Fast probabilistic conversion into quantum gate sequences

Improving the reliability of quantum computation

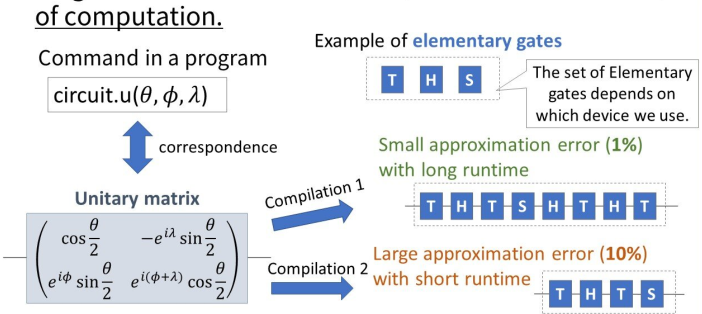
Abstract

Converting a program into a gate sequence is required for performing fault-tolerant quantum computation. The process of this conversion is called compilation. However, to ensure the reliability of the computation, it is usually necessary to increase the gate length, which results in a longer computational time. In this work, we have developed a compilation method that can enhance reliability without increasing the gate length.

We have developed an efficient compiler that probabilistically generates a gate sequence from a list of short gate sequences with an optimal probability distribution that maximizes reliability. Our research has shown that our compiler can achieve the fundamental limit of reliability, both in theory and through numerical simulations. It is imperative to develop a cutting-edge compiler to achieve the full potential of quantum computation, which has the power to revolutionize our society. We believe that our compiler provides a practical foundation for realizing quantum computation.

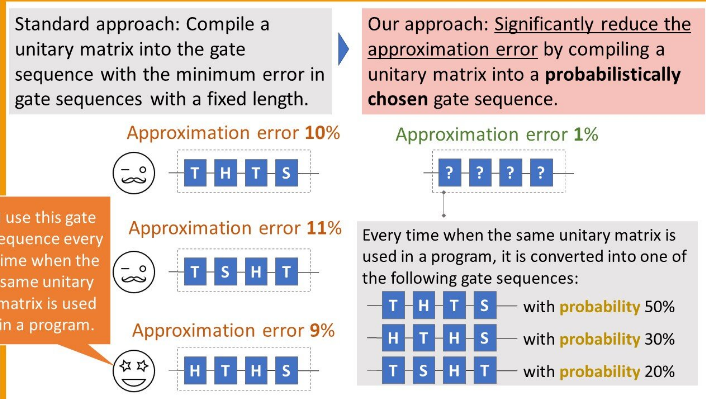
Compilation of quantum program

- We implement a physical operation on multiple qubits and obtain a computation result by measuring them.
- The physical operation consists of unitary matrices, which are primitive commands of a quantum program.
- Since only a very restricted subset of unitary matrices, called elementary gates, is implementable in a real quantum device, each unitary matrix must be compiled into a sequence of elementary gates.
- Compilation causes an **approximation error**, reducing success probability of computation. Increasing gate length can reduce the error but increases the runtime of computation.



The objective is to minimize the approximation error by using the short gate sequences.

Our approach: probabilistic compilation

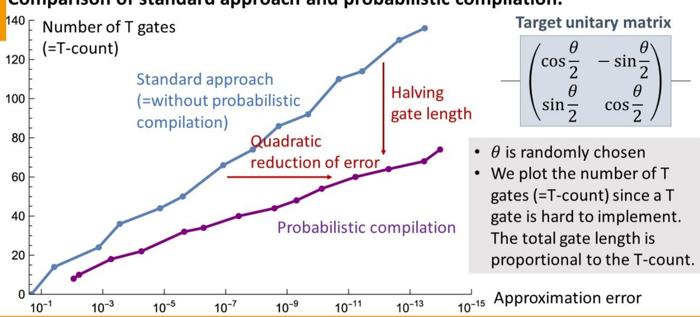


- We have demonstrated that the error can be significantly reduced by sophisticatedly designing a probability distribution p for choosing a gate sequence.
- While a primitive idea of probabilistic compilation can be found in a few previous researches, we have developed the **world's first probabilistic compiler** that can efficiently compile any unitary matrix and achieve the minimum approximation error.
- We have completely revealed the fundamental limit on the reduction rate of approximation error owing to any kind of probabilistic compilers.

Error reduction by probabilistic compilation

- We have verified numerically that the error reduction achieves the fundamental limit ($\epsilon \to \epsilon^2$) when compiling a random 2x2 unitary matrix.
- This means that our probabilistic compiler can reduce gate length by approximately 50% to achieve a certain level of approximation error, resulting in shorter computation runtime.

Comparison of standard approach and probabilistic compilation.



References

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[2] S. Akibue, G. Kato, S. Tani, "Probabilistic unitary synthesis with optimal accuracy," under review.

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