Simulation of strongly correlated systems with 2D tensor networks

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Tensor networks are a class of variational wave functions enabling an efficient representation of quantum many-body states, where the accuracy can be systematically controlled by the so-called bond dimension. A well-known example are matrix product states (MPS), the underlying tensor network of the density matrix renormalization group (DMRG) method, which has become the state-of-the-art tool to study (quasi-) one dimensional systems. Progress in quantum information theory, in particular a better understanding of entanglement in quantum many-body systems, has led to the development of tensor networks for 2D systems, including e.g. projected entangled-pair states (PEPS) or the 2D multi-scale entanglement renormalization ansatz (MERA). In recent years these methods have become very powerful tools for the study of 2D strongly correlated systems, in particular for models where quantum Monte Carlo fails due to the negative sign problem.

In this talk I report on recent progress with infinite projected-entangled pair states (iPEPS) - a two-dimensional tensor network ansatz for 2D ground states in the thermodynamic limit. I present simulation results for the 2D Hubbard model at 1/8 doping in the strongly correlated regime, where a close competition between a uniform d-wave superconducting state and different types of stripes states is found. From systematic extrapolations to the infinite bond dimension limit we conclude that a period 8 stripe state is the lowest energy state. Consistent results are also obtained by density matrix embedding theory, DMRG, and constrained-path auxiliary-field quantum Monte Carlo [1]. Furthermore I show that period 4 stripes - which are typically observed in experiments on the cuprates - become the ground state upon adding a realistic next-nearest neighbor hopping term to the Hubbard model [2]. Finally, I will briefly highlight other recent directions with 2D tensor networks, including an approach to study 2D quantum critical phenomena [3] and simulations at finite temperature [4].

References

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