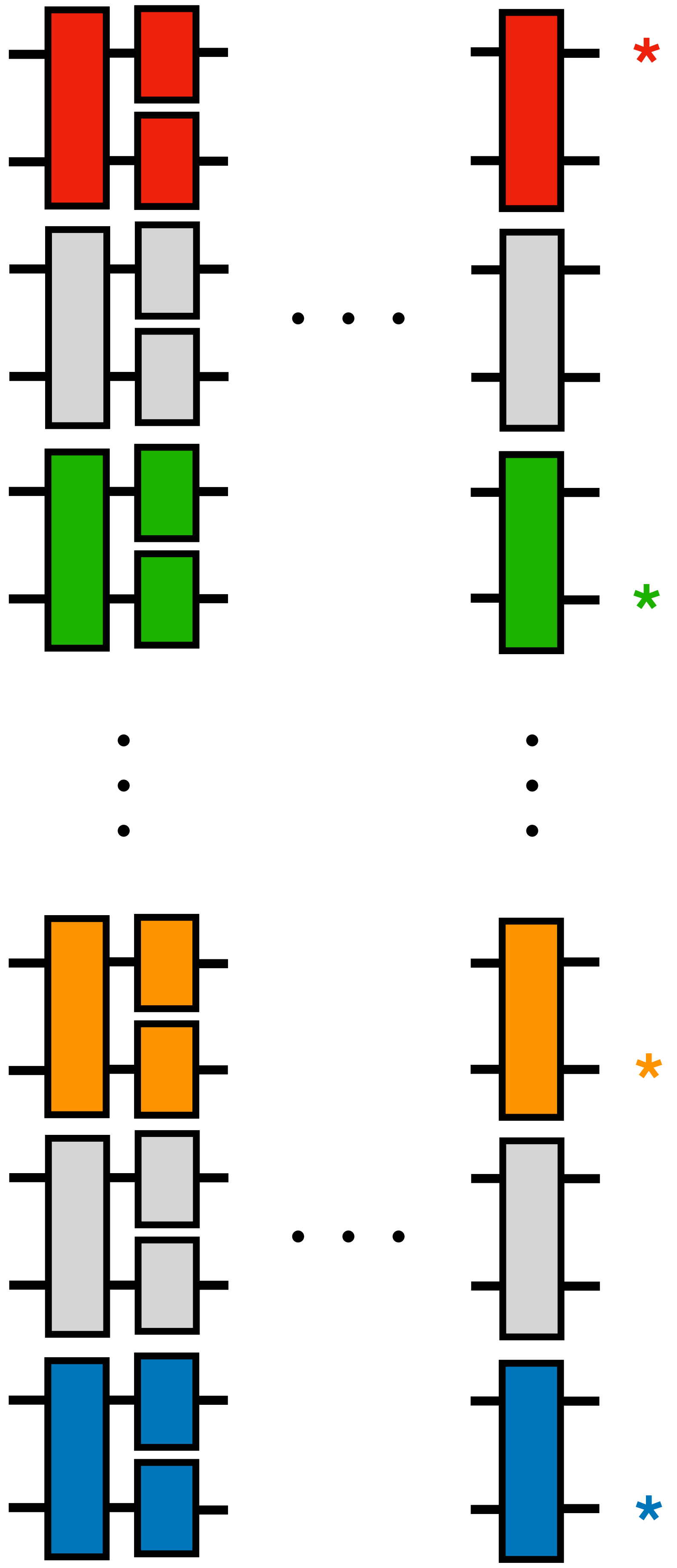
Theoretical analysis? Empirical performance? Other variants?



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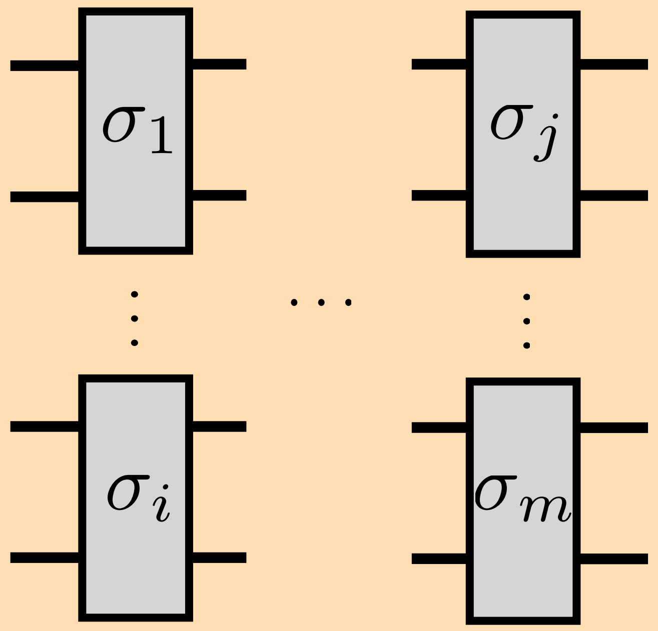

