Floquet Code

From Honeycomb Code to Toric Code

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Outline

Outline

Benefit of Floquet Code

Low-weight Measurement

- As a result, good threshold?

Low Connectivity Requirement

- Give visualization

Floquet Code's Stats

Floquet Code has good qualities

- **Threshold** of $0.2\% - 0.3\%$ without native **weight-2 measurement** [1][1]
- Thershold of $1.5\% - 2.0\%$ with native weight-measurements [1]
- Photon loss threshold: 6.4% on photonic platform [2]
- Code Overhead: $\lim_{n\to\infty} \frac{k}{n} \to \frac{1}{2}$ on qudit codes [3]
- $5.6\times$ fewer physical qubits are needed to implement Floquet code at depolarizing noise of 0.1% compare to surface code [4]

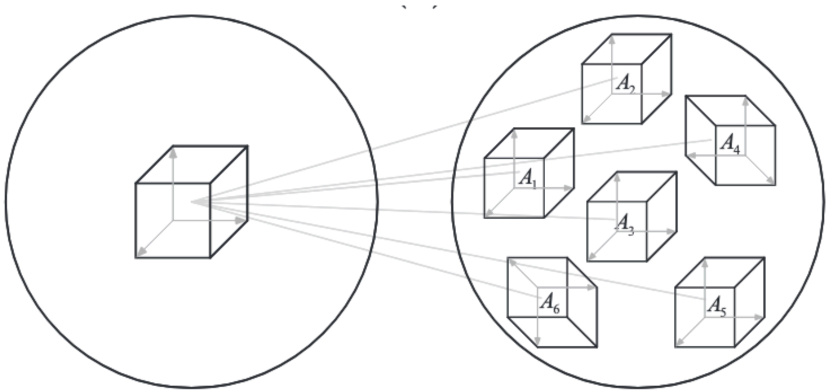
[1] $0.5\% - 0.7\%$ for surface code (which surface code was this? which error model?)

Outline

Stabilizer Code

Example: [[4,2,2]] Code

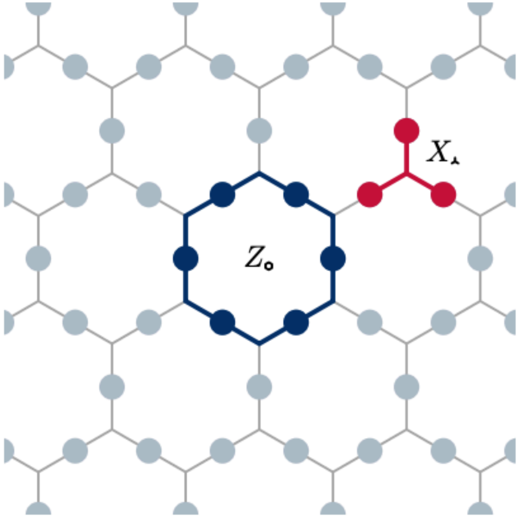
- Stabilizers are product of Pauli operators on qubits: $X_1X_2X_3X_4$ and $Z_1Z_2Z_3Z_4$
- Measurement result of stabilizers signals whether you have an error



- Logical Operators commutes with stabilizers but cannot be generated by them: $\widetilde{X}_1 = X_1X_2$, $\widetilde{X}_2 = X_1X_3$, $\tilde{Z}_1 = Z_1Z_3$ and $\tilde{Z}_2 = Z_1Z_2$

Stabilizer Code

Example: Toric Code



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[1]Kott, Viktor, et al. "Quantum robustness of the toric code in a parallel field on the honeycomb and triangular lattice." arXiv preprint arXiv:2402.15389 (2024).

Subsystem Code

Example: [[4,1,2]] Code

- **Checks**: X_1X_3, X_2X_4, Z_1Z_2, Z_3Z_4
- **Not necessarily commute** with each other
- Generated group has center $X_1X_2X_3X_4$ and $Z_1Z_2Z_3Z_4$.
- Logical operators commutes with all **checks**: X_1X_2, and Z_1Z_3

