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Quantum Machine Learning in Finance – a Review

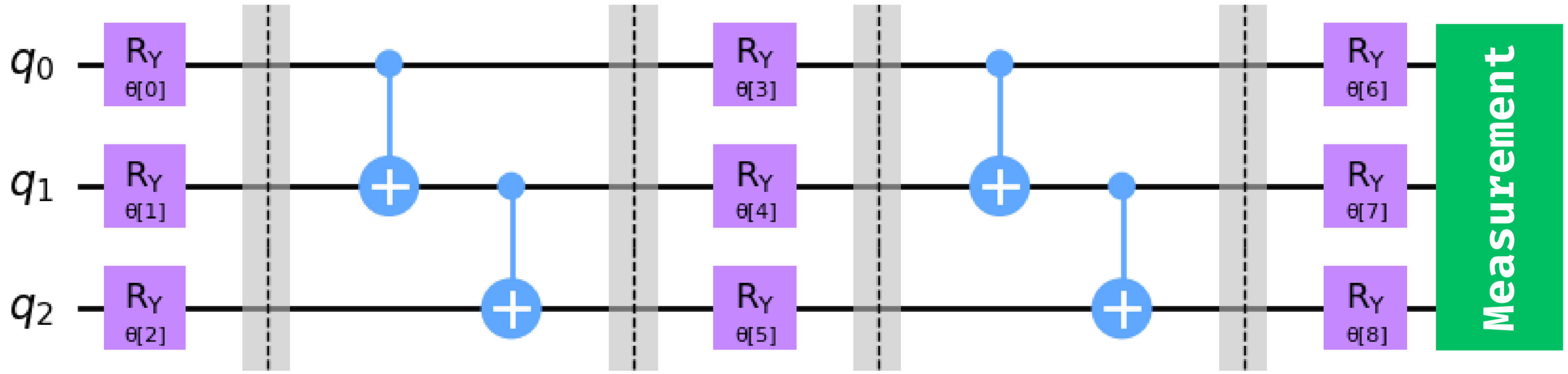
Thanh Nguyen - Institute of R&D, Duy Tan University, Da Nang, Viet Nam
H.L. Thi - Co-Author

Overview

- Variational Quantum Algorithm
- Portfolio Optimisation
- Anomaly Detection
- Credit Scoring
- Some Insights

VQA training

Varialtional Quantum Circuit



- Often being called the ‘Ansatz’,
- Can be use as model for machine learning,
- Each gate acts like a matrix operation.
- Is trainable with an arbitrary optimiser,
- Responsible to process information given the input data,
- Return quantum state (or collapse the state into classical information).

$$X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$Y = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$$

$$Z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

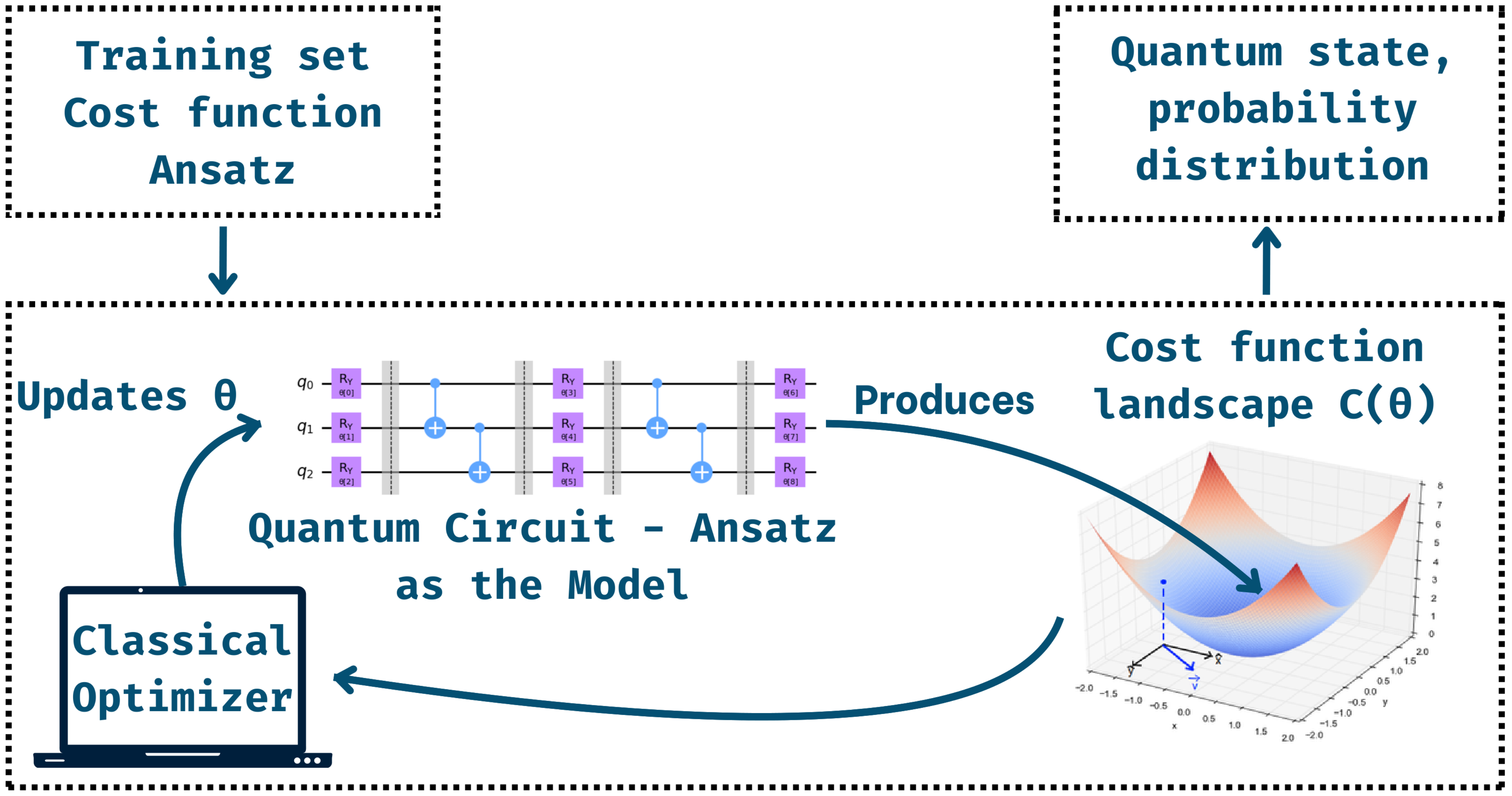
$$CNOT = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

