Quantum convolutional neural networks for the recognition of many-body topological phases of matter

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Existing noisy intermediate-scale quantum computers can perform computations that are challenging for classical computers. However, quantum computing hardware and quantum algorithms need to be further developed to enable the exploitation of quantum computers in areas such as the simulation of many-body systems and machine learning. One of the major challenges in developing scalable quantum computers is characterizing the noisy quantum data produced by near-term quantum hardware. With increasing system size, standard characterization techniques using direct measurements and classical post-processing become prohibitively demanding due to large measurement counts and computational efforts.

Directly processing quantum data on quantum processors can substantially reduce measurement costs. Quantum neural networks based on parametrized quantum circuits, measurements and feed-forward can process large amounts of quantum data, to detect non-local quantum correlations with reduced measurement and computational efforts [1]. Characterizing non-local correlations is crucial in condensed matter physics for classifying quantum phases of matter and understanding new strongly correlated materials such as high-temperature superconductors.

A key requirement for employing quantum neural networks to characterize noisy quantum data produced by near-term quantum hardware is tolerance to errors due to decoherence and gate infidelities. In Ref. [2], we construct quantum convolutional neural networks (QCNNs) capable of recognizing symmetry-protected topological phases of many-body Hamiltonians in the presence of incoherent errors. These networks are designed to mimic renormalization-group flow and quantum error correction. We realize the error-tolerant QCNNs on a 7-qubit superconducting quantum processor [3]. The QCNNs reduce sample complexity exponentially with system size compared to direct Pauli measurements.

In a follow-up project, we generalize the QCNNs to detect intrinsic topological order in two-dimensional systems. Furthermore, we demonstrate that QCNNs can autonomously identify characteristics of topological phases via unsupervised learning.

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