Training Scalability of QRNNs

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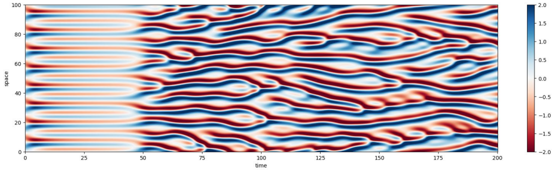
Motivation

- Quantum Neural Networks (QNNs) remain a promising topic of interest in the field of Machine Learning (ML)
- The difficulties associated with training these models on both classical computers and Quantum Processing Units (QPUs) warrants further investigation
- We propose a benchmark of the popular VQC training methods Simultaneous Perturbation Stochastic Approximation (SPSA) and parameter-shift within an end-to-end hybrid trainable Quantum Recurrent Neural Network (QRNN) model
- This will shed light on the differing methods used to train QRNNs, and give an idea of which method results in lower loss and/or higher efficiency
- By doing this analysis, we hope to shed light on what the best practices are for training QRNNs as QPUs become more accessible and more performant

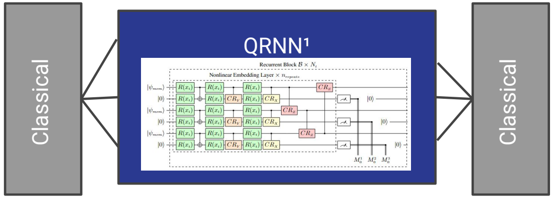
Idea

Training Data



The train data set will be the chaotic Kuramoto Sivashinsky 2-D System.

Hybrid QRNN



Data will be fed into a hybrid PyTorch model and trained using SPSA[2] and Parameter-shift[3] as quantum gradient calculation methods.

Predicted Results

The accuracy of the model will be assessed on its time-series prediction accuracy and efficiency with the two training methods "SPSA" and "Parameter-shift"

1. Connerty, E.L., Evans, E.N., Angelatos, G., Narayanan, V. (2025). Quantum Observers: A NISQ Hardware Demonstration of Chaotic State Prediction Using Quantum Echo-state Networks. arXiv preprint arXiv:2505.06799.
2. Spall, J.C. (1998). AN OVERVIEW OF THE SIMULTANEOUS PERTURBATION METHOD FOR EFFICIENT OPTIMIZATION. *Johns Hopkins Apl Technical Digest, 19*, 482-492.
3. Mitarai, K., Negoro, M., Kitagawa, M., & Fujii, K. (2018). Quantum circuit learning. Physical Review. A/Physical Review, A, 98(3). https://doi.org/10.1103/physreva.98.032309

Milestones

1. Quantum NN Layer

use IBM’s Qiskit to simulate the Quantum circuit in python.

2. PyTorch Integration

Wrap simulated quantum circuitry in PyTorch NN layer. Allowing an effective way to train and analyze a quantum based model.

3. Analysis

Compare Quantum Neural network performance and cost with different training methods.

Challenges

1. Simulating quantum circuits is very difficult for classical computers and will take a lot of time.
2. The hybrid PyTorch layer for the QRNN is still not developed
3. Training recurrent models comes with its own difficulties[1]

1. Pascanu, R., Mikolov, T., Bengio, Y. (2012). On the difficulty of training Recurrent Neural Networks. arXiv preprint arXiv:1211.5063.

Goal

Determine which QRNN training methods are best for hybrid models, and assess the costs and efficiency associated with each of them.