Quantum Computing for Financial Risk Analysis:

Pricing Fixed-Income Assets with **QuMonte**

Sophia Rebello
Rice University, Houston, TX

Tirthak Patel (Advisor)
Rice University, Houston, TX

1 Problem Introduction and Motivation

Monte Carlo simulations estimate probabilistic outcomes for financial scenarios like pricing bonds, equities, and derivatives [3]. While classical methods rely on parallelization through GPUs or distributed computing, their performance deteriorates with increasing complexity [3]. Quantum computing offers exponential acceleration through amplitude amplification and entanglement [5]. However, quantum software for financial applications remains underdeveloped, with existing algorithms lacking optimization for performance, reliability, and scalability [3]. *Our research addresses this gap by developing **QuMonte**, a quantum software solution that leverages optimized code generation and architectural enhancements to make Monte Carlo simulations more efficient for financial risk assessment.*

2 Background and Related Work

Quantum copulas improve risk assessment, using quantum entanglement to represent the joint distributions of random variables with precision [6]. Quantum algorithms, with their all-to-all connectivity and the ability to analyze multiple states simultaneously, can process entire probability distributions efficiently, a task unfeasible with classical computers' point-to-point connectivity [3]. This capability will help us refine the accuracy and scope of Monte Carlo simulations.

The Iterative Amplitude Estimation algorithm improves computational efficiency by using a Grover algorithm variant to reduce qubits and gates, simplifying circuit complexity [4]. Variational Quantum Algorithms (VQAs) iteratively refine parameterized quantum states to solve complex problems like Hamiltonian ground state calculations [1]. In parallel, optimizing circuit expressibility and entanglement, especially in CNOT gate configurations, addresses architectural concerns and minimizes noise [5].

3 Approach and Uniqueness

QuMonte uniquely integrates algorithmic performance and architectural support. *Our approach focuses on optimizing quantum algorithms to enhance financial Monte Carlo simulations for asset pricing.* We utilized Qiskit's software library to construct quantum code optimized for IBM's quantum architecture, minimizing noise and gate depth [2]. The code was iteratively refined using Qiskit Aer simulations and real-world IBM hardware testing. Employing VQAs, we optimized convergence by adjusting parameters, specifically aiming to reduce the L_2 norm, which represents the Euclidean distance between the program output and a financial target. Our optimized quantum circuit has 5 qubits and only uses Rx and Rz gates to minimize complexity.

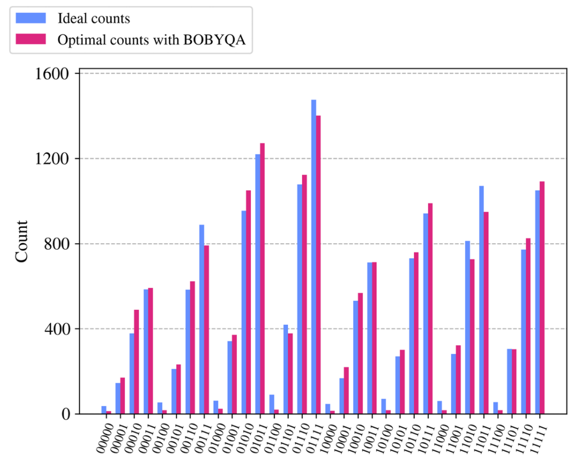

Figure 1. A histogram comparison of the ideal and optimized counts using **BOBYQA** as the optimizer, achieving an optimization score of 0.0172 at maxiter=5500 [2].

4 Results and Contribution

To evaluate our approach, we performed comparative histogram analyses using the norm L_2 as a key metric for precision. Lower L_2 values signify closer alignment with theoretical models, demonstrating the precision of our quantum simulations. The **BOBYQA** optimizer achieved the lowest L_2 norm of 0.0071 in our tests. Figure 1 illustrates the effectiveness of the **BOBYQA** optimizer, where the histogram comparison shows that the optimized circuit closely aligns with the ideal counts. With an optimization score near 0.01, we can confirm the improved computational efficiency and precision of quantum amplitude estimation methods.

Our results show the potential of quantum computing to improve the precision and efficiency of financial models. The application of the **BOBYQA** optimizer highlights the importance of strategic optimization in quantum simulations, an essential aspect of future computing. We demonstrate that optimized quantum code design can improve performance and reliability in financial simulations, potentially setting a new benchmark for computational architectures. Further developments will focus on refining our quantum code and extending optimized quantum approaches to other financial instruments, such as basket options.

References

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