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Area Law and Provably Efficient Algorithm for Quantum Gibbs States in Long-Range Interacting Systems

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The quantum Gibbs state represents thermal equilibrium and is crucial in various fields. In this work, we analyze bipartite quantum correlations in quantum Gibbs states within long-range interacting systems and present an algorithm that constructs these states efficiently and accurately. First, we clarify the optimal condition under which the bipartite information measures adhere to the area law under power-law decaying interactions [1]. We show that the area law is satisfied when the power-law exponent exceeds $(D+1)/2$ for a spatial dimension D. By considering the clustering property, which noncritical systems exhibit, our findings extend the applicability of the area law beyond the traditional boundary of $D+1$, establishing its validity even in areas lacking thermodynamic extensivity. Next, we introduce an algorithm that constructs the matrix product operator of the quantum Gibbs state in one-dimensional long-range interacting systems, maintaining accuracy within a specific error margin [2]. This algorithm is based on the idea of the renormalization group and ensures precision, with its runtime scaling quasi-polynomially with system size.

[1] Donghoon Kim, Tomotaka Kuwahara, and Keiji Saito, Phys. Rev. Lett. **134**, 020402 (2025)

[2] Rakesh Achutha, Donghoon Kim, Yusuke Kimura, and Tomotaka Kuwahara, Phys. Rev. Lett. **134**, 190404 (2025)

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