Quantum Circuit Encoding and Generation

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1 Project Summary

Quantum algorithms face a number of scalability & reliability issues that prevent usefulness in the real world. Research efforts push current hardware towards fault-tolerant systems through quantum architecture, circuit compilation and generation.

This project aims to expose students to these techniques and some of the implementation challenges facing the quantum computing field at large. Students will gain experience with encoding techniques and machine learning for quantum circuit generation. The steps involved will pertain and extend to:

- Processing quantum circuits from any of the popular quantum SDKs, starting with simple gate sets and then expanding to consider custom unitaries.
- Test for qubit ordering between software packages.
- Being able to represent a desired circuit in a plethora of circuit representations.
- Explore machine learning techniques for quantum circuit generation and quantum architecture methods.
    - Understanding ML model inputs / outputs for circuit generation.
    - Testing and verification of circuit fidelity.

Expected Outcome:

- Quantum circuit encoder that can take an input of a desired circuit representation and quantum circuit (of varying gate set).
- Testing suite that verifies the fidelity of a circuit after processing through quantum architecture techniques or machine learning.

Reach Goal(s):

- Setup a pre-trained diffusion model to generate quantum circuits
- Use the circuit encoder to generate a custom dataset of quantum circuits that can be used to train an ML model to generate circuits
- Tune the parameters of an ML model and train on our custom quantum circuit dataset

2 Zoomed-out impact

In this project, we will build a quantum circuit encoding tool that can take in a quantum circuit constructed from gate sets of increasing complexity and convert it to various circuit representations. This will primarily involve using CUDA-Q, NVIDIA's quantum SDK but will also explore other quantum computing tool kits.

This tool can be used in a number of scenarios, but will primarily be the first step in a hybrid quantum-classical computing workflow. The intended function is aimed to enable us to connect between quantum software packages, test future quantum architecture implementation results and stands as the gateway to training machine learning models.

3 Learning Goals

This field session will enable you to *follow your dream* of having a meaningful career by:

- Using CUDA-Q (& other software packages) to simulate quantum circuits
- Representing quantum circuits in different encoding schemes
- Understand some of the challenges facing the quantum computing research field
- Learn about ML model generation for more complicated use-cases than typical applications such as images or text.

Note: The group may use generative AI for coding and conceptual understanding, but it is important that every component of this project is understood such that you are able to re-iterate the functionality in your own words.

4 Desired Background

- Quantum Computing (programming, theory, quantum mechanics)
- Machine Learning
- Computational Modeling (CFD, chemistry, many-body physics, multi-physics)

5 Preferences

- Backgrounds are desired, not required
- Team size: 3-4
- Work location: On-site (campus) meetings, other work can be performed as desired
- This will be an ideal opportunity for anyone who is interested in grad school, research, or exposure to the field of quantum computation

Note: A team with meaningful contributions will see their names on the author list of any future publications featuring this work.