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Classification of quantum phases with quantum machine learning

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We show that a Support Vector Machine with a quantum kernel provides an accurate prediction of the phase transition in quantum many-body models, even when trained far from the critical point.

The surging popularity of machine learning techniques has prompted their application to the study of physical properties, in particular to the detection of phase transitions. Recently, SVMs have been successfully employed for the prediction of the critical point of the 2D classical Ising model [1]. At the same time, machine learning has hybridized with quantum computation to yield quantum machine learning, where neural networks are replaced by variational quantum circuits and classical kernels give way to quantum kernels. These leverage the exponentially large Hilbert space in their favour, providing rich feature spaces where complex datasets can be accurately classified and promising a quantum advantage [2], [3]. However, many proposals ignore the challenge of loading classical data onto quantum memory or deal with synthetic data sets with no practical applications. In this context, we find that the study of quantum many-body systems provides the perfect testbed in the search for a practical quantum speed up, because the ground state wavefunctions that constitute the data set are quantum in origin, and thus classically intractable in large systems.

In this poster we propose to train a SVM with a kernel constructed with the ground states of a given Hamiltonian to identify phase transitions. We also present two quantum algorithms that materialize the implementation of this technique in a quantum computer. In particular, we test the validity of the method with the transition of the Ising chain in transverse field (ICTF) at different extremes of the ferromagnetic constant J. The SVM learns to classify the two phases and is then able to correctly classify a set of ground states spanning uniformly along J, giving us an estimation of the critical point J_c. We then perform a finite size scaling analysis to extract the $N \to \infty$ critical point. To benchmark our results, we replicate the results in [4] where a dip in the fidelity, the overlap between adjacent ground states in a uniform sampling of J, is used as a signature of the phase transition.We show that quantum-kernel SVMs, despite being trained with samples far from the phase transition, are an excellent tool to accurately predict quantum critical points.

[1] C. Giannetti, B. Lucini and D. Vadacchino, ”Machine Learning as a universal tool for quantitative investigations of phase transitions”, Nucl. Phys. B Vol. 944 114639 (2019)
[2] M. Schuld and N. Killoran ”Quantum Machine Learning in Feature Hilbert Spaces”, 10.1103/Phys-RevLett.122.040504 (2019)
[3] Y. Liu, S. Arunachalam and K. Temme A rigorous and robust quantum speed-up in supervised machine learning, arXiv:2010.02174v2 [quant-ph]
[4] SHI-JIAN GU, ”Fidelity approach to quantum phase transitions”, Int. J. Mod. Phys. B Vol. 24, No. 23, pp. 4371-4458 (2010)

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