WISER Quantum Project

Quantum-Enhanced Portfolio Optimization

By Yasaman Yaghoobi

Welcome to this presentation on a cutting-edge approach to portfolio optimization, developed as part of a WISER Quantum Project. We're exploring how hybrid quantum-classical methods can push the boundaries of what's possible in financial modeling.

WISER Quantum Project

The Challenge: Optimizing High-Dimensional Portfolios

High-dimensional portfolio optimization is a cornerstone of financial's operations. However, classical solvers face significant hurdles when dealing with the scale and speed demanded by daily trading decisions.

Speed

Optimal solutions are needed in minutes, not hours.

Scale

Portfolios can involve thousands of assets and complex constraints.

Optimality

Classical methods often yield local, not global, optima within tight deadlines.

Our goal was to determine if a hybrid quantum-classical approach could deliver superior or faster solutions to this intricate problem.

Our Solution: A Three-Part Hybrid Enhancement

We meticulously enhanced the standard Variational Quantum Eigensolver (VQE) workflow at three crucial stages to address the limitations of classical optimization.

1 Smarter Problem Formulation

Converted constrained problems into an unconstrained QUBO format. We developed a per-constraint penalty system, scaling penalties based on rule importance for a smoother optimization landscape.

2 Problem-Specific Quantum Circuit

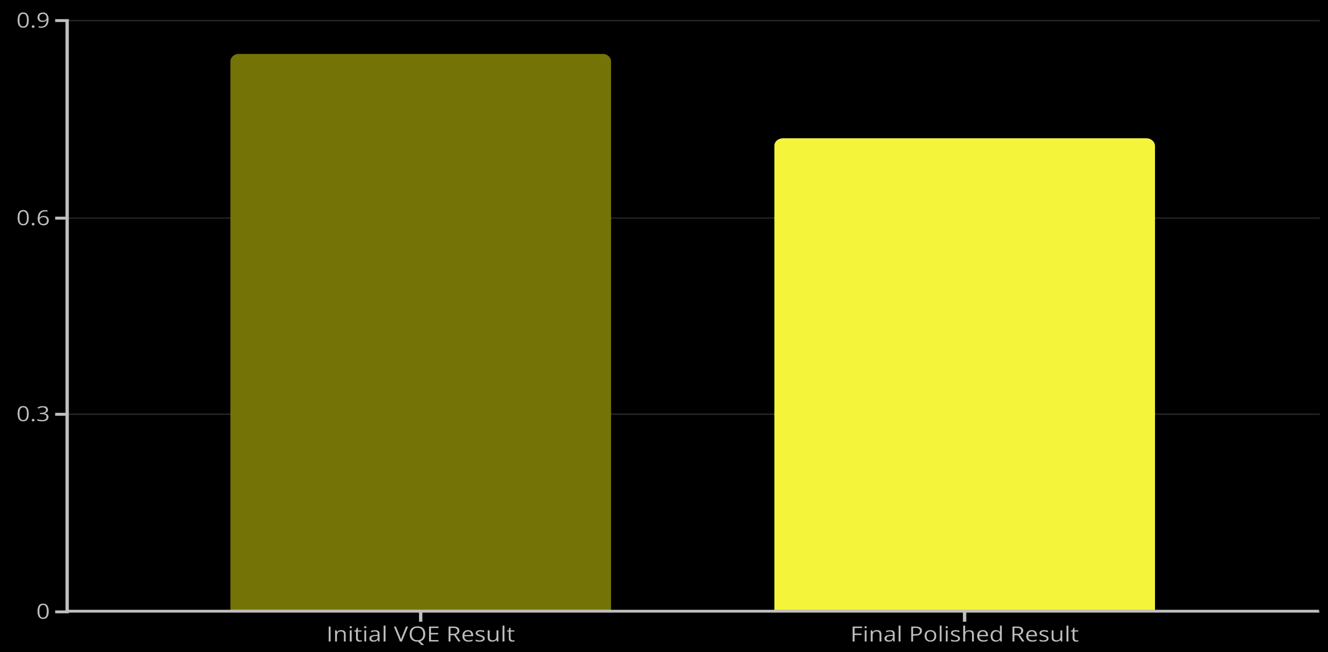
Replaced generic ansätze with a tailored QAOA (Quantum Approximate Optimization Algorithm) ansatz, built directly from the financial problem's structure for enhanced efficiency and accuracy.

3 Advanced Classical Polishing

Post-VQE, we integrated a powerful Variable Neighborhood Search (VNS) to refine solutions, enabling the algorithm to escape local optima and achieve superior results.

Results & Impact: Delivering Superior Optimization

Our enhanced pipeline successfully found an improved solution on a representative portfolio optimization problem, demonstrating the power of quantum-classica



Optimality: The workflow significantly reduced the objective function value, with the QAOA ansatz providing a strong foundation further refined by VNS.

Speed & Scalability: Designed for HPC environments like Bridges-2, this solution offers a clear path to solving large-scale (31+ qubit) problems that are intractable

This work serves as a successful prototype, validating a sophisticated pipeline for quantum-enhanced financial optimization at scale.

