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Improved Product-state Approximation Algorithms for Quantum Local Hamiltonians

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Abstract: The ground state energy and the free energy of Quantum Local Hamiltonians are fundamental quantities in quantum many-body physics, however, it is QMA-Hard to estimate them in general. In this paper, we develop new techniques to find classical, additive error product-state approximations for these quantities on certain families of Quantum k-Local Hamiltonians. Namely, those which are either dense, have low threshold rank, or are defined on a sparse graph that excludes a fixed minor, building on the methods and the systems studied by Brandão and Harrow, Gharibian and Kempe, and Bansal, Bravyi and Terhal.

We present two main technical contributions. First, we discuss a connection between product-state approximations of local Hamiltonians and combinatorial graph property testing. We develop a series of \textit{weak Szemer\'edi regularity} lemmas for k-local Hamiltonians, built on those of Frieze and Kannan and others. We use them to develop \textit{constant time} sampling algorithms, and to characterize the 'vertex sample complexity' of the Local Hamiltonian problem, in an analog to a classical result by Alon, de la Vega, Kannan and Karpinski. Second, we build on the information-theoretic product-state approximation techniques by Brandão and Harrow, extending their results to the free energy and to an asymmetric graph setting. We leverage this structure to define families of algorithms for the free energy at low temperatures, and new algorithms for certain sparse graph families.

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