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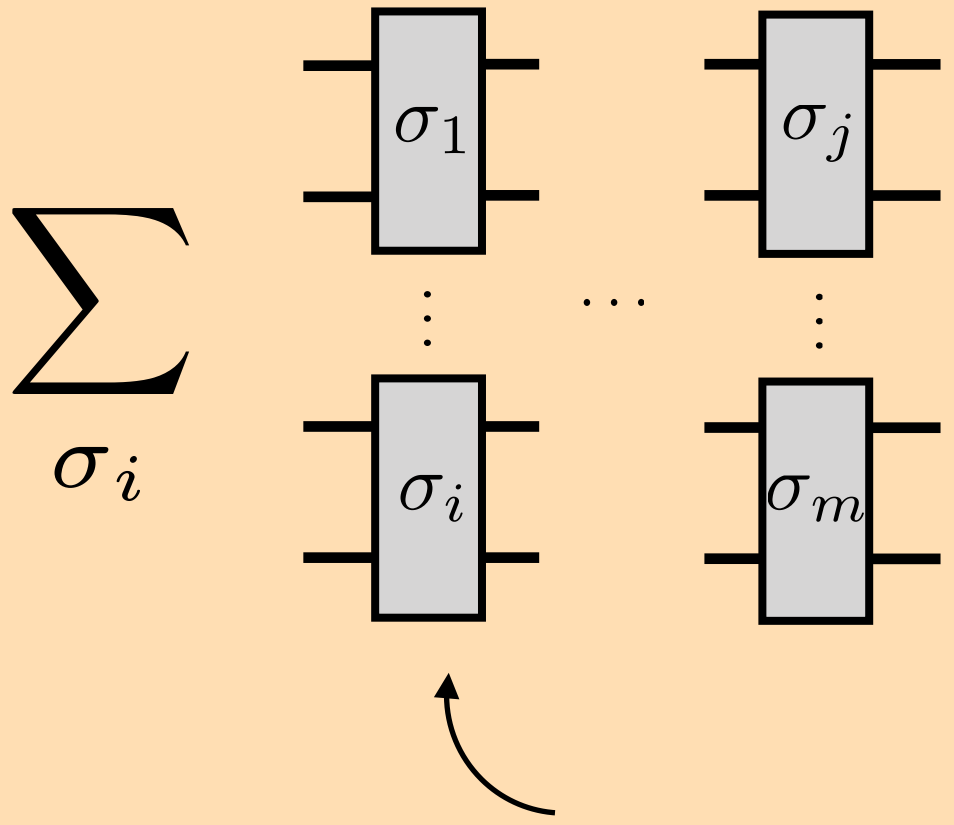

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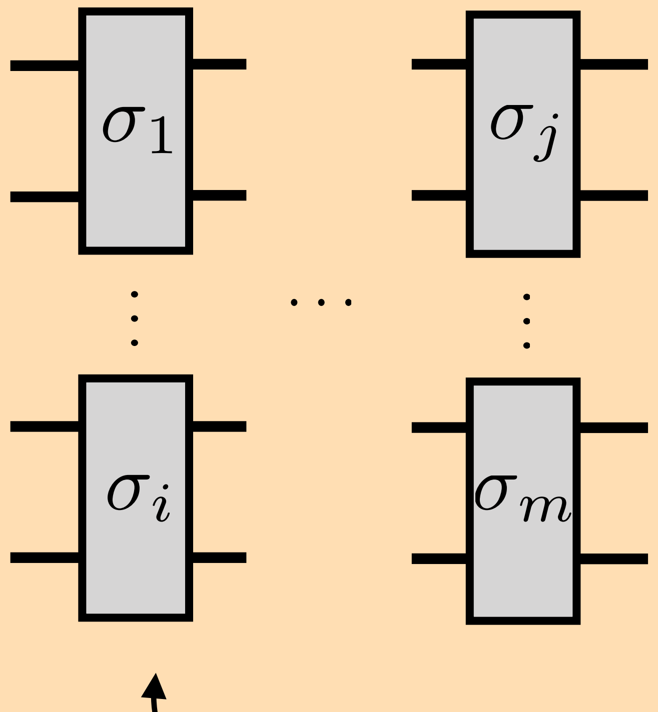