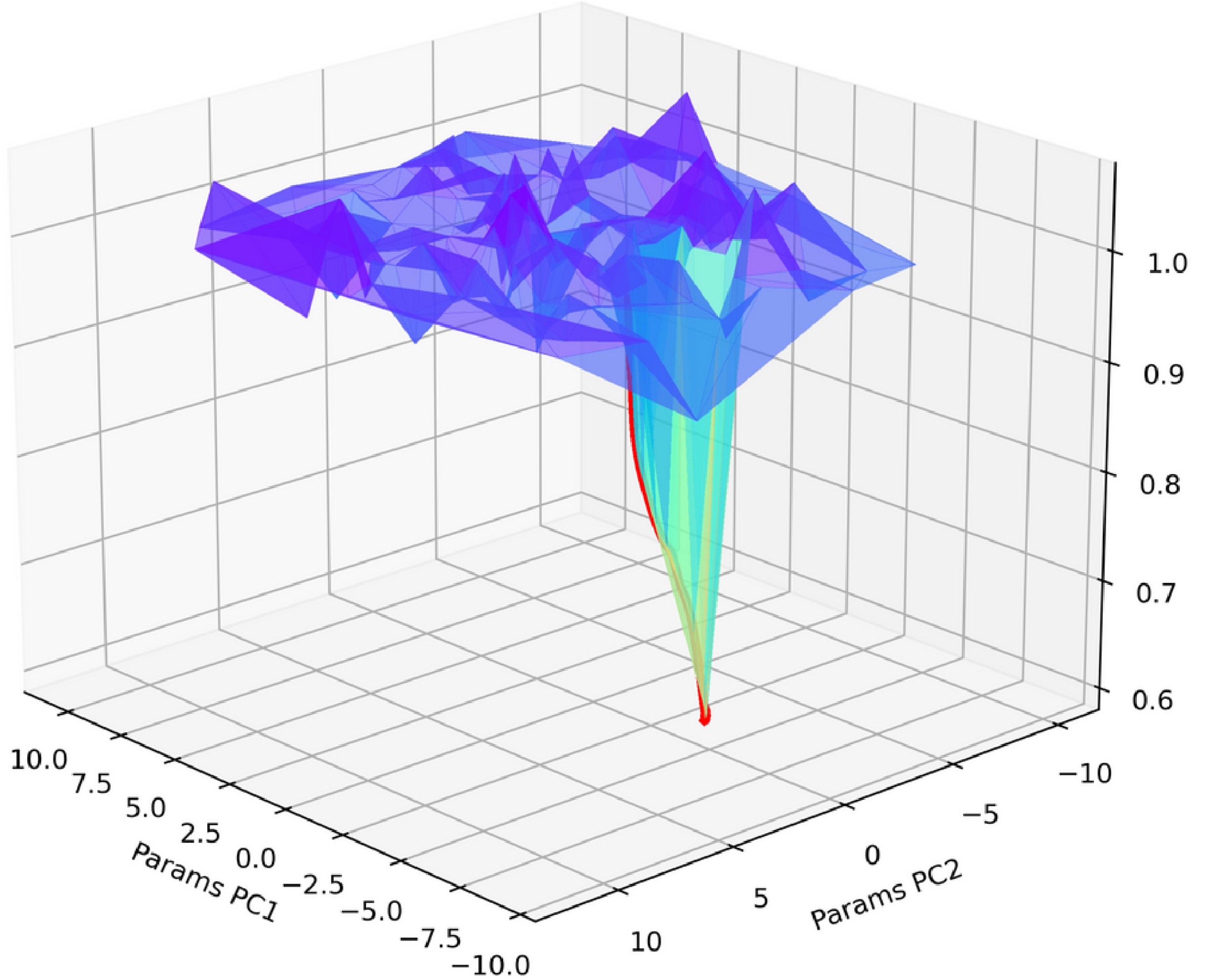
$$R_y(\theta) = \begin{bmatrix} \cos\left(\frac{\theta}{2}\right) & -\sin\left(\frac{\theta}{2}\right) \\ \sin\left(\frac{\theta}{2}\right) & \cos\left(\frac{\theta}{2}\right) \end{bmatrix}$$

