Title: The impact of connectivity in qubit networks and the symmetry in the XY model on the quantum machine learning's performance

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Abstract:

Quantum machine learning (QML) has gathered significant attention recently due to being able to leverage noisy intermediate-scale quantum (NISQ) processors, and various models have been proposed to do that [1-6]. Several of those QML models [4-6] utilize Hamiltonian dynamics rather than fully programmable quantum gate arrays and thus are expected to bypass the circuit-level gate decomposition induced overhead. These models are composed of quantum and classical information processing parts where only the classical part is optimized during training. The quantum part provides only fixed Hamiltonian dynamics.

One of the models utilizing such Hamiltonian dynamics is called Quantum Extreme Reservoir Computation (QERC) [6], which can be used for solving classification tasks. It has achieved a testing accuracy rate of 97.1% using only 11 qubits on the MNIST image classification task (one of the important datasets in computer vision). Given its performance, the Hamiltonian dynamics used in the QERC model is effective as a computational resource. To understand the mechanism for how this Hamiltonian dynamics contributes to the computation, the network properties of the unitary map generated by the Hamiltonian have been investigated, and non-trivial relations between the unitary maps and its performance reported [6, 7]. In this work, we take a complementary approach and investigate the relation between the Hamiltonian dynamics and its performance with respect to the physical network among qubits.

We investigated the impact of the connectivity of qubit interaction networks on the QERC performance. For the Hamiltonian dynamics we adopted the XY Hamiltonian defined on the graph representing an interaction network and observed the difference in accuracy rate between different graphs. It was found that the periodicity of the unitary map [8] prevents it from achieving a high accuracy rate. However, we showed that graphs with simple connectivity do not have such a periodicity achieve a high accuracy rate which was almost comparable to that of a random feature map. Furthermore, we also investigated the generalization performance enhanced by the symmetry in the XY model. This work reveals that the XY Hamiltonian with simple connectivity between qubits is sufficient to perform QERC with high performance.

[1] V. Havlíček, *et al*., Nat **567**, 209 (2019).
[2] M. Schuld, *et al*., Phys. Rev. Lett. **122**, 040504 (2019).
[3] M. Noori, *et al*., Phys. Rev. Applied **14**, 034034 (2020).
[4] K. Fujii, *et al.*, Phys. Rev. Applied **8**, 024030 (2017).
[5] S. Ghosh, *et al*., npj Quantum Info. **5**, 35 (2019).
[6] A. Sakurai, *et al*., Phys. Rev. Applied **17**, 064044 (2022).
[7] A. Hayashi, *et al*., Phys. Rev. A **108**, 042609 (2023).
[8] C. Godsil, Discrete Mathematics **312**, 129-147 (2012).