Empirical Analysis of Hybrid Quantum-Classical Algorithms for Optimization Problems in Large-Scale Machine Learning

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Abstract. This paper investigates the efficacy of hybrid quantum-classical algorithms applied to optimization problems within large-scale machine learning frameworks. As the demand for efficient data processing continues to escalate, traditional algorithms often struggle to cope with complex datasets. We present a case study utilizing a modified variational quantum eigensolver (VQE) in conjunction with classical optimization techniques, highlighting significant improvements in convergence rates and solution accuracy over purely classical methods. Our results suggest that integrating quantum processing can effectively tackle optimization challenges, providing a salient step toward practical quantum advantage in machine learning. The paper concludes with implications for future research and applications of quantum computing in artificial intelligence.

Keywords: quantum computing, hybrid algorithms, machine learning, optimization, variational quantum eigensolver, classical optimization, data processing, AI integration

Introduction

The emergence of artificial intelligence (AI) and machine learning (ML) as pivotal technologies in various sectors is undeniable. With the proliferation of data generated in our increasingly digital world, the optimization of machine learning algorithms has become a paramount challenge—one that traditional computational methods are often ill-equipped to

resolve. As we look toward the years 2024 to 2026, the significance of enhancing optimization processes is expected to grow, affecting industries ranging from finance to healthcare. Current classical optimization techniques face limitations in terms of time complexity and scalability when applied to large datasets, constraining their effectiveness and impeding the adoption of advanced machine learning solutions. Emerging quantum computing technologies present a potential paradigm shift in how we approach these optimization problems. Hybrid algorithms that leverage both quantum and classical resources have been proposed as a means to circumvent the limitations of classical approaches, yet empirical assessments remain sparse. This paper aims to fill this gap by conducting a detailed empirical analysis of a specific case study involving a hybrid quantum-classical algorithm, focusing on its application to optimization problems inherent in large-scale machine learning scenarios. We introduce a modified variational quantum eigensolver (VQE) algorithm, which we have augmented with classical optimization techniques to enhance its performance. Our investigation is structured as follows: we begin by outlining the theoretical foundations of our hybrid approach and the specific challenges it addresses within the scope of machine learning. Following this, we present our experimental setup, including the datasets utilized and the performance metrics assessed. We then discuss the results, highlighting the improvements observed in convergence rates and solution accuracy compared to classical methods alone. Finally, we consider the broader implications of our findings on the field of quantum computing and machine learning. This exploration not only contributes to the understanding of hybrid quantum-classical algorithms but also posits important questions regarding their future applicability in real-world scenarios where optimization is crucial.

References

1. Рагимов, Э. Р. О. (2010). Механизм верификации безопасности программных средств, функционирующих в системе защиты информации корпоративных сетей. Вопросы защиты информации, (4), 37-40.
2. Рагимов, Э. Р. (2006). Об одном подходе оценки риска при проектировании защищенных корпоративных сетей. Информационные технологии моделирования и управления, (1), 94-98.
3. Suleymanov, T. I., Mamedov, S. E., Ragimov, E. R., & Rahimov, J. R. (2024). Wind influence on the pollutants emitted spread by motor vehicles. Synchroinfo Journal, 10(4), 14-20.
4. Mamedov, S. E., & Rahimov, E. R. (2024). Information model of vehicle telematics data cluster collection using UAV. Synchroinfo Journal, 10(2), 21-27.
5. Барат, И. Э., Рагимов, Д. Р., Рагимов, Э. Р., & Велиев, Г. С. (2023). СРАВНИТЕЛЬНАЯ ХАРАКТЕРИСТИКА НЕПАРАМЕТРИЧЕСКИХ, А ТАКЖЕ ИНТЕГРИРОВАННЫХ ПО

ПАРАМЕТРУ СРЕДНЕВЗВЕШЕННЫХ ОЦЕНОК ГЕОЭКОЛОГИЧЕСКИХ ИЗМЕРИТЕЛЬНЫХ ДАННЫХ. Вестник Забайкальского государственного университета, 29(1), 44-50.

6. Рагимов, Э. (2011). КВАЛИМЕТРИЧЕСКИЕ ПОКАЗАТЕЛИ БЕЗОПАСНОСТИ ПРОГРАММНЫХ КОМПЛЕКСОВ, РЕАЛИЗУЮЩИХ СИСТЕМУ УПРАВЛЕНИЯ КОРПОРАТИВНЫМИ СЕТЯМИ. Problems of information technology, 2(1), 18-23.
7. Рагимов, Э. Р. О. (2011). Метрология элементов безопасности программных комплексов, реализующих систему защиты информации корпоративных сетей. Вопросы защиты информации, (2), 36-41.
8. Искендерзаде, Э. Б. О., Рагимов, Э. Р. О., & Джейхун, Р. (2024). НОВЫЕ КРИТЕРИИ ОЦЕНКИ ЭМИССИИ С И CO2 В ВОЗДУХ АВТОМОБИЛЬНЫМ ТРАНСПОРТОМ. Природные системы и ресурсы, 14(2), 47-54.
9. Рагимов, Э. Р. (2012). Определение квалиметрических показателей назначения программных комплексов в рамках эксплуатируемой корпоративной сети. Телекоммуникации, (8), 34-40.
10. Рагимов, Э. Р. О. (2012). Методология оптимальной идентификации расположения программных единиц в комплексе безопасных программ, реализующих систему защиты информации корпоративной сети. Вопросы защиты информации, (1), 51-57.