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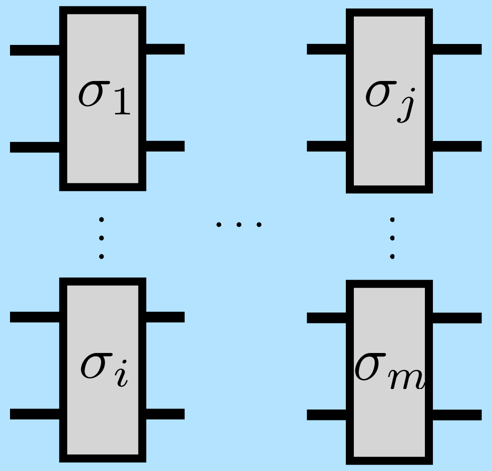
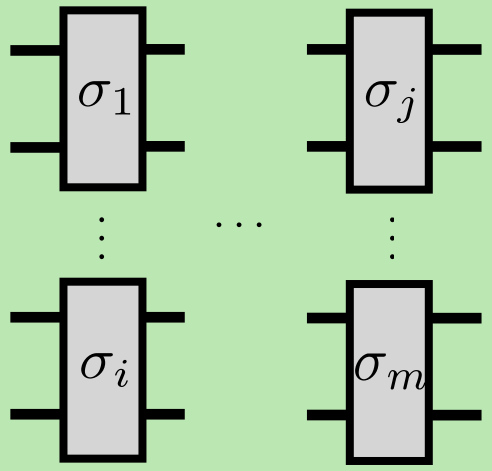
Google's Noisy Simulation



Our Lightcone Algorithm



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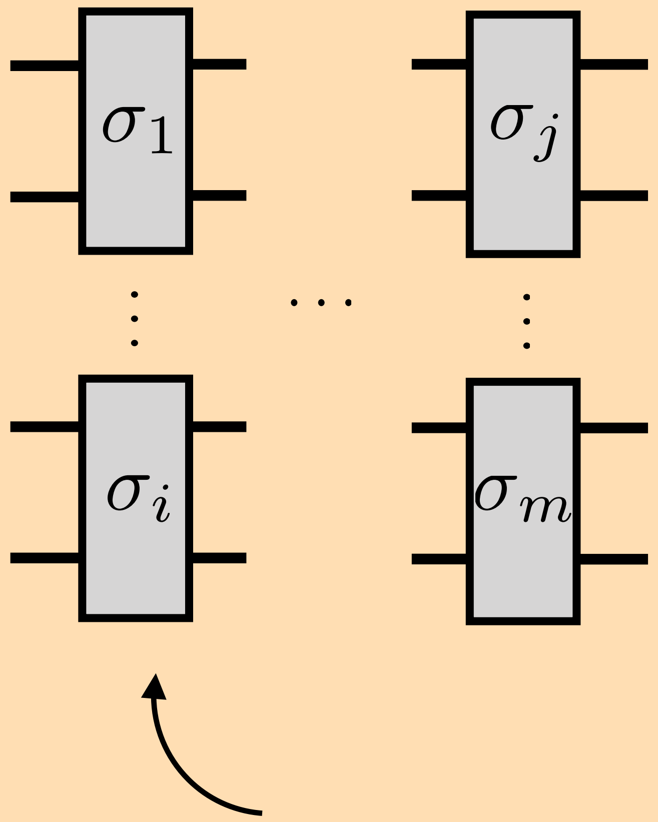

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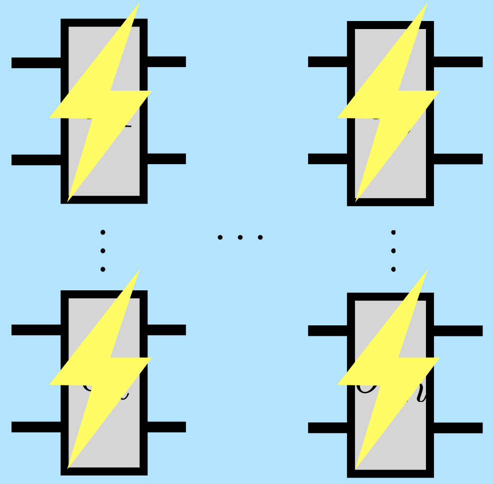

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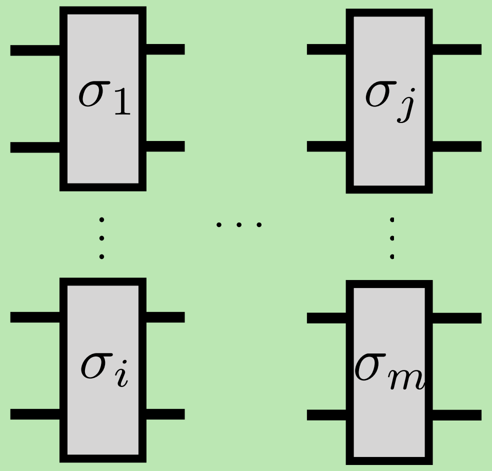

