Assessing the Performance of Quantum Machine Learning on the MNIST Dataset

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Motivation

- Emerging Quantum Technology: Rapidly advancing, potential to revolutionize computational tasks that are intractable for classical computers.

- Potential for Quantum Advantage: Possibly outperform classical deep learning models in terms of accuracy, speed, and efficiency on standard tasks.

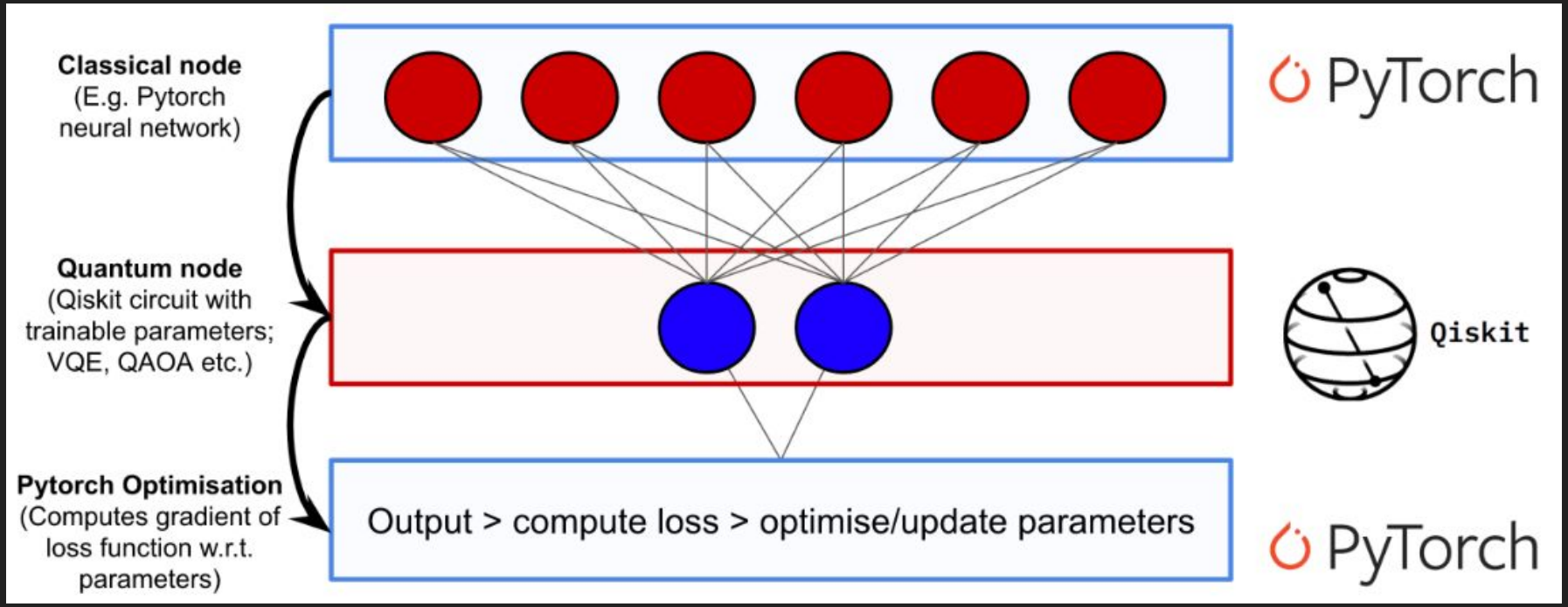
- Access to Resources: First-ever IBM quantum computer on a university campus.