Outline

Motivations

Static Code

Floquetification

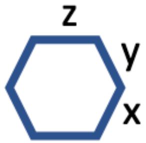
Conclusion

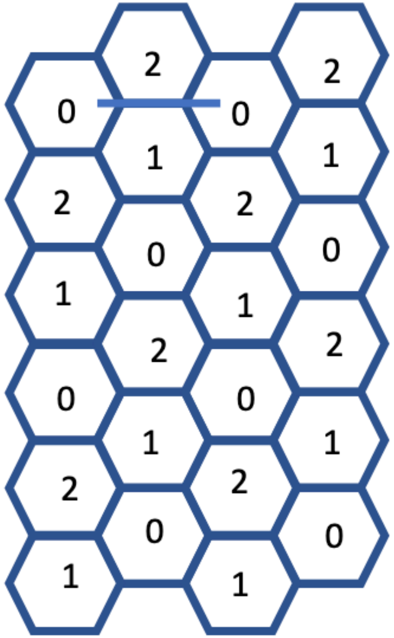
Appendix

Honeycomb Code:

Definition:

1. Qubits on vertices of lattice
2. Each edge associated with a check
3. Each plaquette associated with a type 0,1,2
4. Each edge associated with a type 0,1,2
5. Measurement sequence according to edge type



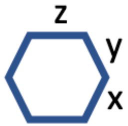


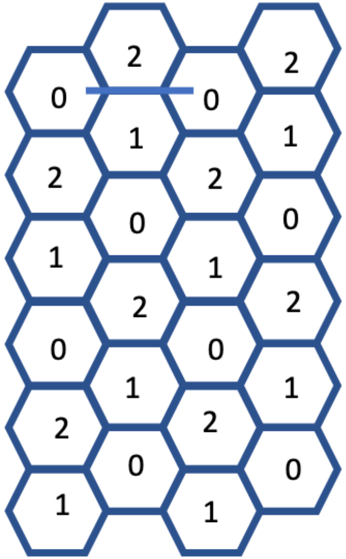
Honeycomb Code:

Check Measurement gives rise to instantaneous stabilizer groups

Given a state stabilized by $\mathcal{S}$: a group generated by Pauli String operators, projective measurement of Pauli String operators P modifies the stabilizer group of the state as

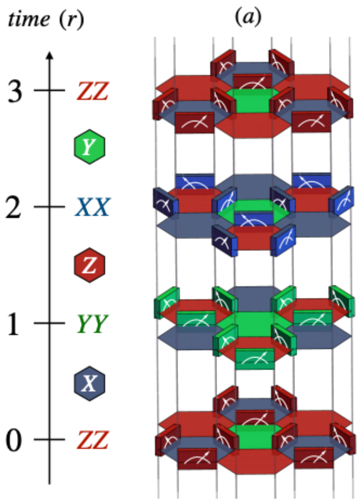
1. if $P \in \mathcal{S}$ or $-P \in \mathcal{S}$, ISG remains
2. if $P \notin \mathcal{S}$ and $-P \notin \mathcal{S}$
    1. P commutes with all of $\mathcal{S}$, include $\pm P$ in ISG depending on the measurement result
    2. P commutes with all of $\mathcal{S}_0 \subset \mathcal{S}$, ISG is $\mathcal{S}_0 \cup \pm P$





Honeycomb Code:

Measurement Visualized



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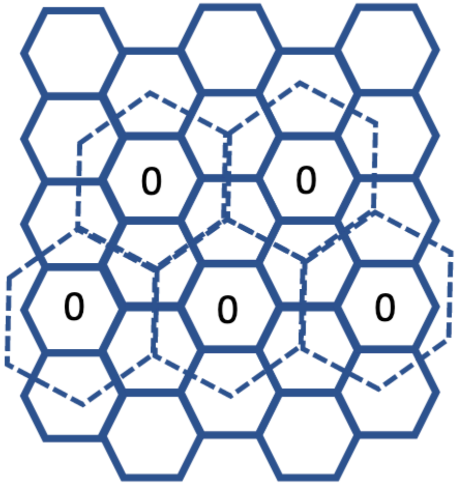
[1]Zhu, Guo-Yi, and Simon Trebst. "Qubit fractionalization and emergent Majorana liquid in the honeycomb Floquet code induced by coherent errors and weak measurements." arXiv preprint arXiv:2311.08450 (2023).

Honeycomb Code:

Embeded Toric Code

- ISG at step $r \geq 3$ contains all hexagons and $r \bmod 3$ edge checks.
- Each edge check halfs the degree of freedom of qubits on the edge.
- Effectively, the code is a **lattice of hexagons** with **embedded toric code** on each hexagon.



