Can Complex Quantum Gates Be Described Using Basic Quantum Gates

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Abstract

Quantum computers are still in their noisy intermediate-scale quantum era of development, and one of the challenges is that current quantum circuits can only support a limited set of basic gates. This research investigates how complex quantum gates can be described using only these basic gates.

This study analyses existing literature on quantum gate decomposition. It highlights the work of da Silva and Park, who showed that an n-qubit controlled single-qubit unitary gate can be decomposed into a circuit with a linear depth of single-qubit and CNOT gates. This method outperforms the current implementation in IBM's Qiskit software for circuits which implement five-qubit gates and onwards.

Based on the findings, this research concludes that complex quantum gates can indeed be described using only basic gates. The discussed literature provides insights into how to translate complex gates to basic gates and how to optimize this process.

Introduction

Currently, quantum computers have been built by companies like Google, IBM, and Microsoft. However, the quantum computers that exist today have close to zero practical uses. The reason for this being that quantum computing is currently in an infant stage, also called the noisy intermediate-scale quantum era (NISQ). The NISQ era is called like this because the current quantum circuits are susceptible to noise [1].

This study will not focus on the noise that is currently limiting the practical use cases of the quantum computers, instead, it will focus on the quantum circuits.

Quantum circuits can be found at the heart of quantum computing and are composed of quantum gates. These gates manipulate qubits to perform various operations.

While theoretical quantum circuits often include a wide variety of complex gates, physical quantum computers are limited by their hardware and can only support a small set of native gates or basic gates. These basic gates are the specific quantum operations that can be reliably executed on a given quantum device.

This study aims to provide a way of describing complex quantum gates by making using of basic gates.

Methodology

This study was conducted purely based on existing literature. The search engine that was used to find the work that is included in this study is: Google Scholar.

Keywords included in the search queries were: Quantum, Gates, Complex, Basic, Native, Circuit, Transpile, Description, Qiskit, Clifford+T, and Decomposition.

Results

The company IBM has created a quantum information science kit (qiskit), this kit can be used to write and execute quantum circuits on their own physical quantum computer or in a locally ran simulator.

Within Qiskit, IBM has built a transpiler. A transpiler functions by taking in a piece of source code written in a language and rewriting it to another language. In the case of qiskit, it functions by taking in a quantum circuit and outputting the same circuit, but rewritten to make use of only basic quantum gates that are supported by a given quantum device.

The documentation of qiskit mentions, for example, that the transpiled circuit has a higher depth (the amount of gates in the circuit) as the pre-transpiled circuit. Looking at the explanation, it seems only logical that the depth increases. For example, a SWAP gate is not a basic gate and must be decomposed, which requires three CNOT gates [2].

The decomposition of these complex gates is what allows the gap between theoretical concepts and physical implementation to be bridged.

A previous study that discusses the optimization of gate decomposition for high-level quantum gates states that, to the best of their knowledge, the state-of-the-art in quantum gate decomposition is represented by the works of: Iten et al.[5], Vale et al.[6], and da Silva and Park[4] [3].

When analyzing the work of da Silva and Park [4], they show that an n-qubits controlled single-qubit unitary gate can be decomposed into a circuit with a lenear depth of single-qubits and CNOT gates. They are able to achieve this by applying a $\sqrt[k]{U}$ instead of an $R_x(\pi/k)$ and $\sqrt[k]{U}^{\dagger}$ instead of an $R_x(-\pi/k)$ to apply an n-qubit controller U gate [4].

When making a comparison with the Qiskit transpiler it becomes visible that the method that da Silva and Park propose in their paper [4] beats the current Qiskit implementation from five-qubit gates onwards.

Discussion

Because this study was solely done by making use of already available research, the claims made in the previous studies can not be confirmed nor can they be denied. However, this literature study provides valuable insight into whether complex quantum gates can be described using basic gates or not.

Conclusion

Based on the Qiskit documentation and the conclusion of other researches, an assumption can be made that it is indeed possible to describe complex gates making use of only basic gates.

The discussed literature provides insights in how to implement a translation from complex gates to basic gates and what possible optimizations can be done to such implementation, or, in the case of Qiskit, they can provide a tool to translate the quantum gates within a quantum circuit to their basic versions.

References

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