Synergy between noisy quantum computers and scalable classical deep learning for quantum error mitigation

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Abstract: This study integrates (simulated) noisy data from quantum computers with classical neural networks to enhance quantum error mitigation, enabling accurate predictions for circuits with more qubits than those used for training, outperforming zero-noise extrapolation methods.

We investigate the synergy between noisy quantum computers and scalable classical convolutional neural networks (CNNs) to address the challenge of quantum error mitigation [1]. Our approach combines noisy quantum data $\boldsymbol{z}^{(noisy)}$ with classical circuit descriptors $\boldsymbol{\theta}$ to train CNN models capable of predicting accurate expectation values $m_z = \frac{1}{N}\sum_{n=1}^{N} z_n = \frac{1}{N}\sum_{n=1}^{N}\langle\psi|Z_n|\psi\rangle$ for parameterized quantum circuits with N qubits. This method demonstrates significant improvements over traditional error mitigation techniques such as zero-noise extrapolation (ZNE).

As shown in Fig. 1a, classical-only learning struggles to emulate a specific class of quantum circuits [2]. By contrast, the CNN leverages the additional noisy quantum data to achieve better predictions.

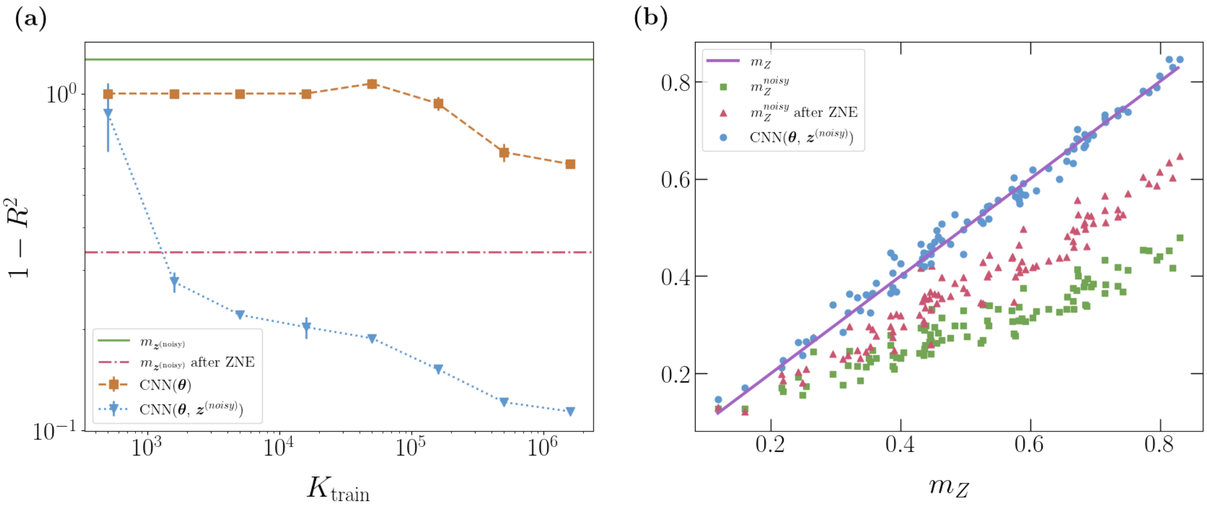

Fig. 1 (a) Prediction error $1 - R^2$ as a function of the number of instances in the training set K_{train}. (b) Scatter plot of predictions versus ground-truth expectation values m_Z for quantum circuits with 16 qubits. The CNN is trained on circuits with less than 10 qubits.

Fig. 1b highlights the strength of our method, showing that CNN predictions not only align closely with ground-truth expectation values but also outperform ZNE-corrected noisy outputs. We utilize a scalable training framework [1-3] where the CNNs are trained on small-scale circuits and successfully generalize to larger circuits. These findings demonstrate the potential of combining classical deep learning with noisy quantum computation to enhance the accuracy of quantum circuits [1,4,5], paving the way for more reliable quantum simulations and computations in near-term devices.

Example References

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