02

How to verify quantum computations by circuit partitioning

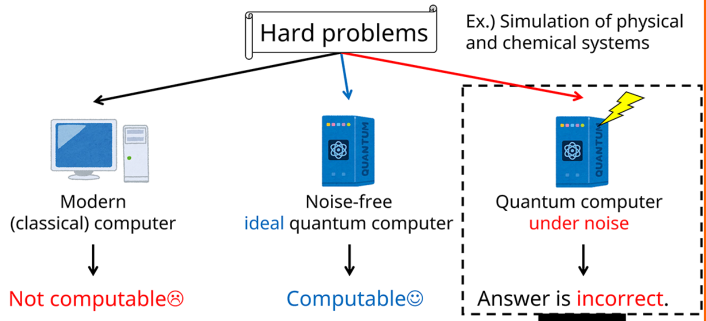
Is that quantum computer really working correctly?

Abstract

The size of quantum computers is increasing year by year; accordingly, it becomes harder to verify whether errors occur during quantum computation. We introduce our recent research on how to verify whether a near-future quantum computer works correctly. Most known verification methods do not apply to near-future quantum computers, since they are tailored to fault-tolerant universal quantum computers. Our novel verification method can be applied to quantum computers even without fault-tolerance in the near-future. Verification of quantum computation is crucial to realize cloud quantum computing systems, in which no or only limited information on errors is known to users. Further improvement on our method will surely contribute to reliable cloud quantum computing systems, so that quantum computers will be available to anyone anytime and anywhere.

Background & Our Results

Quantum computers are expected to outperform classical computers but are sensitive to noise.



It is important to verify the correctness.

✓ **Key point**: Verification should be performed by using classical computers or small-scale quantum devices.

Our result [1] NISQ…Noisy Intermediate-Scale Quantum

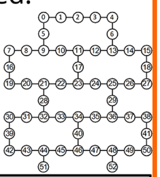
We have proposed a method of efficiently verifying whether outputs of NISQ computers are correct.

NISQ Computer

Near-future quantum computers with following limitations:

- Applicable two-qubit operations are limited.
- Error correction cannot be performed.

→Complex computation is out of scope.

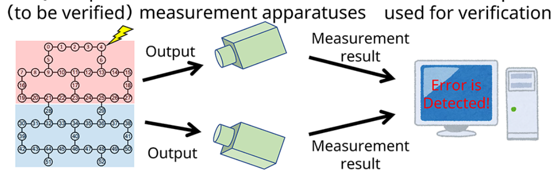


IBM's NISQ computer chip (schematic diagram)

Problem Since existing methods regard the limitations of NISQ computers as errors, they cannot be applied to NISQ computers☹

Our proposed method

Approach Measure output states of NISQ computers by using small-scale quantum measurement devices.

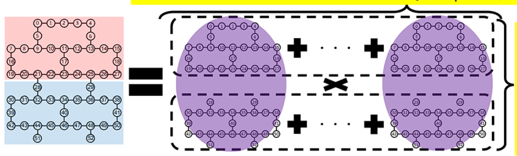


Issue The information on the quantum correlation between quantum states in red and blue regions is lost by dividing the output states.

Solution Represent the quantum correlation by the sum and (tensor) product of separable states, and then check the necessary parts of them.

➡ The verification becomes possible!

Observation The accuracy of the verification becomes worse as the number of "states" increases. → In the case of NISQ computers, it is not large.



Observation It takes long time to check all products. → It is sufficient to randomly check only $O(S^{2/3})$ patterns colored in purple.

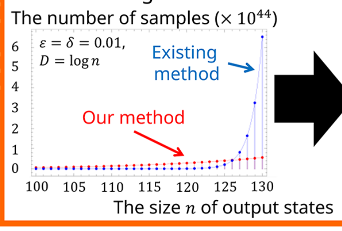
Comparison with existing method [FL11]

Our method requires the fewer number S of samples than the existing method.

[FL11] S. T. Flammia, Y.-K. Liu, *Phys. Rev. Lett.*, Vol. 106, 230501, 2011.

ϵ: Accuracy of verification (Value of error)
δ: Probability of error being larger than ϵ
D: Number of quantum operations across the two regions. In the case of NISQ computers, $D = O(\log n)$.

$$S = O\left(\frac{2^{12D}}{\epsilon^6}\left(D + \log\frac{1}{\delta\epsilon^4}\right)^3\right)$$



When $n = 130$, our method requires 8×10^6 times fewer samples than the existing method.

References

[1] Y. Takeuchi, Y. Takahashi, T. Morimae, S. Tani, "Divide-and-conquer verification method for noisy intermediate-scale quantum computation," *Quantum*, Vol. 6, p. 758, 2022.

Contact

Yuki Takeuchi
Computing Theory Research Group, Media Information Laboratory