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Hybrid Quantum–Classical Learning Approaches for Scalable Optimization Beyond NISQ Limitations

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Abstract: *Quantum computing promises computational advantages for solving complex optimization problems; however, current Noisy Intermediate-Scale Quantum (NISQ) devices suffer from limited qubit counts, short coherence times, and high error rates. Fully fault-tolerant quantum algorithms remain impractical in the near term, necessitating hybrid approaches that integrate classical and quantum computation. This paper proposes a* ***Hybrid Quantum–Classical Machine Learning Framework (HQC-MLF)*** *for large-scale combinatorial and continuous optimization tasks. The framework leverages parameterized quantum circuits (PQCs) embedded within classical optimization loops, enabling efficient search in high-dimensional spaces while mitigating hardware constraints. We introduce adaptive ansatz selection, classical preconditioning, error mitigation strategies, and resource-aware scheduling to enhance scalability. Experimental evaluations on logistics routing, portfolio optimization, and energy load balancing demonstrate improved convergence speed and solution quality compared to purely classical baselines under realistic NISQ simulations. The proposed architecture provides a practical pathway toward near-term quantum advantage in real-world optimization problems.*

Keywords*:* Hybrid Quantum Computing, Variational Quantum Algorithms, Machine Learning, Large-Scale Optimization, NISQ Devices, Quantum Approximate Optimization Algorithm, Resource-Aware Scheduling