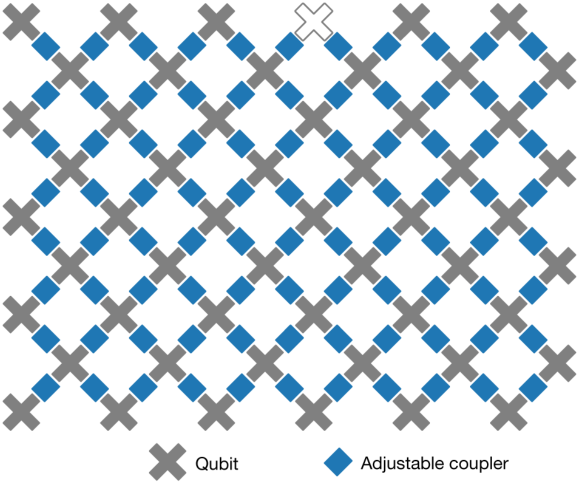
Can we implement good quantum LDPC codes on near-term devices?

Maxime Tremblay[1], Michael Beverland[2], Nicolas Delfosse[2]

[1]Université de Sherbrooke, [2]Microsoft Research

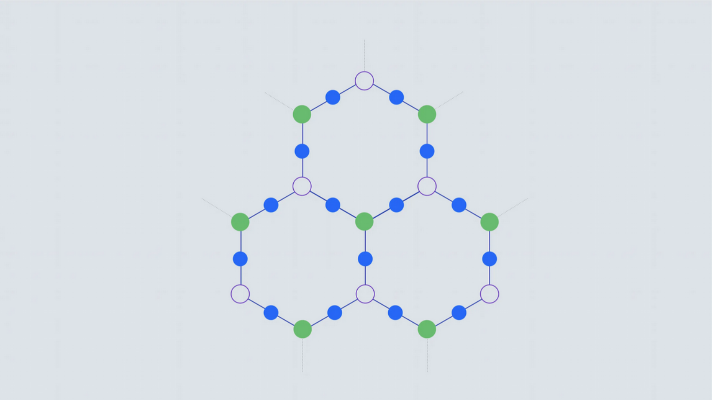
February 4, 2022



Arute et al. Nature 574, 505–510 (2019)

The IBM Quantum heavy hex lattice

As of August 8, 2021, the topology of all active IBM Quantum devices will use the heavy-hex lattice, including the IBM Quantum System One's Falcon processors installed in Germany and Japan.



Near-term quantum computers will be locally connected.

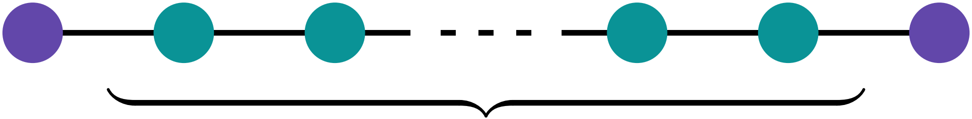
Can we achieve large scale fault-tolerant quantum computing on locally connected devices?

Tradeoffs for reliable quantum information storage in 2D systems

Sergey Bravyi,[1] David Poulin,[2] and Barbara Terhal[1]
[1] *IBM Watson Research Center, Yorktown Heights NY 10598, USA*
[2] *Département de Physique, Université de Sherbrooke, Québec, Canada*
(Dated: September 11, 2018)

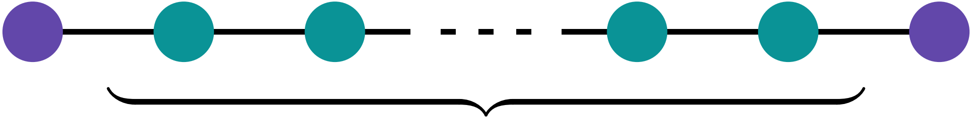
Long range interactions from local operations

