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Reshaping noises to improve accuracy of quantum computation

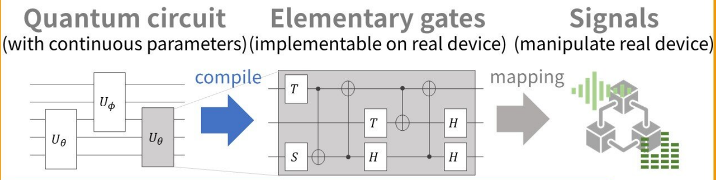
Crafting noises in quantum computing!

Abstract

Quantum computers face challenges due to various types of noise during calculations. Although many suppression methods have been proposed, it is difficult to control noise when its "shape" is irregular. This study introduces a method to reshape the noise by adding artificial noise to naturally occurring noise. We devised a way to add artificial noise that minimizes the reshaped noise. By reshaping the noise, it becomes easier to suppress, and the overall noise can be significantly reduced. These combined effects are expected to greatly improve the accuracy of quantum calculations. Enhanced precision in quantum computing could enable large-scale, complex calculations and simulations, potentially solving major issues in fields such as pharmaceuticals, logistics, healthcare, and scientific technology. This research outcome is anticipated to pave the way for quantum computers to contribute to a richer future society.

Noise applied during circuit implementation

- Quantum computers are much more powerful than classical ones. However, they are more susceptible to noise, which leads to larger calculation errors.
- Noise occurs not only in the real device but also in the process called **compilation**, where quantum circuits are converted into a form suitable for the real device.

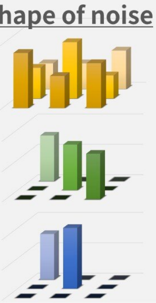


Types of noise and suppression methods

- Various methods have been proposed to suppress noise by repeating the same calculation.
- The cost for noise suppression (e.g., the number of repetitions) varies depending on the type of noise. In particular, logical noise is difficult to suppress.

Logical noise: Noise applied by discretizing continuous parameters during compilation.

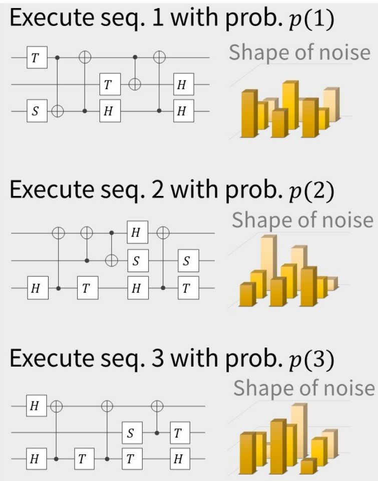
Physical noise: Noise that occurs in the real device. Quantum error correction will reduce it in the long term.



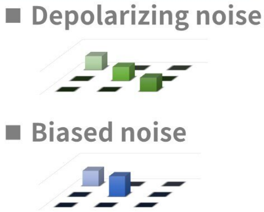
Types of noise	Shape of noise	Suppression methods and cost
Coherent noise: (e.g., logical noise)		**Method: Probabilistic error cancellation** Cost: **Large**
Depolarizing noise: (e.g., physical noise)		**Method: Rescaling** Cost: **Small**
Biased noise: (unnatural noise)		**Method: Error detection** Cost: **nearly zero**

Reduction and Transformation of Logical Noise

- We proposed a probabilistic compilation that switches elementary gate sequences probabilistically.
- This achieves an optimization that reduces noise and reshapes it into a regular form simultaneously.

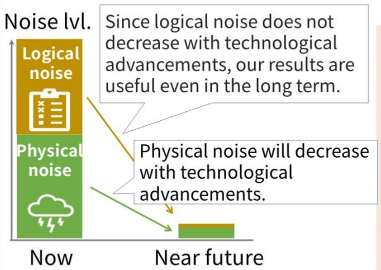


- By sophisticatedly designing $p(x)$, we merge and counteract the logical noise.
- While minimizing the overall noise, convert it into depolarizing or biased noise that is easier to suppress.



Effects of our research

We can reshape all noise occurring during computation into forms that are easy to suppress, enabling accurate calculations even in near-term quantum computers.



We significantly reduce errors ϵ (e.g., ϵ =10%) resulting from logical noise.
$\epsilon \to \epsilon^2$ **(depolarizing noise)**
$\epsilon \to \epsilon^3$ **(biased noise)**
E.g., **10%→1% (or 0.1%)**
It requires a long compilation time to reshape logical noise into biased noise.

References

[1] N. Yoshioka, S. Akibue, H. Morisaki, K. Tsubouchi, Y. Suzuki, "Error crafting in mixed quantum gate synthesis", *arXiv*, 2405.15565, 2025.

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