Solving the Quantum Many-Body Problem with Artificial Neural Networks

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Abstract

The challenge posed by the many-body problem in quantum physics stems from the difficulty of describing the non-trivial correlations encoded in the wave function. In principle, an exponential amount of information is needed to fully characterize a generic many-body quantum state. However, it is often the case that a wave function representing a physical many-body system can be characterized by an amount of information much smaller than the maximum capacity of the corresponding Hilbert space. This leads to the enourmous success of numerical methods either aiming at sampling (Quantum Monte Carlo) or compressing (Tensor Network methods) the many-body state. The existing methods however suffer from limitations (sign problem for Quantum Monte Carlo, and dimensionality for Tensor Networks) which strongly limit the physical systems we can explore. In our work we demonstrate that an alternative route is viable. We show that systematic machine learning of the wave function can reduce the exponenentialy complexity of the wave-function to a tractable computational form, for some notable cases of physical interest. We introduce a variational representation of quantum states based on artificial neural networks with variable number of hidden neurons. A reinforcement-learning scheme is then demonstrated, capable of either finding the ground-state or describing the unitary time evolution of complex interacting quantum systems. We show that this approach achieves very high accuracy in the description of equilibrium and dynamical properties of prototypical interacting spins models in both one and two dimensions, thus offering a new powerful tool to solve the quantum many-body problem.

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