[5]

Outline

Conclusion

- Honeycomb Code on a hexagonal lattice is “equivalent” to Toric Code on a hexagonal superlattice
- Floquet code has comparable quality as surface code but requires lower connectivity on hardware

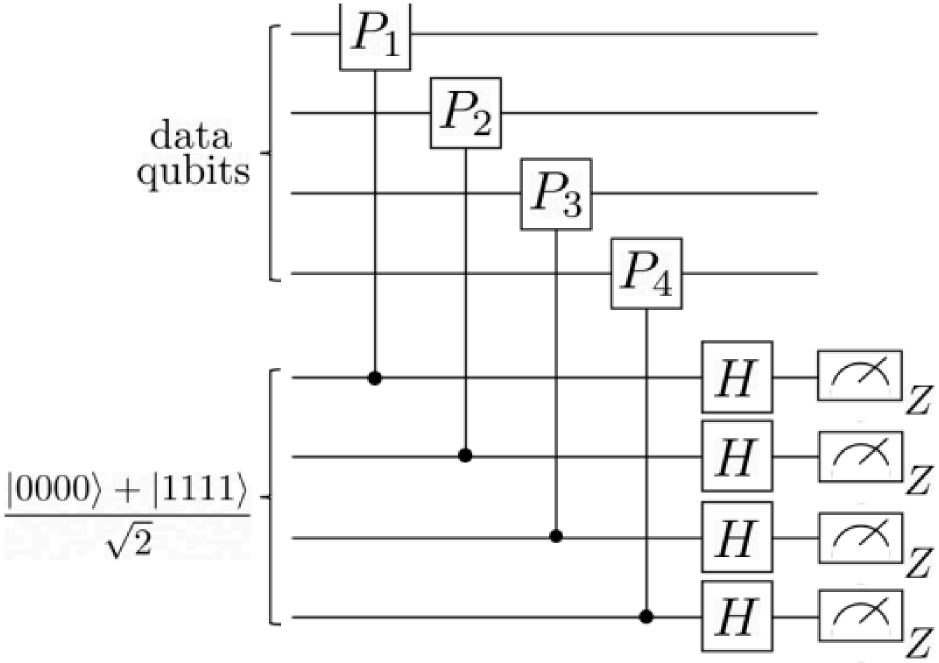
Outline

Terms

- “The **teraquop footprint** is the number of physical qubits required to create a logical qubit reliable enough to survive one trillion operations."

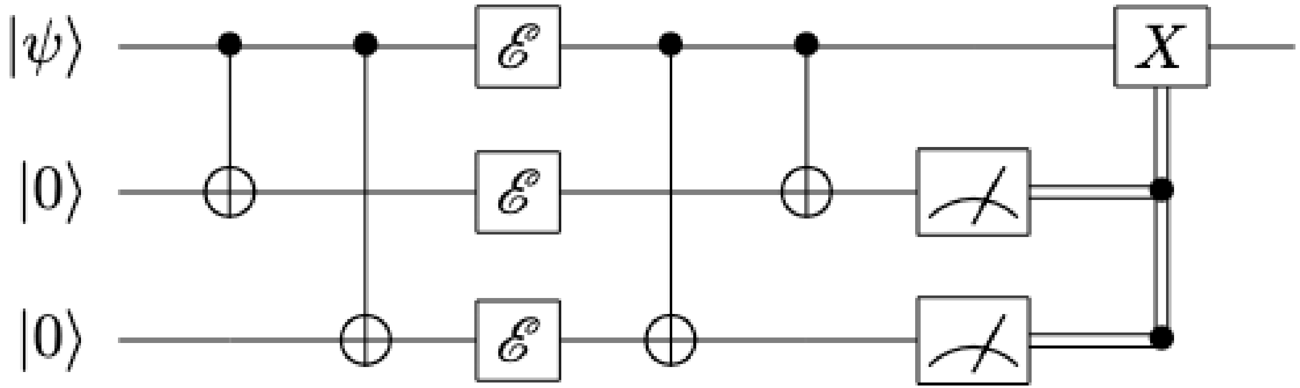
Terms

Static Code: Shor-style Measurement



Terms

Repetition Code: Encoding, Syndrome Extraction, and Error Correction



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3. Tanggara, A., Gu, M., Bharti, K.: Simple Construction of Qudit Floquet Codes on a Family of Lattices, http://arxiv.org/abs/2410.02022
4. Higgott, O., Breuckmann, N. P.: Constructions and Performance of Hyperbolic and Semi-Hyperbolic Floquet Codes, http://arxiv.org/abs/2308.03750

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5. Hastings, M. B., Haah, J.: Dynamically Generated Logical Qubits. Quantum. 5, 564–565 (2021). https://doi.org/10.22331/q-2021-10-19-564