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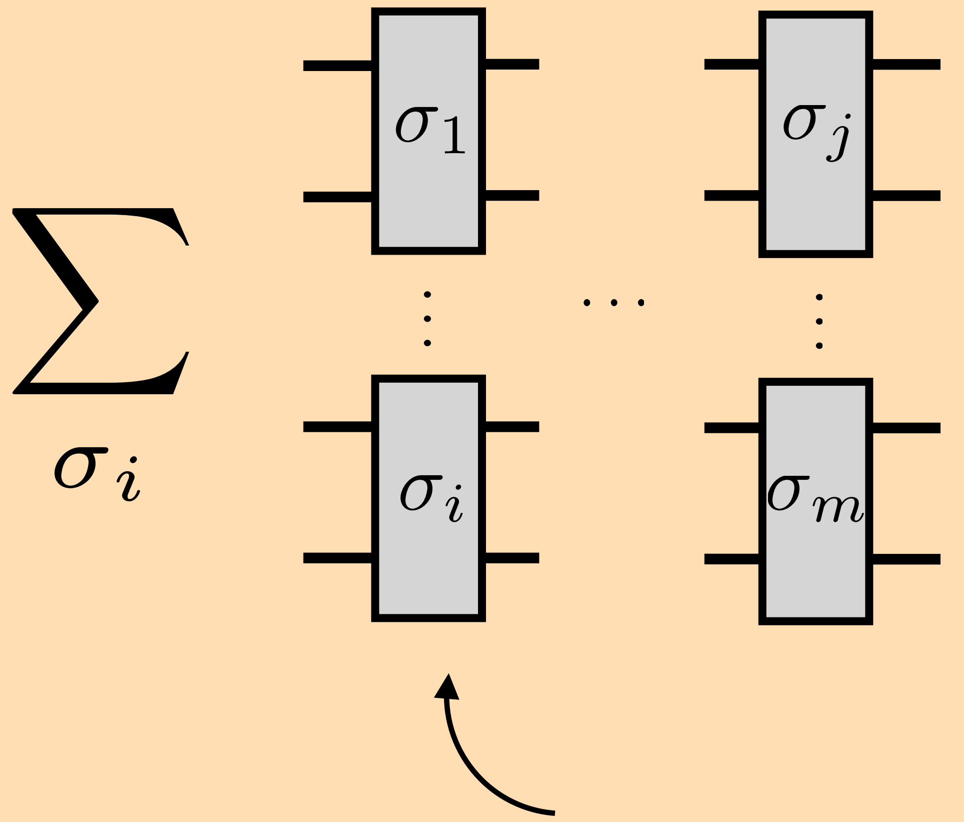

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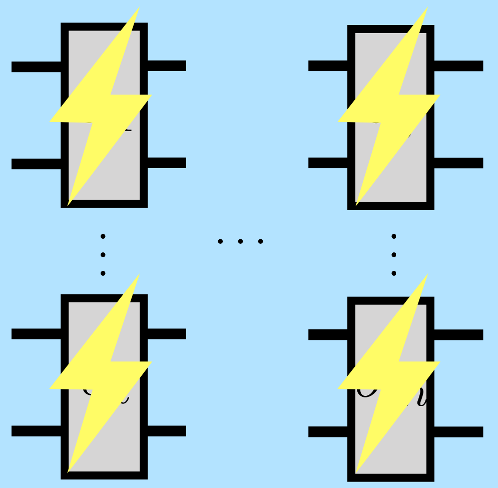
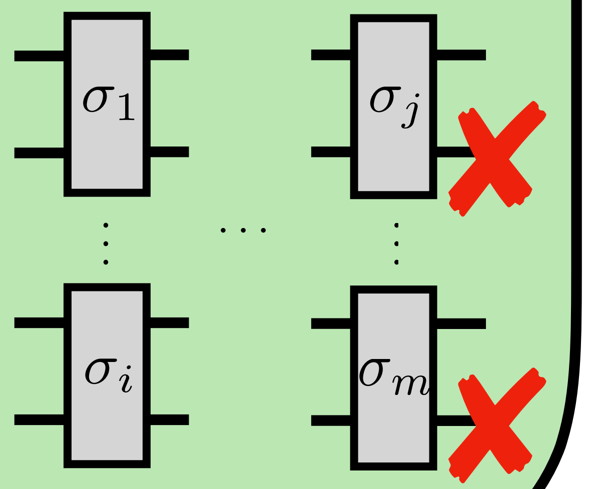


