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Editorial: Tensor network approaches for quantum many-body physics and machine learning

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Editorial on the Research Topic
Tensor network approaches for quantum many-body physics and machine learning

As a higher-order generation of matrix, tensor is defined as a multi-way array that has been widely used in data science and machine learning. The network model, connecting multiple tensors with contraction operations is known as tensor network (TN). Its most successful applications firstly appeared in quantum physics as an efficient representation of quantum many-body states and their operations. Various methods based on TN have been developed to efficiently simulate quantum systems of interacting spins, bosons, and fermions at zero and finite temperatures. Significant progresses have also been achieved by TN in the hybridization of quantum information sciences and condensed matter physics, including the characterization of multipartite entanglement and variational quantum algorithms.

In recent years, we have witnessed the fast development of TN methods for machine learning (ML). A new research field known as quantum (or quantum-inspired) ML emerged, where TN has been playing an essentially important role. Compared with the mainstream ML models particularly neural network with "black-box" nature, TN shows great potential on the development of "white-box" ML, where the underlying theoretical framework could be built based on quantum information science and quantum many-body physics. Some pioneering works have demonstrated the feasibility and perspective of this direction, where TN has been successfully used on classification, generation modeling, representation learning, feature extraction, anomaly detection, to name but a few.

This topic collects four relevant papers on applying tensor and TN for challenging problems in ML. Luo et al. considered the reconstruction of unknown tensor, which is an essential problem in data recovery. The challenge lies in the reconstruction from a small number of observations. A critical point that affects the reconstruction performance is the underlying low-rank structure of tensor. The authors propose to simultaneously impose low-rankness in both spectral and original domains by combining t-SVD and Tucker decomposition. The upper bounds on the estimation error are analyzed in both deterministic and non-asymptotic ways. Its effectiveness is shown on both synthetic and real datasets by comparing with the exact low-tubal-rank tensor recovery.

The "quantum nature" of TN inspires many novel and interpretable ML methods, which include two works collected in this Research Topic. Evenbly proposed the number-state preserving TN to build the classifiers for supervised ML. The number-state preserving TN state possesses well-defined particle numbers and causal cone structures in the TN contractions. These properties endow the TN classifiers with interpretability based on the physical picture of number state and high efficiency by borrowing the idea of quantum algorithms (specifically the multipartite entanglement renormalization ansatz).

In quantum physics, entanglement is recognized as one of the most fundamental concepts to distinguish "quantum" from "classical." How entanglement could assist and enhance the quantum and quantum inspired ML is one of the hottest topics in this interdisciplinary field. In the work by Liu et al., an entanglement-based feature extraction scheme was proposed. The authors demonstrated that the entanglement entropy, which measures the amount of quantum correlations in many-body states, can quantitatively characterize the importance of features (e.g., pixels of images). High accuracy can be retained by just keeping less than 10% features with highest entanglement entropy. This work shows the potential of using TN and quantum information theories for developing white-box ML methods.

With the fast development and broad perspective of using TN for novel ML methods, new approaches to solve challenging problems are illuminated. Among others, combinatorial optimization problems are of general interest for both mathematical investigations and various real-life applications. Hao et al. developed a TN algorithm for locally constrained combinatorial optimization problems. The key idea is encoding the problem to the ground-state simulation of a designed Hamiltonian, which can be efficiently solved by the existing TN algorithms. Quadratic asymptotic time complexity is demonstrated on the open-pit mining problem.

We expect that this Research Topic will stimulate further studies on the quantum-inspired ML as well as the potential quantum advantages on efficiency and interpretability of learning models.

Author contributions

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Conflict of interest

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