And many more ...

VQA training

Variational Quantum Algorithm [1]





Typical hybrid process of machine learning that involves both quantum components and classical components.

The optimiser finds the combination of parameters for the ansatz, and take the ansatz predictions to calculate cost function to further optimising the model. Until the process converges at some optimum point.

Portfolio Optimisation

With Variational Quantum Eigensolver [2]

→

Formulate the PO Problem

For a number of assets, within a period of trading time, we aim at finding the optimal value of trade investment that satisfy the objective function, which is to **maximises the return** (profit) while **minimising the risk factor**, subject to investment and/or other factors.

→

Convert to Quadratic Unconstrained Binary Optimisation Problem

PO problem can be formulated as Constrained Quadratic Optimisation problem which can be transformed to QUBO problem with binary encoding.

→

Convert into Hamiltonian Problem

By using VQE to find the ground state of the Hamiltonian, we can obtain the optimal or sub-obtimal result.

Anomaly Dectection

Quantum Support Vector Machine + Classification [3]

QSVM can transform classical data into quantum states.

One novelty application of QSVM was presented for analysing real payment dataset and improving the fraud detection task of a quantum classifier in terms of prediction accuracy.

Quantum Kernel Component Analysis [4]

Kernel Principal Component Analysis,
For Quantum Computers

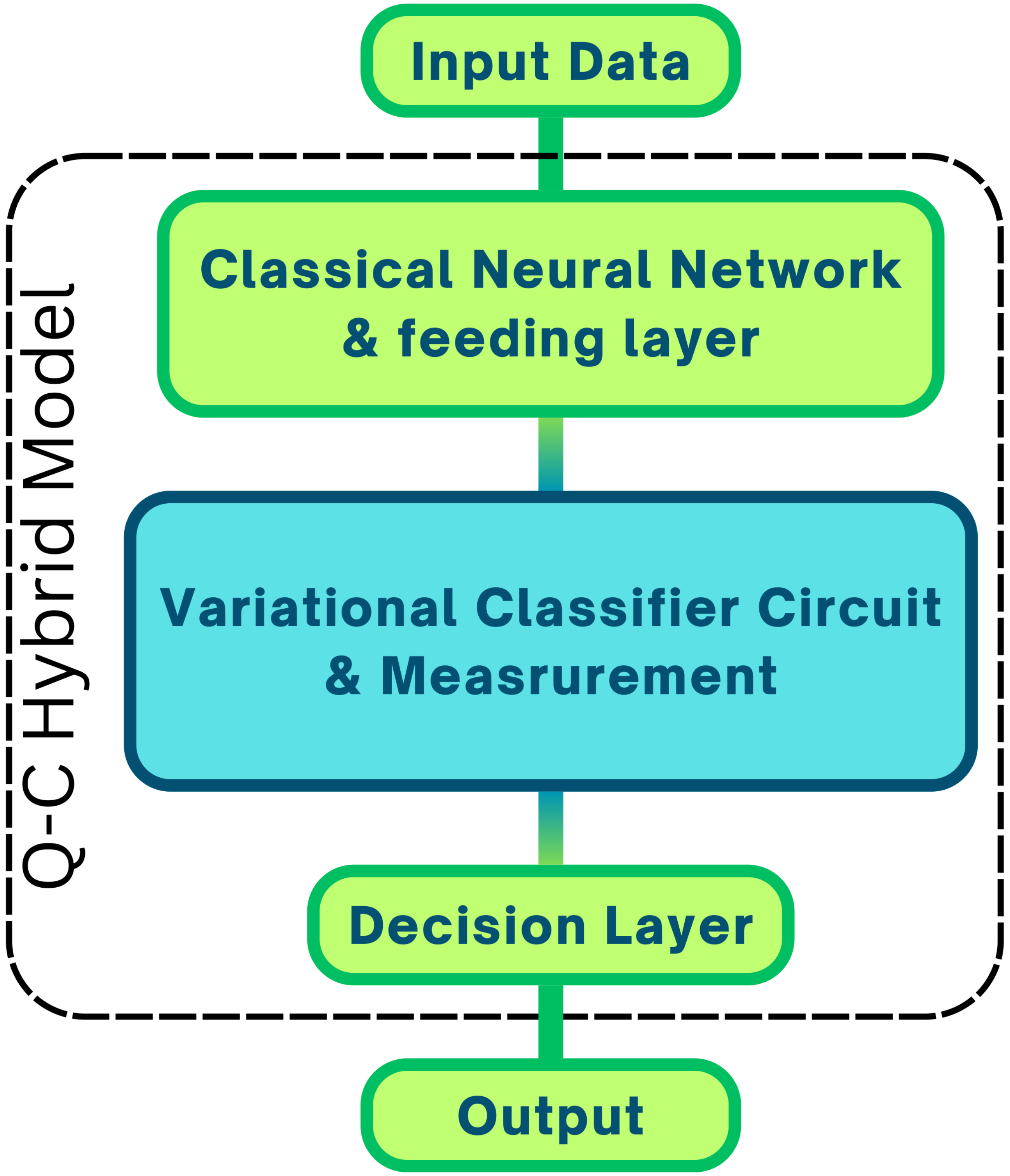
Find the distance between the datapoint and the centroid of the training data, this can quantify how the point stray away from the pattern. It implies that that a larger distance is more anomalous than smaller one.