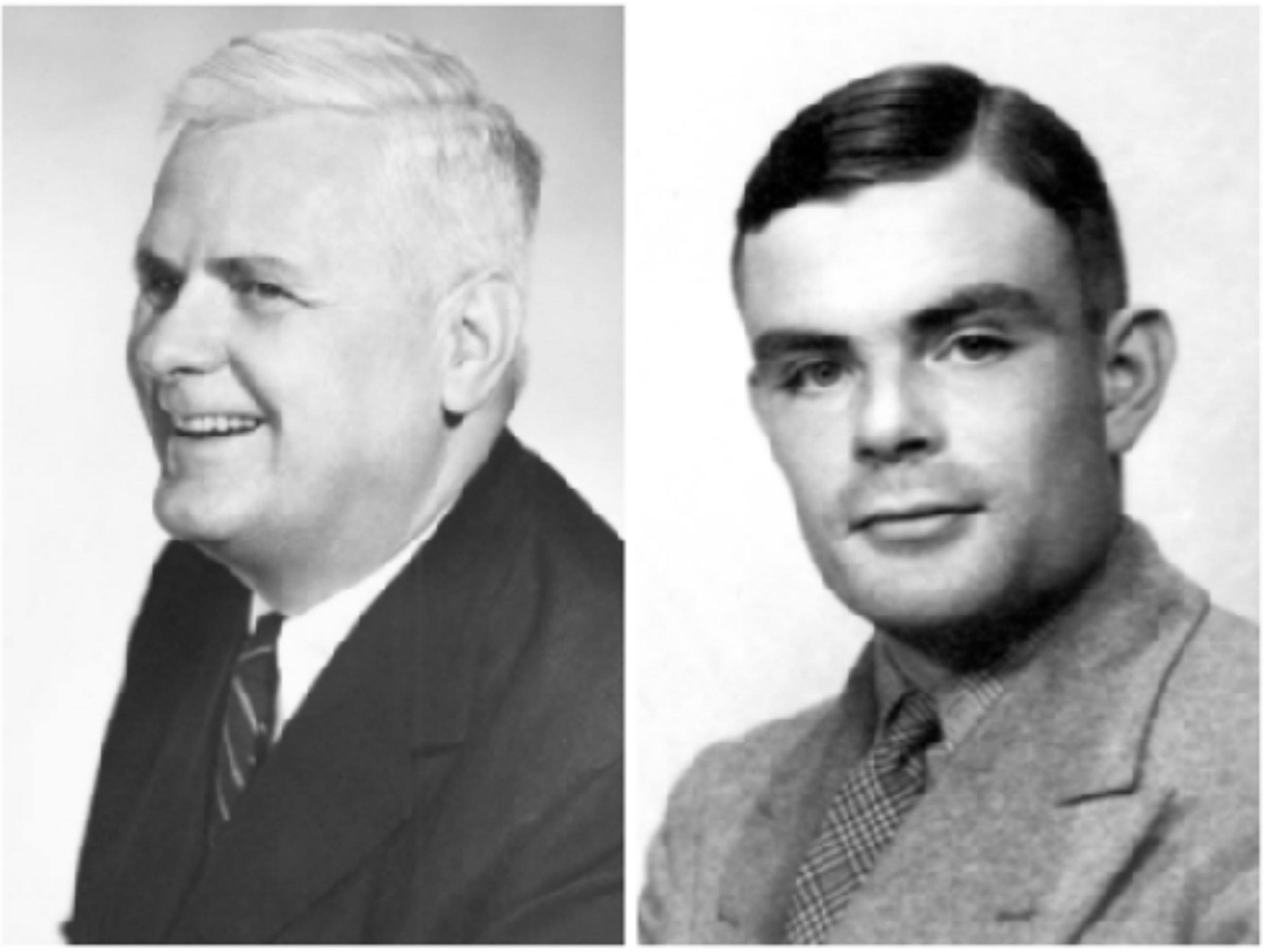
Our Lightcone Algorithm

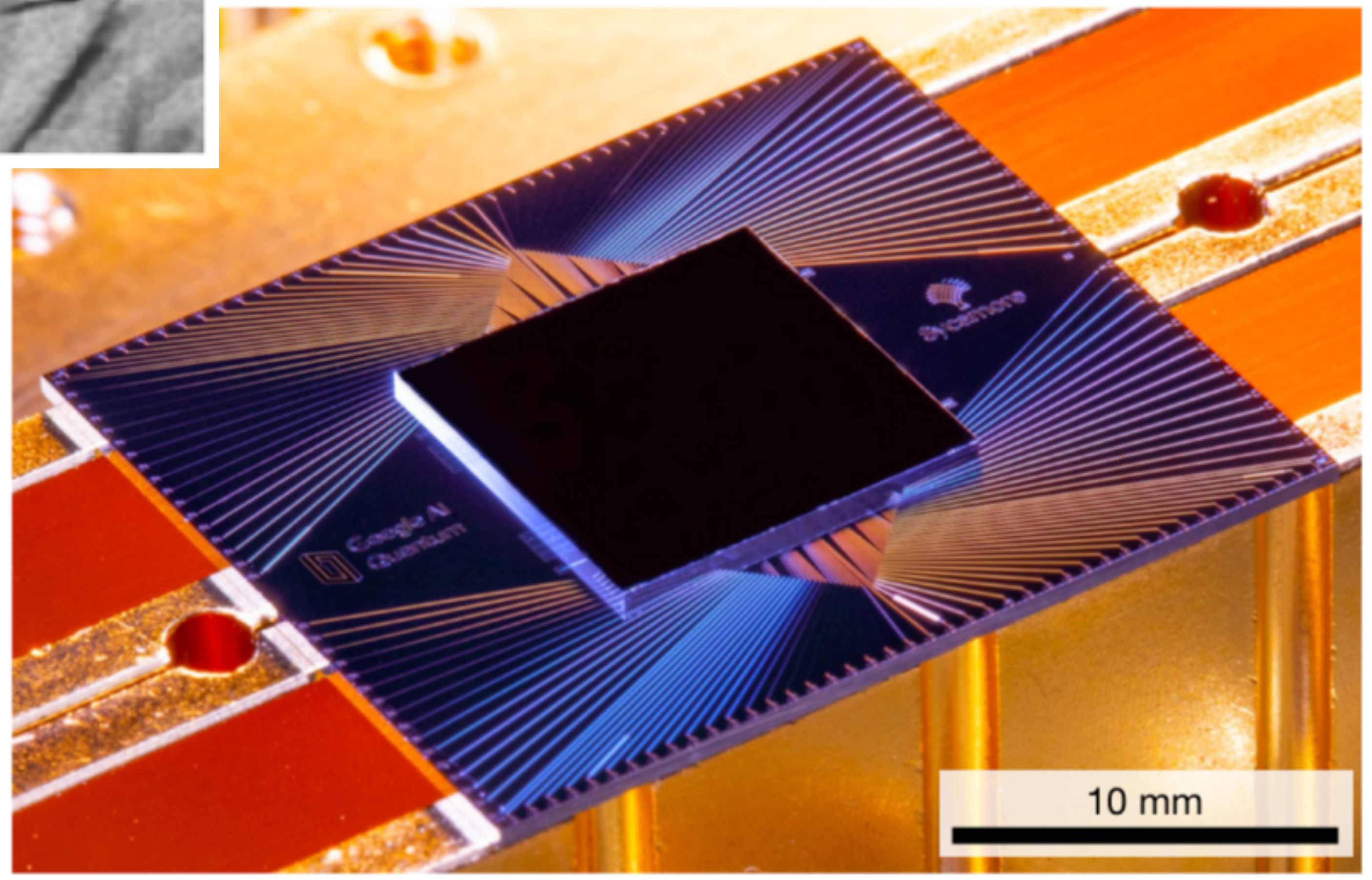
Picking disjoint lightcones = adding noise to non-chosen output qubits.



