Introduction

Edge Detection is one of the computationally intensive modules in image analysis. It is used to find important landmarks by identifying a significant change (or “edge”) between pixels and voxels. We present a hybrid Quantum Edge Detection method by improving three aspects of an existing widely referenced implementation, which for our use cases generates incomprehensible results for the image decomposition, which is required to utilize D-NISQ (Distributed Noisy Intermediate-Scale Quantum) model. We introduce a new decrement permutation circuit and relevant optimizations for mapping realistic images on today’s noise Quantum Processor Units (GPU); (3) we can improve the edge detection circuit fidelity to approximately 70%, preserve the edge detection circuit fidelity to approximately 50% from <10%, and reduce the number of CX gates by approximately 68% to under 100, by using a moderate noise Quantum Processor Unites (QPU); (3) we can improve the encoding circuit fidelity to approximately 50% from <10%, and transform into the desired 2D to 1D mapping can be rectified by the use space filling curves introduced by the image decomposition, which is required to utilize D-NISQ (Distributed Noisy Intermediate-Scale Quantum) model.

Overview

An image is decomposed to a 1D input vector \(f = (f_0, f_1, ..., f_{2^n - 1})^T\) and transformed into the normalized quantum state \(|\psi\rangle = (|c_0\rangle, |c_1\rangle, ..., |c_{2^n - 1}\rangle)^T\) via a series of unitary operations on qubits \(q_i\) through \(q_{n-1}\). The Quantum Hadamard Edge Detection circuit takes this input vector performs a series of amplitude permutations of the form:

\[
(U_H^\otimes n)(|\psi\rangle) \rightarrow (c_0, c_1, c_2, ..., c_{2^n - 1}) \rightarrow (c_0, c_1, c_2, ..., c_{2^n - 1}, -c_0, ..., -c_{2^n - 1})
\]

The locality preservation for the 2D to 1D mapping can be rectified by the use space filling curves introduced by the image decomposition, which is required to utilize D-NISQ (Distributed Noisy Intermediate-Scale Quantum) model. We introduce a new decrement permutation circuit and relevant optimizations for mapping realistic images on today’s noise Quantum Processor Units (GPU); (3) we can improve the edge detection circuit fidelity to approximately 70%, preserve the edge detection circuit fidelity to approximately 50% from <10%, and reduce the number of CX gates by approximately 68% to under 100, by using a moderate noise Quantum Processor Unites (QPU); (3) we can improve the encoding circuit fidelity to approximately 50% from <10%, and transform into the desired 2D to 1D mapping can be rectified by the use space filling curves introduced by the image decomposition, which is required to utilize D-NISQ (Distributed Noisy Intermediate-Scale Quantum) model.

Methodology

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Results

We encode a particle image onto a simulated noisy IBM hardware backend with an increasing number of \(n\) qubits per domain where each domain contains \(2^n\) pixels of the image, the results are averaged across all domains to demonstrate the limitations of amplitude encoded circuits. We build the respective QHED circuits of each domain size displaying the effects of our modifications:

Acknowledgements

This work was funded in part by the Center for Nuclear Fermography (CNF), which is administered by the Southeastern Universities Research Association (SURA) under an appropriation from the Commonwealth of Virginia, and the Richard T. Cheng Endowment at Old Dominion University. The performance evaluation was performed using the Wahab computing cluster at Old Dominion University.