Future Scope: Scaling and Benchmarking

The initial success of this project opens several exciting avenues for future research and development, focusing on further scaling and real-world performance validation.

Scale Up

Conduct experiments on even larger problem sizes, aiming for 100+ bonds within the HPC system to push computational limits.

Increase QAOA Depth

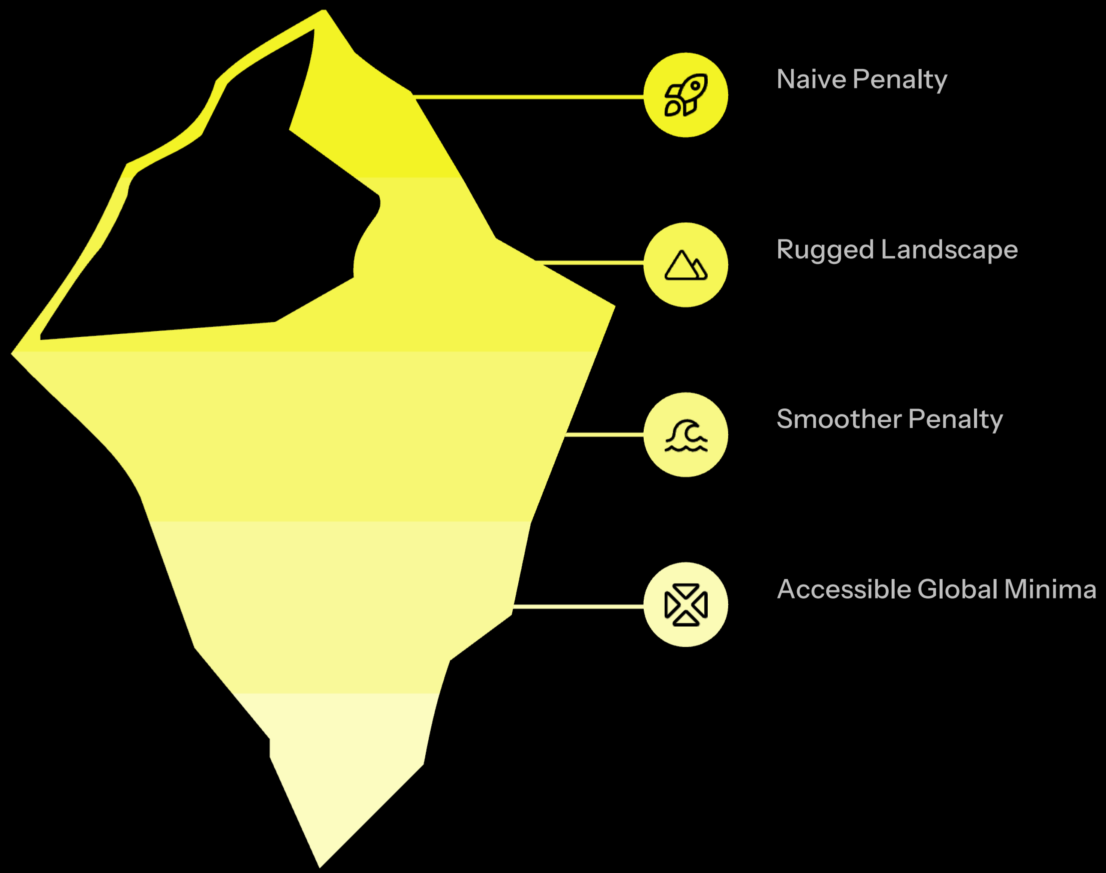
Test deeper QAOA circuits (reps=2, 3, ...) to explore if increased circuit complexity leads to even better optimization solutions.

Real Hardware Execution

Execute the final, optimized workflow on actual IBM quantum hardware to rigorously benchmark performance in a noisy quantum environment.