Perspectives

We are still few steps away from the quantum supremacy regime?





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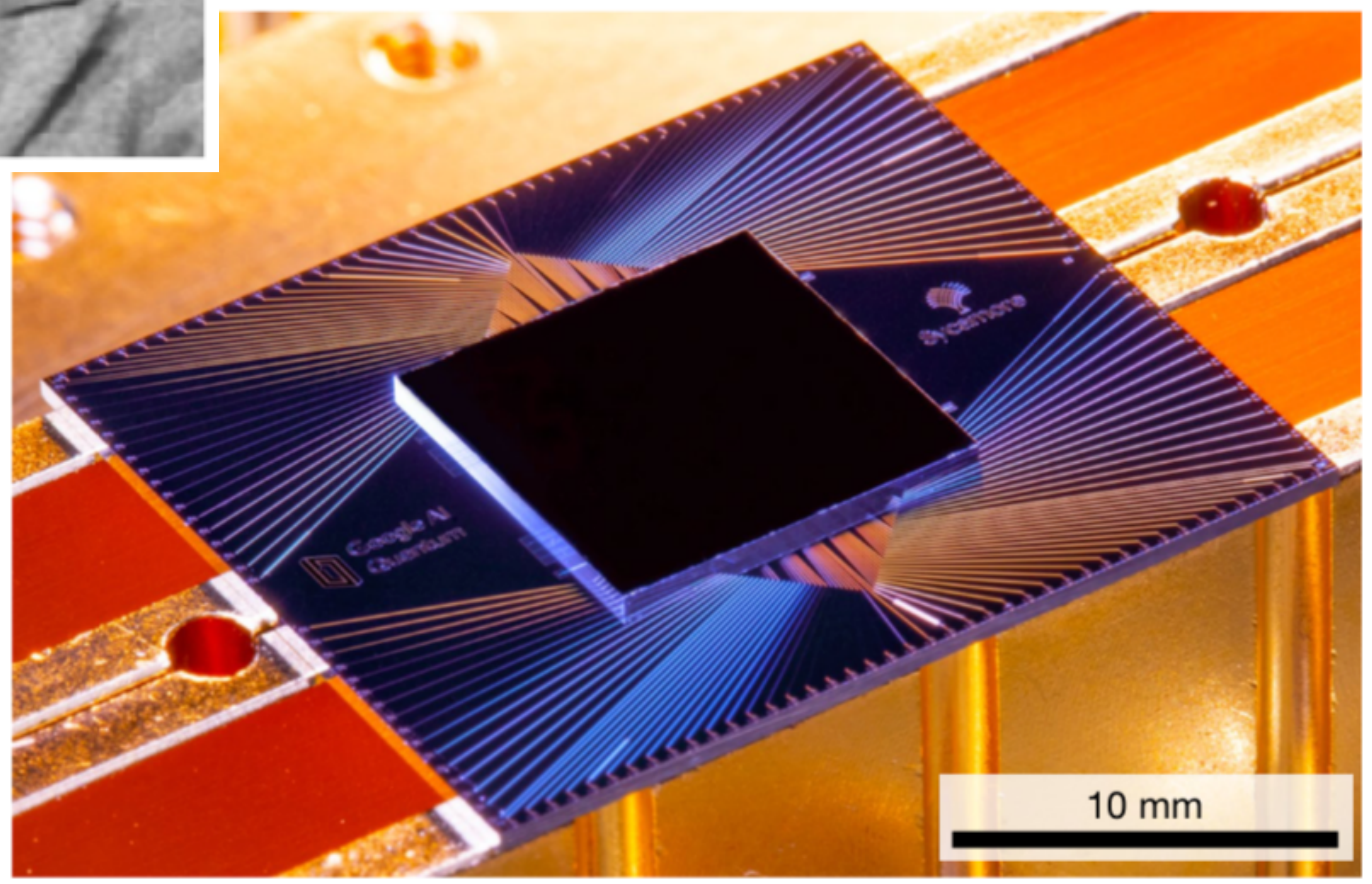