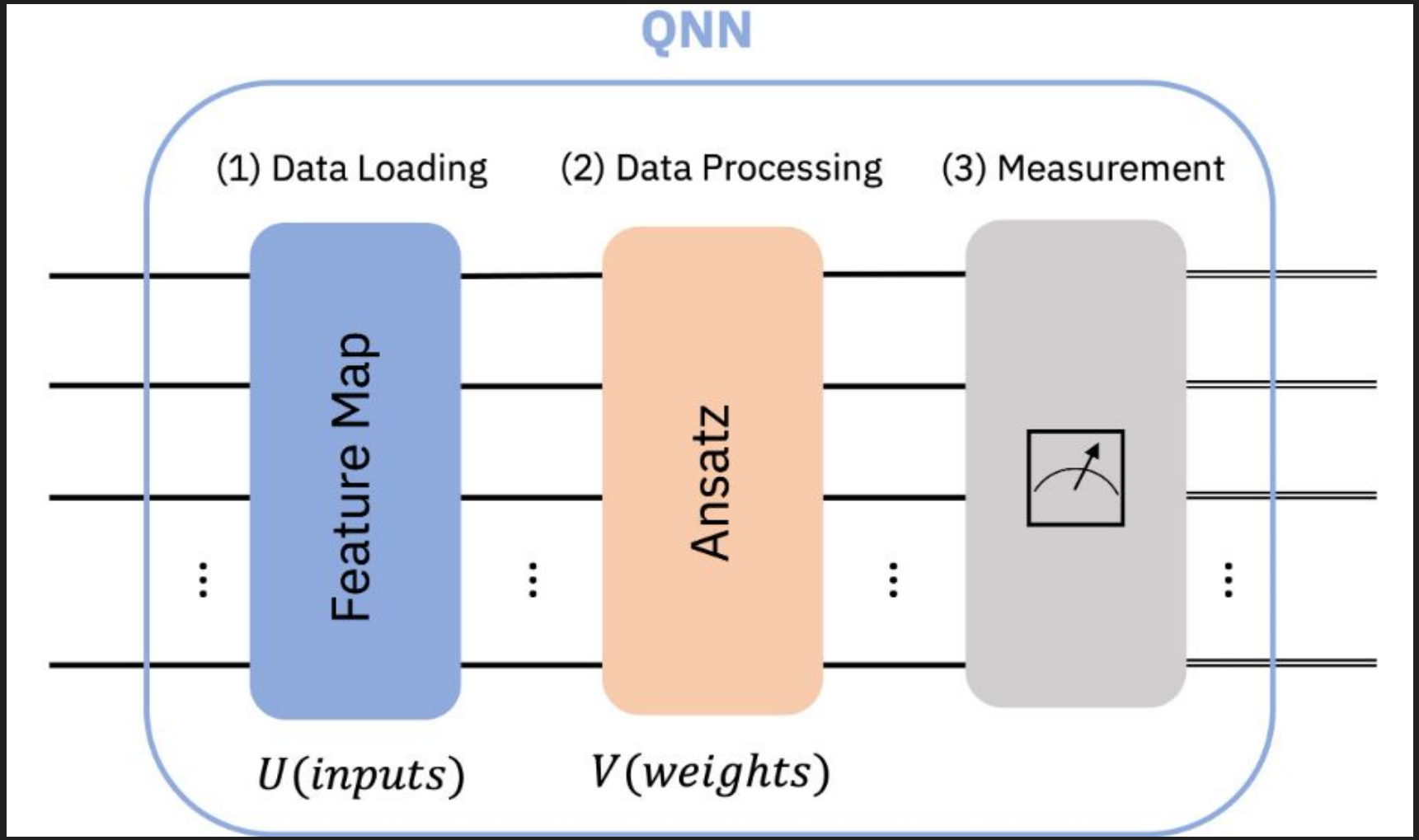
Methodology

- Expand upon our existing hybrid network that we worked on previously
  - append more quantum layers or classical layers to the hybrid network
  - more qubits

- Implement a QNN utilizing Qiskit’s inherent QNN classes, run on ibm_rensselaer

- Benchmark them on MNIST dataset and document performance results


Classical node
(E.g. Pytorch neural network)
Quantum node
(Qiskit circuit with trainable parameters; VQE, QAOA etc.)
Pytorch Optimisation
(Computes gradient of loss function w.r.t. parameters)
Output > compute loss > optimise/update parameters
PyTorch
Qiskit
PyTorch


QNN
(1) Data Loading
(2) Data Processing
(3) Measurement
Feature Map
Ansatz
$U(inputs)$
$V(weights)$

Solution

We will evaluate the hybrid, QNN, and classical NN on accuracy, training time, network complexity (layers), and scalability (dataset size).

- 10, 25, 50, and 100? epochs
- Number of qubits for the quantum architectures will vary depending on training time
- 1, 2, and 5 quantum layers for hybrid QNN
- Number of samples will also vary depending on training time

Milestones

- Documenting the results and attempting different ways of trying to improve QML to rival classical

- Hybrid accuracy was similar to classical though with a larger training time.

