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General tensor network theory for frustrated classical spin models in two dimensions

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Frustration is a ubiquitous phenomenon in many-body physics that influences the nature of the system in a profound way with exotic emergent behavior. Despite its long research history, the analytical or numerical investigations on frustrated spin models remain a formidable challenge due to their extensive ground-state degeneracy. In this paper, we propose a unified tensor network theory to numerically solve the frustrated classical spin models on various two-dimensional (2D) lattice geometry with high efficiency. We show that the appropriate encoding of emergent degrees of freedom in each local tensor is of crucial importance in the construction of the infinite tensor network representation of the partition function. The frustrations are thus relieved through the effective interactions between emergent local degrees of freedom. Then the partition function is written as a product of a one-dimensional (1D) transfer operator, whose eigenequation can be solved by the standard algorithm of matrix product states rigorously, and various phase transitions can be accurately determined from the singularities of the entanglement entropy of the 1D quantum correspondence. We demonstrated the power of our general theory by numerically solving 2D fully frustrated XY spin models on the kagome, square, and triangular lattices, giving rise to a variety of thermal phase transitions from infinite-order Brezinskii-Kosterlitz-Thouless transitions, second-order transitions, to first-order phase transitions. Our approach holds the potential application to other types of frustrated classical systems like Heisenberg spin antiferromagnets.

References:

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