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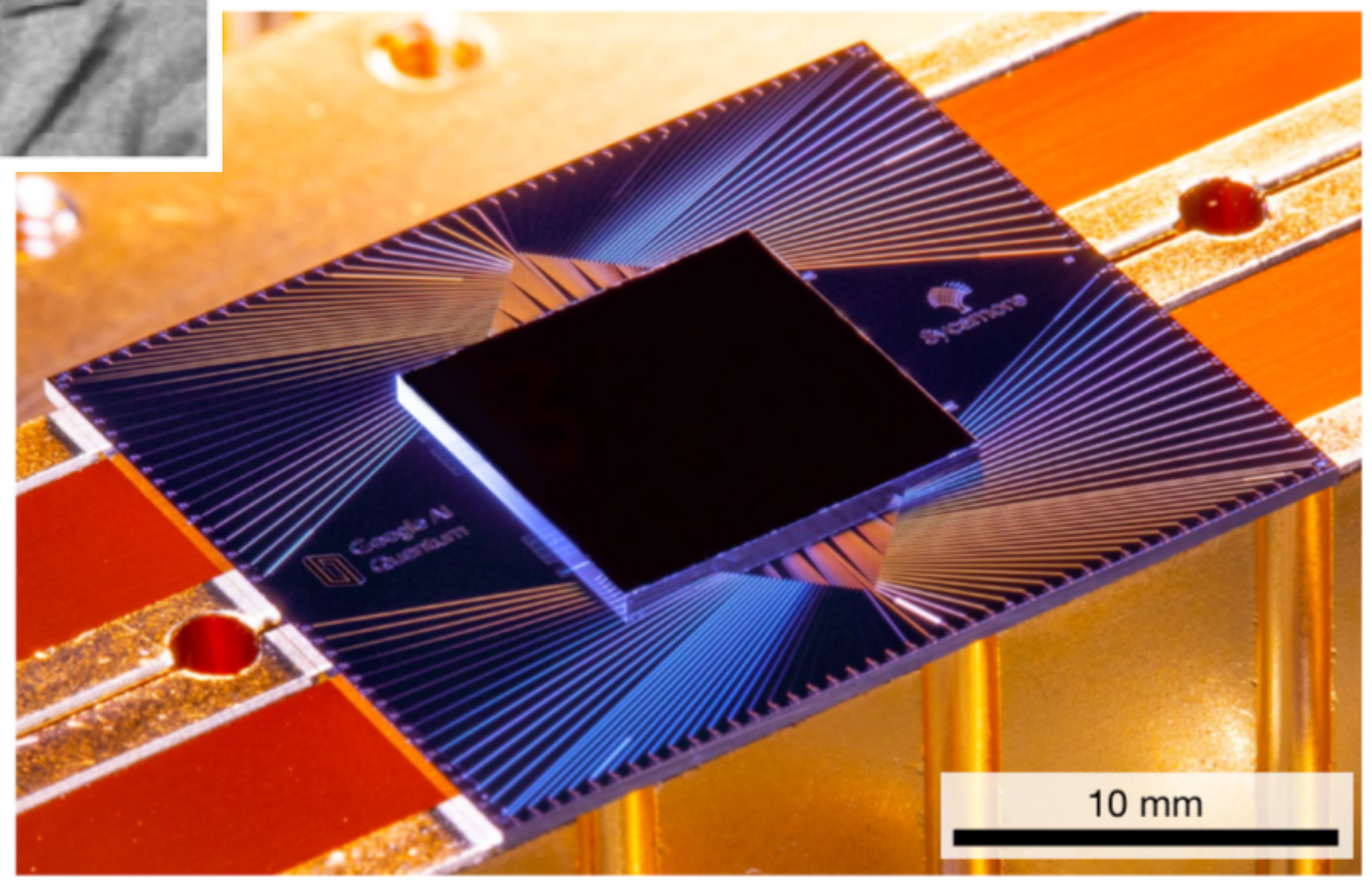