Long range interactions from local operations

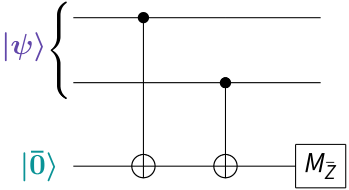


$$|\bar{0}\rangle \equiv |++\cdots++\rangle + |--\cdots--\rangle$$

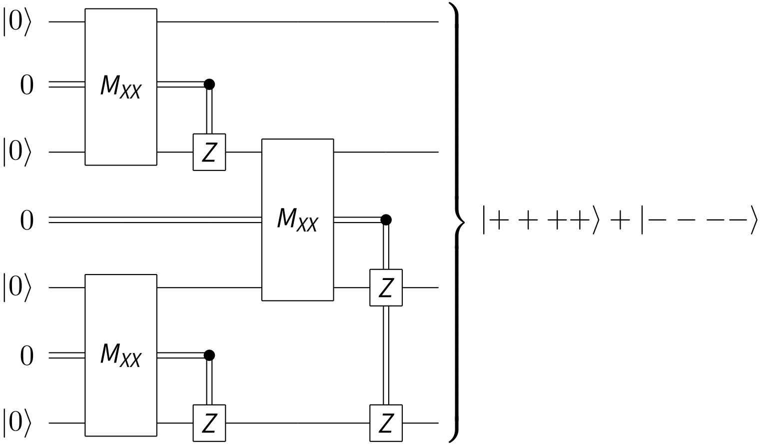
Long range interactions from local operations



$$|\bar{0}\rangle \equiv |+ + \cdots + +\rangle + |- - \cdots - -\rangle$$



Long range interactions from local operations



Main results

Theorem

Let C be a Clifford circuit measuring computing Pauli operators $S_1, \dots, S_r$. Then, for any subset of qubits L, we have

$$depth(C) \geq \frac{n_{cut}}{64|\partial L|}.$$

Main results

Theorem

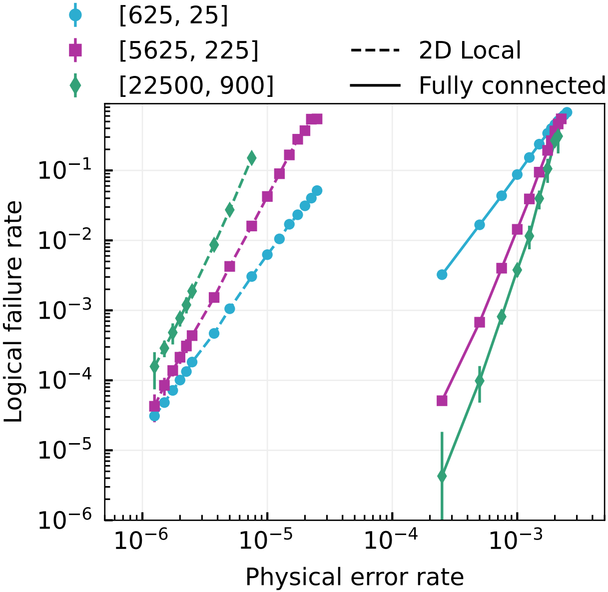
Let C be a Clifford circuit measuring computing Pauli operators $S_1, \ldots, S_r$. Then, for any subset of qubits L, we have

$$depth(C) \geq \frac{n_{cut}}{64|\partial L|}.$$

Corollary

For families of local-expander quantum LDPC codes of length n, a syndrome extraction circuit C implemented as a local Clifford circuit on a $\sqrt{N} \times \sqrt{N}$ grid of qubits satisfies

$$depth(C) \geq \Omega\left(\frac{n}{\sqrt{N}}\right).$$


[625, 25]
[5625, 225]
[22500, 900]
2D Local
Fully connected
Logical failure rate
Physical error rate
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-6}
10^{-5}
10^{-4}
10^{-3}

References

- Bounds on stabilizer measurement circuits and obstructions to local implementations of quantum LDPC codes
  arXiv 2109.14599
- Constant-overhead quantum error correction with thin planar connectivity
  arXiv 2109.14609

Outline

1. Quick review of stabilizer codes
2. Clifford circuits
3. Graphs, graphs and more graphs
4. Proof of the main theorem
5. Circuit implementations