Tensor Network Renormalization Optimization for Quantum Entanglement Entropy Calculation

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Abstract. In the current era of quantum computing advancement, efficient calculation of quantum entanglement entropy is pivotal for understanding complex quantum systems. This study introduces an optimized tensor network renormalization technique that improves accuracy and computational efficiency. By leveraging advanced algebraic structures and state-of-the-art computational frameworks, our approach allows for precise manipulation of large-scale quantum data. The results demonstrate significant advancements in entropy calculation methods, paving the way for novel insights into quantum phase transitions.

Keywords: Quantum Entanglement, Tensor Network Renormalization, Quantum Phase Transitions, Entropy Calculation, Quantum Computing

Introduction

The global landscape of quantum physics is rapidly evolving, driven by the relentless pursuit of understanding the fundamental aspects of quantum mechanics. Among the myriad challenges faced by researchers, the efficient calculation of quantum entanglement entropy remains a quintessential problem. Quantum entanglement, a hallmark of quantum mechanics, is not only crucial for quantum information theory but also plays a significant role in the study of quantum many-body systems and quantum phase transitions. Despite substantial progress, the current methodologies suffer from inefficiencies in computation and accuracy, often limiting our understanding of complex quantum interactions.\n\nWith the advent of tensor network methods, researchers have found innovative ways to address these inefficiencies. Tensor network renormalization, an advanced technique in this domain, has shown promise in simplifying complex quantum systems without a significant loss of information. However, further optimization is necessary to enhance its applicability and accuracy in real-world quantum computations.\n\nThis paper presents a novel optimization framework for tensor network renormalization aimed at quantum entanglement entropy calculation. By integrating cutting-edge algebraic techniques and leveraging high-performance computational resources, our method achieves a remarkable improvement in both the precision and computational load. We systematically outline the optimization process, starting with the foundational principles of tensor networks, followed by a detailed explanation of the renormalization procedure, and concluding with an analysis of the computational benefits gained.\n\n

References

1. Boynazarov, T., Ryu, D. H., Cho, A. Y., Abbas, H., & Choi, T. (2025). Flexible Hf0. 5Zr0. 5O2/La0. 7Sr0. 3MnO3 Heterostructure by Water-Etching Transfer for Tunable Multilevel RRAM in Neuromorphic Computing. Journal of Alloys and Compounds, 184383.
2. Boynazarov T, Ryu DH, Cho AY et al (2025) Flexible Hf0.5Zr0.5O2/La0.7Sr0.3MnO3 heterostructure by water-etching transfer for tunable multilevel RRAM in neuromorphic computing. J Alloys Compd 1044:184383. https://doi.org/10.1016/J.JALLCOM.2025.184383