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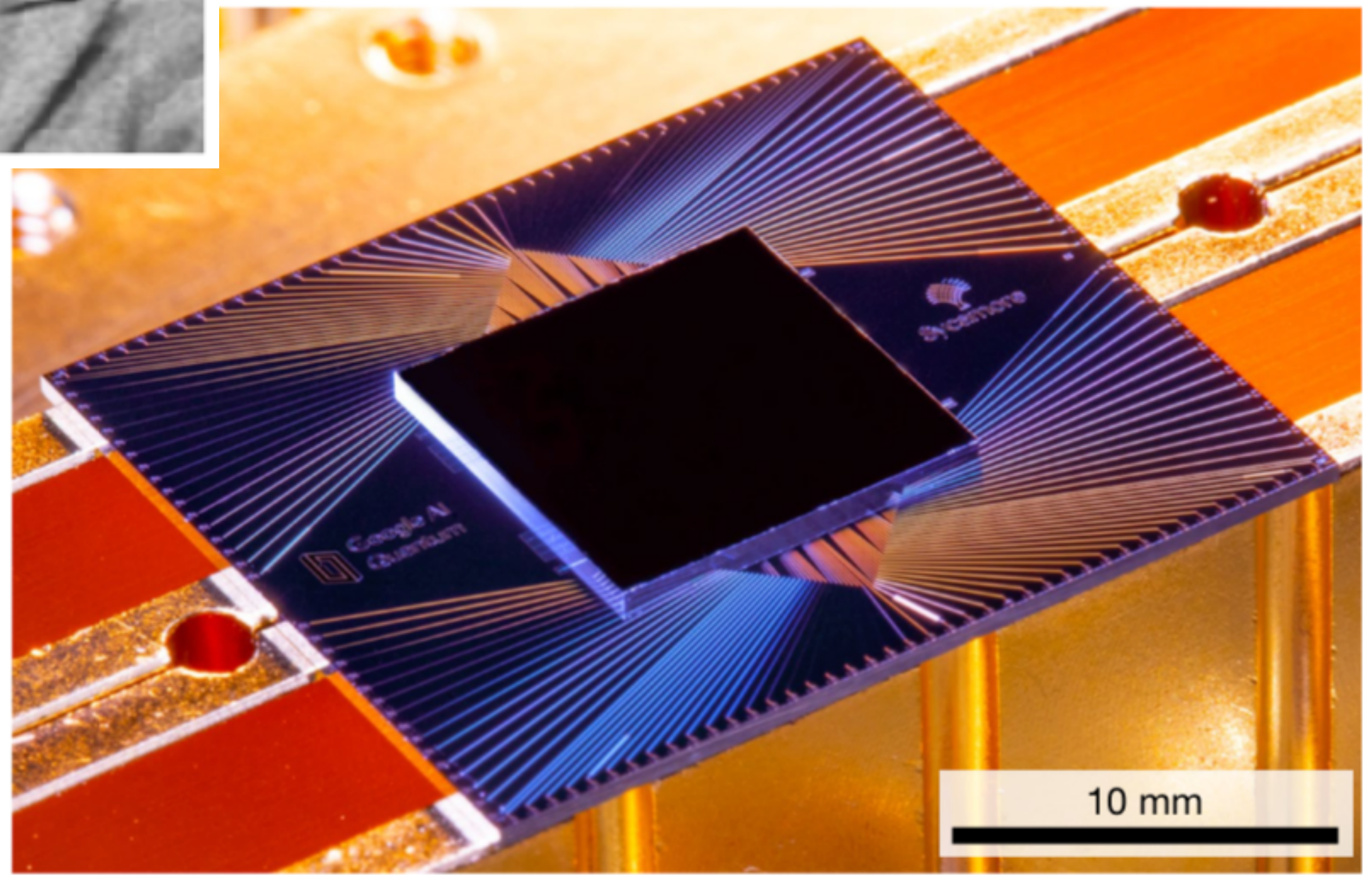
- Noise in real-world quantum devices is essential and subtle.
- A random walk picture for Linear XEB.



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Experiment

New Proposal?

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Thanks for your attention!