Credit Scoring

Variational Quantum Classifier with hybrid model [5]

Classical Nets and Quantum Circuit can compliment each other to produce better result, capable of learning complex patterns in data as well as mitigating noises.

This novel approach had shown promising performance in terms of classification accuracy, shown that the quantum enhanced model can score higher than most classical counterparts.



Insights

VQA as a Framework ...

HIGHLIGHT 1: PERFORMANCE

The law of Quantum mechanics greatly enhances the information density and subsequently the processing power of Quantum Models. VQA have potential to surpass traditional ML in terms of performance benchmarkings.

HIGHLIGHT 2: CUSTOMISATIONS

VQA is a robust framework that is highly customisable, we have seen many ways to encode/pre-process data (QKCA, QSVM), as well as designing the model (pure and ensemble quantum - classical) and choices of optimisers.

HIGHLIGHT 3: USE CASES

In Finance sectors, due to the stochastic nature of the market, ML algorithms play pivotal role in analysing and giving insight for business owners. Therefore, applications of QML in finance sectors can be highly demanded given that QML can surpass traditional ML algorithms.

HIGHLIGHT 4: SCALABILITY

Today Quantum machines are facing many constraints. However, we can expect the post-NISQ machines to build larger models and have more capacity to learn complex data patterns.

Thank you for listening!

QnA time!

Reference used

[1] Marco Cerezo, Andrew Arrasmith, Ryan Babbush, Simon C Benjamin, Suguru Endo, Keisuke Fujii, Jarrod R McClean, Kosuke Mitarai, Xiao Yuan, Lukasz Cincio, et al. Variational quantum algorithms. Nature Reviews Physics, 3(9):625–644, 2021.

[2] Samuel Mugel, Carlos Kuchkovsky, Escolastico Sanchez, Samuel Fernandez Lorenzo, Jorge Luis-Hita, Enrique Lizaso, and Roman Orus. Dynamic portfolio optimization with real datasets using quantum processors and quantum-inspired tensor networks. Physical Review Research, 4(1):013006, 2022.

[3] Michele Grossi, Noelle Ibrahim, Voica Radescu, Robert Loredo, Kirsten Voigt, Constantin Von Altrock, and Andreas Rudnik. Mixed Quantum–Classical Method for Fraud Detection With Quantum Feature Selection. IEEE Transactions on Quantum Engineering, 3:1–12, 2022.

[4] Nana Liu and Patrick Rebentrost. Quantum machine learning for quantum anomaly detection. Physical Review A, 97(4):042315, 2018.

[5] Nikolaos Schetakis, Davit Aghamalyan, Michael Boguslavsky, Agnieszka Rees,Marc Raktomalala, and Paul Griffin. Quantum machine learning for credit scoring. arXiv preprint arXiv:2308.03575, 2023