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Tensor-entanglement renormalization

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Traditional mean-field theory is a simple generic variational approach for analyzing various symmetry breaking phases. However, this simple approach only applies to symmetry breaking states with short-range entanglement. Tensor-entanglement renormalization group (TERG) is a generic approach for studying 2D quantum phases with long-range entanglement (such as topological phases) based on a new class of trial wavefucntions - the tensor product states (TPS), also known as projected entangled pair states (PEPS). Those TPS (PEPS) are built from local tensors. They can describe both states with short-range entanglement (such as the symmetry breaking states) and states with long-range entanglement (such as topological/quantum order). TERG is a real space renormalization group algorithm that can efficiently simulate expectation values for TPS wave functions in 2D and higher dimensions. As an attempt in this direction, we demonstrate our algorithm by studying several simple 2D quantum spin models, including both symmetry breaking phase transitions and topological phase transitions. However, as any variational method, the TERG approach could not find all the degenerate ground states for gapped systems and generally could not give out (approximately) correct critical exponent for critical systems. To solve these problems, we study the renormalization group flow of a Lagrangian (partition function) by representing its path integral through a tensor network. Using a tensor-entanglement-filtering renormalization group (TEFRG) method that removes local entanglement and coarse grains the lattice, we show that the renormalization flow of the tensors in the tensor network has a nice fixed-point structure. The isolated fixed-point tensors characterize various phases. The tensor fixed points can describe both the symmetry breaking phases and topological phases. The ground state degeneracy for gapped systems can be easily read out from the fixed point tensor. The scaling dimensions, the central charge and dynamic correlation functions for the critical systems that describe the continuous phase transitions between symmetry breaking and/or topological phases can also be calculated from the TEFRG approach.