FCM: A Fusion-aware Wire Cutting Approach for Measurement-based Quantum Computing

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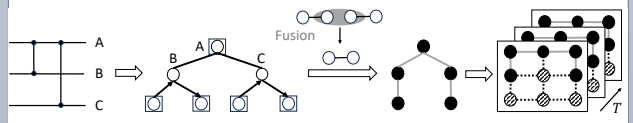
Introduction

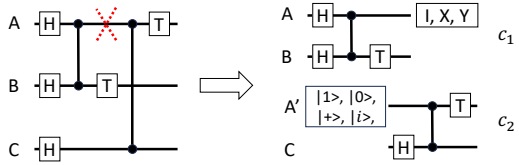
- MBQC carries out computation by one-way measurements on entangled photon qubits and highly error-prone quantum operations named fusion.
- Current compilation frameworks on MBQC result in too many fusions and low fidelity. While naïve wire cutting can decompose circuits, it fails to achieve the highest fidelity.
- We propose **FCM**, a Fusion-aware Cutting approach for MBQC. It uses mixed-integer programming (MIP) to achieve the balance between post-processing overhead and fidelity.
- FCM can reduce the maximum number of fusions of all subcircuits by **59.6%** on average (up to **69.1%**).

Background

- A standard compilation procedure of MBQC.



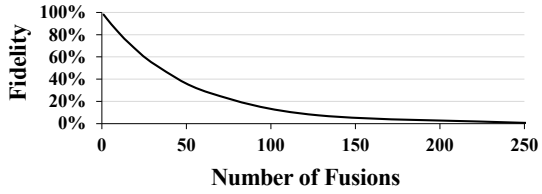
- The fusion is a native measurement operation in MBQC to connect graph states with a success rate of 75%.
- Wire cutting splits one circuit into two subcircuits, post-processing is required to reconstruct the original result.



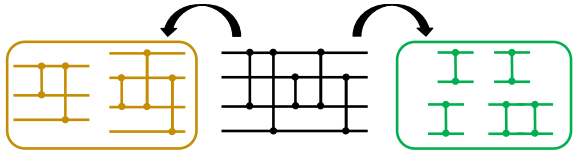
- Wire cutting improves fidelity with post-processing overhead, which increases with #cuts exponentially.

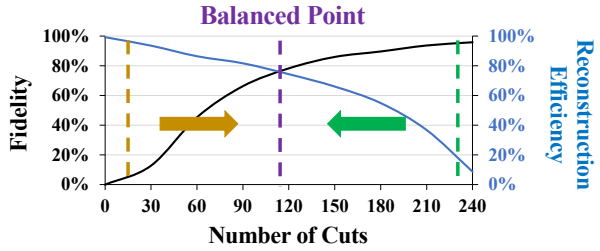
Motivation & Design

- The fidelity of MBQC paradigm deteriorates rapidly as gate operations and fusions increase.

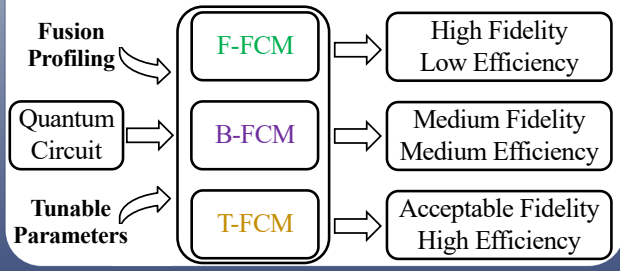


- Trade-off between fidelity and reconstruction efficiency is significant when applying wire cutting to reduce fusions.



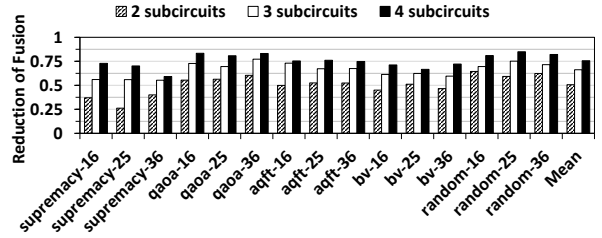


FCM: A fusion-aware MIP model to achieve different trade-off between the post-processing efficiency and the overall fidelity.



Result

- **B-FCM**:



- **F-FCM**: Reduces fusions up to **69.1%**, **85.5%**, and **90.7%** for k = 2, 3, and 4, respectively.
- **T-FCM**:

Benchmark	#Qubit	Reduction of #Cuts (#Subcircuits) under different thresholds T	
		1000	500
random	16	- (-)	7.1% (2)
	25	15.0% (2)	12.2% (3)
	36	14.3% (2)	11.6% (4)
qaoa	16	13.3% (2)	21.7% (3)
	25	11.1% (2)	19.2% (3)
	36	10.5% (2)	18.2% (4)

Conclusion

1. We reveal the potential opportunity of decomposing a circuit for fusion reduction through wire cutting.
2. We formulate the problem using MIP and optimize cutting decision under different settings.
3. FCM can achieve effective trade-off between the overall fidelity and the post-processing overhead.

References

[1] Wei Tang et al. 2021. CutQC: using small Quantum computers for large Quantum circuit evaluations. In ASPLOS, 2021. 473–486.

[2] Hezi Zhang et al. 2023. OneQ: A Compilation Framework for Photonic One-Way Quantum Computation. In ISCA, 2023. 12:1–12:14.