WISER Quantum Project

Project 2:
Quantum for Portfolio Optimization

Czcibor Ciostek
Weronika Golletz

PROBLEM STATEMENT

Our Project

We explore quantum optimization techniques for a constrained portfolio optimization problem, formulated as a binary quadratic problem with linear constraints (QUBO with penalties).

The Problem

Classically, solving large constrained quadratic problems—especially with binary or integer variables—is NP-hard and scales poorly.

Why It Matters

Such problems arise in high-value applications like portfolio construction, resource allocation, and logistics. Efficient quantum–classical algorithms, like the Variational Quantum Eigensolver (VQE), could deliver faster or higher-quality solutions on near-term quantum hardware.

OUR SOLUTION

WISER Quantum Project

Project objectives
We set out to improve the performance of VQE on a constrained portfolio optimization problem, formulated as a QUBO with penalty terms.

Our goals were to:
- Identify the best ansatz and parameter settings for fast, high-quality convergence.
- Study the effects of penalty values and initialization strategies.
- Assess scalability and statistical robustness.
- Explore new ansatz designs like the Heat Exchange ansatz.

OUR SOLUTION

Approach & tools
We started from the provided GitHub repository, analyzed its performance on a 31-bond problem, and built on it.

We:
- Analyzed TwoLocal and bfcd ansatzes across CVaR parameters, repetition depths, and entanglement topologies.
- Tested penalty weights for constraint embedding.
- Compared fixed vs. random parameter initialization.
- Built a synthetic problem generator to test scalability and variability.
- Implemented the Heat Exchange ansatz from recent literature.

All experiments were run in Qiskit with classical simulation.

OUR SOLUTION

Evolution:
We began by reproducing existing results, then systematically varied parameters to identify the most robust configuration.
We extended the work to generated problems of different sizes, enabling scaling analysis and statistical testing.

RESULTS

Goals met?
Yes — we identified configurations that improved convergence, optimized constraint satisfaction, and provided insights into scaling behavior.

RESULTS

Key results:

- Ansatz selection: For the 31-bond problem, TwoLocal and bfcd with $\alpha=0.1$, $r=2$, and bilinear entanglement achieved the best combination of optimality and convergence speed.

- Penalty parameter: $\lambda=1.1$ gave best convergence for both ansatzes, but highest constraint satisfaction occurred at $\lambda=1.1$ for TwoLocal (80%) and $\lambda=1.5$ for bfcd (90%).

- Initialization: $\pi/3$ initialization was more consistent and had highest feasibility (90% for TwoLocal, 70% for bfcd); random initialization gave mixed performance.

- Scalability: Runtime grows predictably with bonds, but the relative optimality gap and performance variance increase for larger problem sizes.

- Statistical robustness: Some problem instances are significantly harder — in the worst cases, solutions were >50% worse than the optimum.

Exploration of new designs: Implemented the Heat Exchange ansatz for future integration into the VQE workflow.

FUTURE SCOPE

- Integrate Heat Exchange ansatz into the VQE pipeline and benchmark against TwoLocal and bfcd.

- Develop richer feasibility metrics to distinguish minor from major constraint violations, enabling trade-offs between speed and accuracy.

- Extend scaling studies to quantum hardware, testing beyond simulation qubit limits and comparing real execution times.

- Explore alternative ansatz and solver designs to better handle hard problem instances and reduce performance variance.

WISER Quantum Project

Project 2:
Quantum for Portfolio Optimization

Czcibor Ciostek
Weronika Golletz