  (500 training, 250 test for 2 classes)

- Our attempts and structure can be built off of to possibly one day find an implementation of QML architecture that can rival classical machine learning

Deliverables (In Progress Results)

500 training, 250 test for 2 classes

Optimizer: Adam LR 0.001, Loss: CrossEntropy, 2 qubits, 50 epochs

Hybrid

Performance on test data:

Loss: 0.1679

Accuracy: 97.5%

Training Time elapsed: 0h 15m 21s

Classical

Performance on test data:

Loss: 0.1464

Accuracy: 97.3%

Training Time elapsed: 0h 0m 10s

Deliverables (In Progress Results)

500 training, 250 test for 5 classes

Optimizer: Adam LR 0.001, Loss: CrossEntropy, 2 qubits, 50 epochs

Hybrid

Performance on test data:

Loss: 0.9791

Accuracy: 38.0%

Training Time elapsed: 0h 31m 0s

Classical

Performance on test data:

Loss: 0.0212

Accuracy: 97.2%

Training Time elapsed: 0h 0m 24s

Deliverables (In Progress Results)

500 training, 250 test for 5 classes

Optimizer: Adam LR 0.001, Loss: CrossEntropy, 5 qubits, 50 epochs

Hybrid

Performance on test data:

Loss: 1.1632

Accuracy: 39.3%

Training Time elapsed: 10h 15m 59s

Classical

Performance on test data:

Loss: 0.0212

Accuracy: 97.2%

Training Time elapsed: 0h 0m 24s

Present Qiskit Code

Current Obstacles (Qiskit updates fast)

Warning

The original primitives (referred to as the V1 primitives), V1 Sampler and V1 Estimator, have been deprecated in `qiskit-ibm-runtime` 0.23. Their support will be removed on 15 August 2024.

Current Obstacles (Time constraints)

ID / Name	Status	Created	Completed	Usage	Mode	Compute resource	Tags
ctx2r48ezn20008sjh60	Pending Est. wait: 8 hours	12 Aug 2024	--	Est. 5m 10.8s	Job	ibm_rensselaer Queue position: 1	
ctx2r2g46w90008rfjzg	Pending Est. wait: 4 hours	12 Aug 2024	--	Est. 5m 10.8s	Job	ibm_rensselaer	
ctx2r1846w90008rfjz0	Pending	12 Aug 2024	--	Est. 5m 10.8s	Job	ibm_rensselaer	
ctx2r0846w90008rfjy0	In progress	12 Aug 2024	--	0s	Job	ibm_rensselaer	
ctx2qyfv0kkg008q135g	In progress	12 Aug 2024	--	0s	Job	ibm_rensselaer	
ctx2qwf3zkm0008sk7y0	In progress	12 Aug 2024	--	0s	Job	ibm_rensselaer	
ctx2qtq66x8g008q7q10	In progress	12 Aug 2024	--	0s	Job	ibm_rensselaer	
ctx2qsf66x8g008q7q0g	In progress	12 Aug 2024	--	0s	Job	ibm_rensselaer	

Details

Mode:	Job
QPU name:	ibm_rensselaer
Instance:	rpi-rensselaer/general/general
Program:	circuit-runner
# of shots:	4000
# of circuits:	300

Status details

Status

Completed

Usage stats

Actual QR usage

6m 9s

Status timeline

- Created: Aug 12, 2024 11:36 AM
- Pending: 6m 7.3s
- In progress: Aug 12, 2024 11:42 AM
  Qiskit runtime usage: 6m 9s
- Completed: Aug 12, 2024 12:14 PM

Total completion time: 38m 7.6s

References

[1] Arsenii Senokosov, Alexandr Sedykh, Asel Sagingalieva, Basil Kyriacou, & Alexey Melnikov (2024) Quantum machine learning for image classification. arXiv e-print. Retrieved from https://arxiv.org/pdf/2304.09224

[2] Kevin Shen, Bernhard Jobst, Elvira Shishenina, & Frank Pollmann (2024) Classification of the Fashion-MNIST Dataset on a Quantum Computer. arXiv e-print. Retrieved from https://arxiv.org/pdf/2403.02405

[3] Tak Hur, Leeseok Kim, & Daniel K. Park (2022) Quantum convolutional neural network for classical data classification, arXiv e-print. Retrieved from https://arxiv.org/pdf/2108.00661

[4] Qiskit Community, "Qiskit Machine Learning Tutorials," Qiskit Community. [Online]. Available: https://qiskit-community.github.io/qiskit-machine-learning/tutorials/. [Accessed: July. 21, 2024].