Deeper Dive: Why Smart Penalties Matter

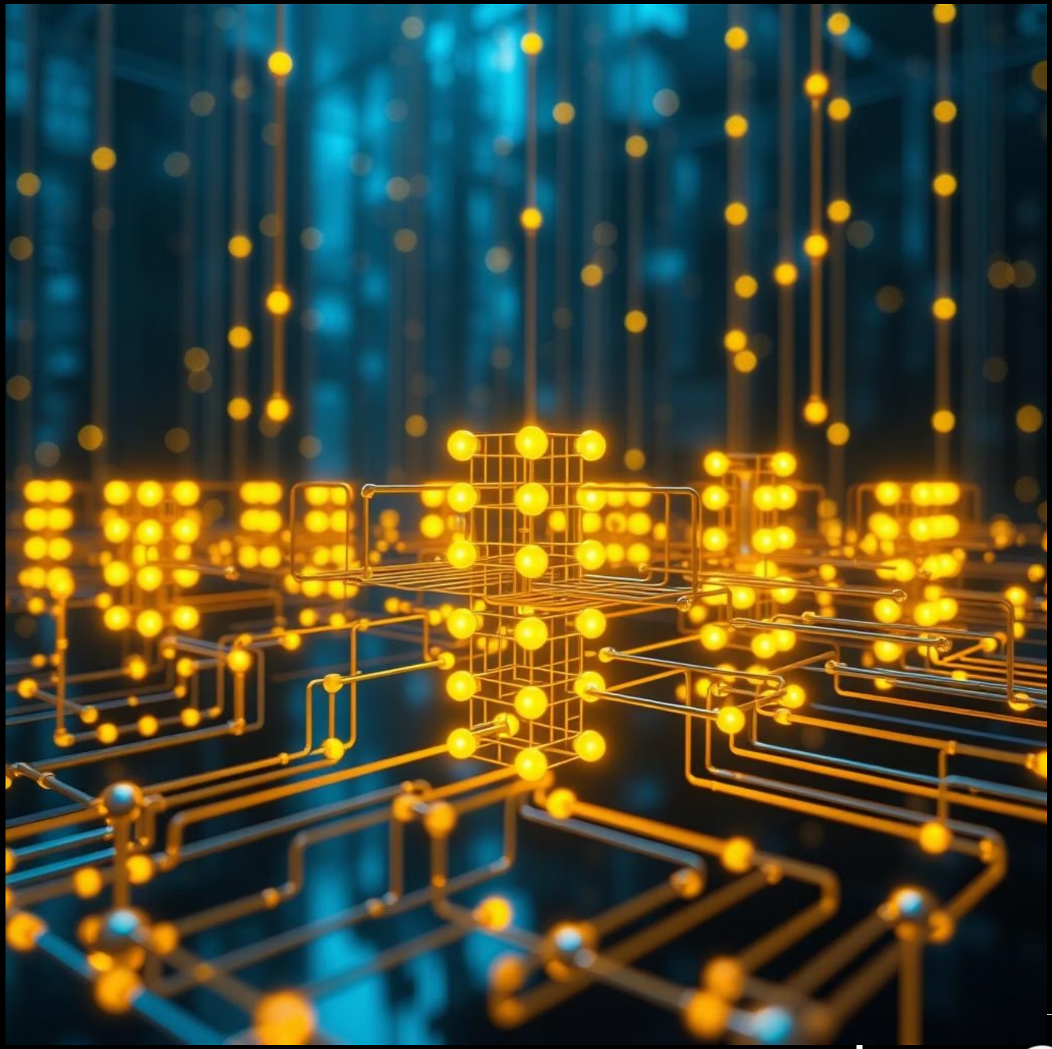
The transformation of a constrained optimization problem into an unconstrained Quadratic Unconstrained Binary Optimization (QUBO) problem is crucial for quantum algorithms. However, a naive penalty approach can create rugged energy landscapes, trapping the algorithm in suboptimal solutions.



Our per-constraint penalty system, where each violation is weighted according to its financial importance, smooths this landscape. This innovative approach guides the quantum algorithm towards true global optima more effectively.

QAOA: Tailoring Quantum Power to Finance

Quantum Approximate Optimization Algorithm (QAOA) is particularly well-suited for combinatorial optimization problems like portfolio selection. By designing a QAOA ansatz that directly mirrors the structure of our financial problem, we enhance the algorithm's ability to find high-quality solutions.



Benefits of Problem-Specific QAOA

- **Increased Efficiency:** Fewer quantum operations are needed to reach a good solution compared to generic ansätze.
- **Higher Accuracy:** The circuit's structure intrinsically understands the problem's constraints and objectives.
- **Reduced Noise Sensitivity:** Shorter, more targeted circuits are less susceptible to errors on noisy intermediate-scale quantum (NISQ) devices.

VNS Polishing: Bridging Quantum and Classical Strengths

> "The hybrid approach truly shines when quantum algorithms provide a strong starting point, and classical heuristics refine it."

Even the best quantum algorithms on NISQ devices can sometimes converge to local optima. This is where classical polishing, specifically Variable Neighborhood Search (VNS), becomes indispensable.

1

Quantum-Generated Initial Solution

VQE with QAOA provides a high-quality, quantum-optimized starting point.

2

VNS Explores Neighborhoods

VNS systematically explores a changing set of neighborhoods around the current solution, ensuring a broad search.

3

Escaping Local Optima

Its ability to move between different neighborhoods allows it to escape "good" but not "great" local optima.

4

Global Optimization Closer

This iterative refinement pushes the solution closer to the global optimum, yielding a truly superior result.

The VNS acts as a powerful "finishing touch," ensuring that the initial quantum advantage translates into a practical, high-quality final solution for Vanguard's portfolio managers.

Key Takeaways & Next Steps

Quantum Potential Validated

Our hybrid approach demonstrably improves portfolio optimization over classical methods.

Tailored Solutions Win

Smarter problem formulation (per-constraint penalties) and custom QAOA ansätze are key.

Hybrid is the Present

Classical polishing (VNS) is essential for practical, high-quality results today.

Next Steps

- Collaborate with portfolio management teams to refine problem specifications and integrate feedback.
- Expand testing to even larger, more complex real-world datasets on Bridges-2.
- Initiate benchmarks on IBM's quantum hardware to assess performance in noisy environments and guide future algorithm design.