Real-time error mitigation for variational optimization on quantum hardware

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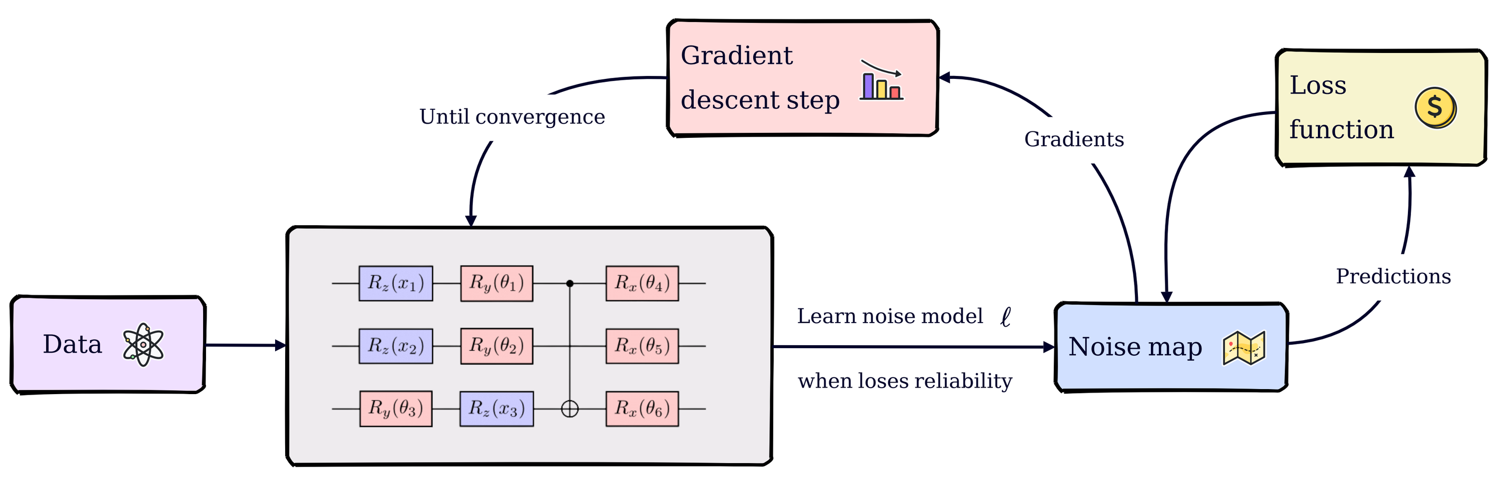
Aim

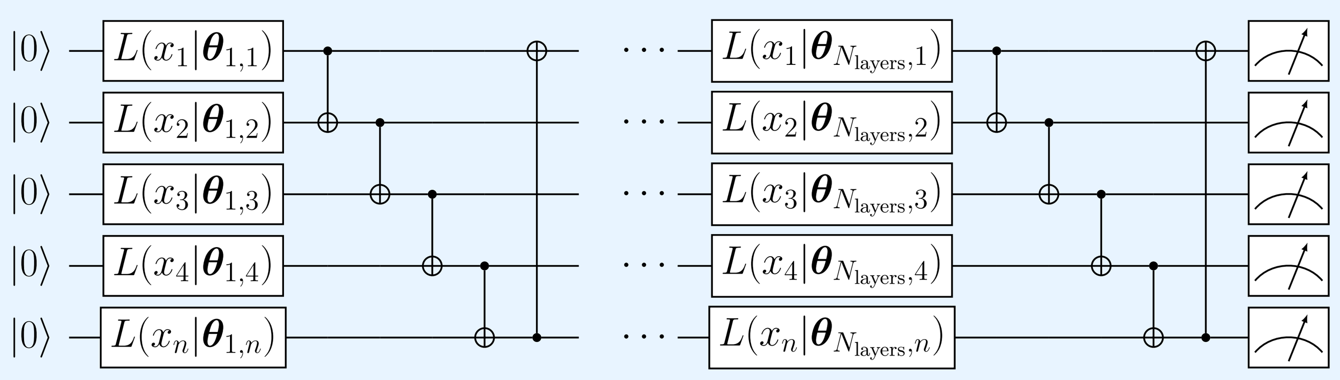
we put forward the inclusion of error mitigation routines in the process of training Variational Quantum Circuit (VQC) models. In detail, we define a Real Time Quantum Error Mitigation (RTQEM) algorithm to coadiuvate the task of fitting functions on quantum chips with VQCs.

Schematic pipeline of the RTQEM algorithm



Ansatz

We tackle multi-dimensional regression problems using a VQC as Quantum Machine Learning (QML) model. The data $\boldsymbol{x}$ are encoded into the circuit via Data Reuploading:



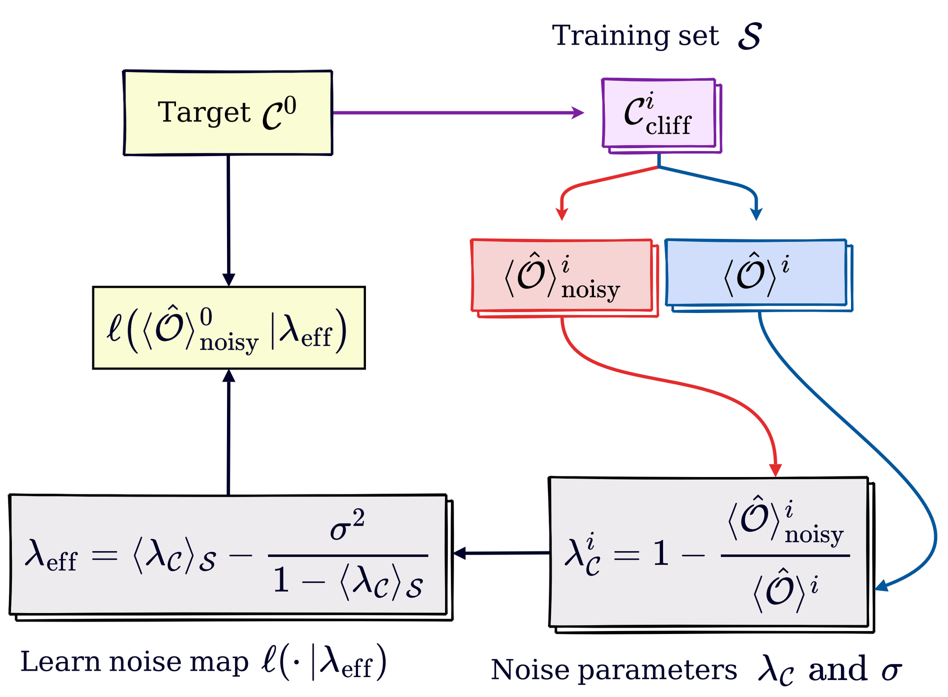
where we use the following definition of the uploading channel:

$$L(x_j|\boldsymbol{\theta}_{l,j}) = R_z(\theta_3\, x_j + \theta_4) R_y(\theta_1\, \kappa(x_j) + \theta_2)\,, \tag{1}$$

which uploads the j-th component of $\boldsymbol{x}$ at the circuit layer l.

Noise of a quantum hardware

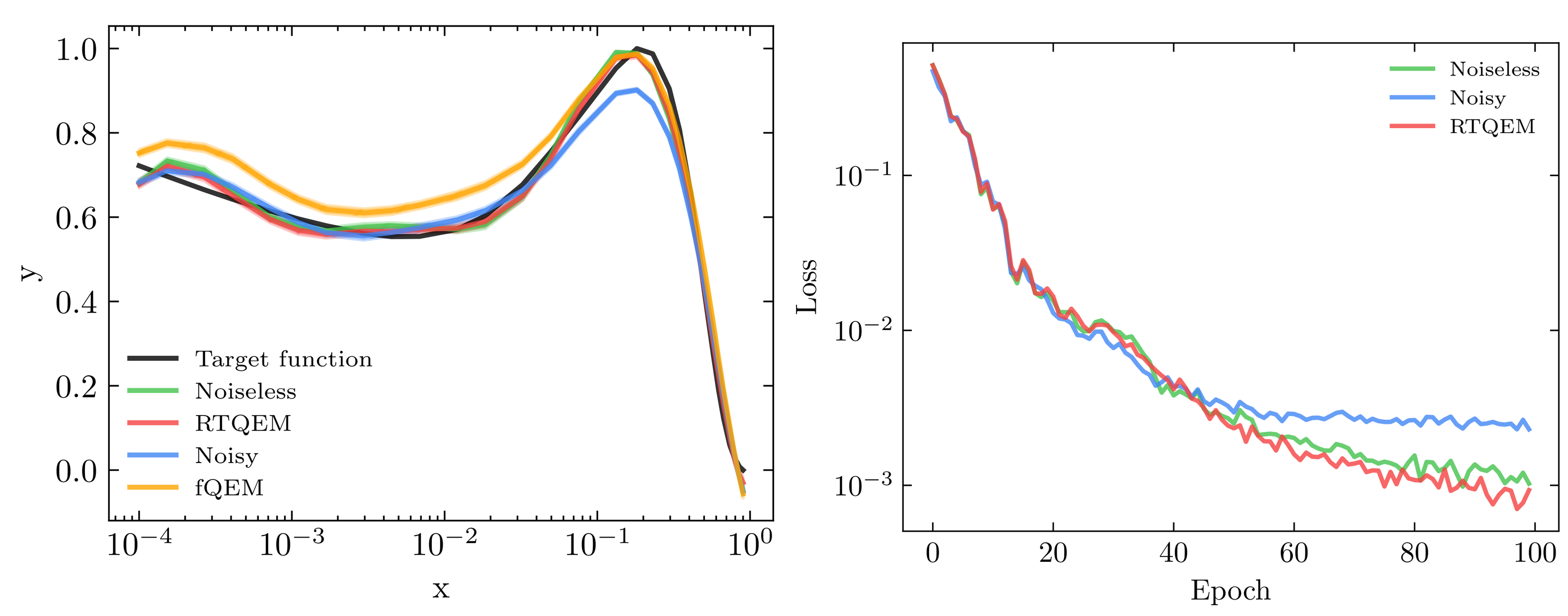
We consider a quantum system affected by local pauli noise with parameters $-1 \le q_X, q_Y, q_Z \le +1$ and readout noise parametrized by bit-flip probability $(1 - q_M)/2$. This setup gives rise to Noise-Induced Barren Plateaus (NIBP), which tend to concentrate the expectation value around 0.



To mitigate the effect of the noise, we use the Importance Clifford Sampling (ICS) technique, which is a learning-based method which can be used to learn a noise map ℓ using a training set of Clifford circuits $\mathcal{S} = \{\mathcal{C}^i_{\rm cliff}\}$ built on top of the target circuit $\mathcal{C}^0$.

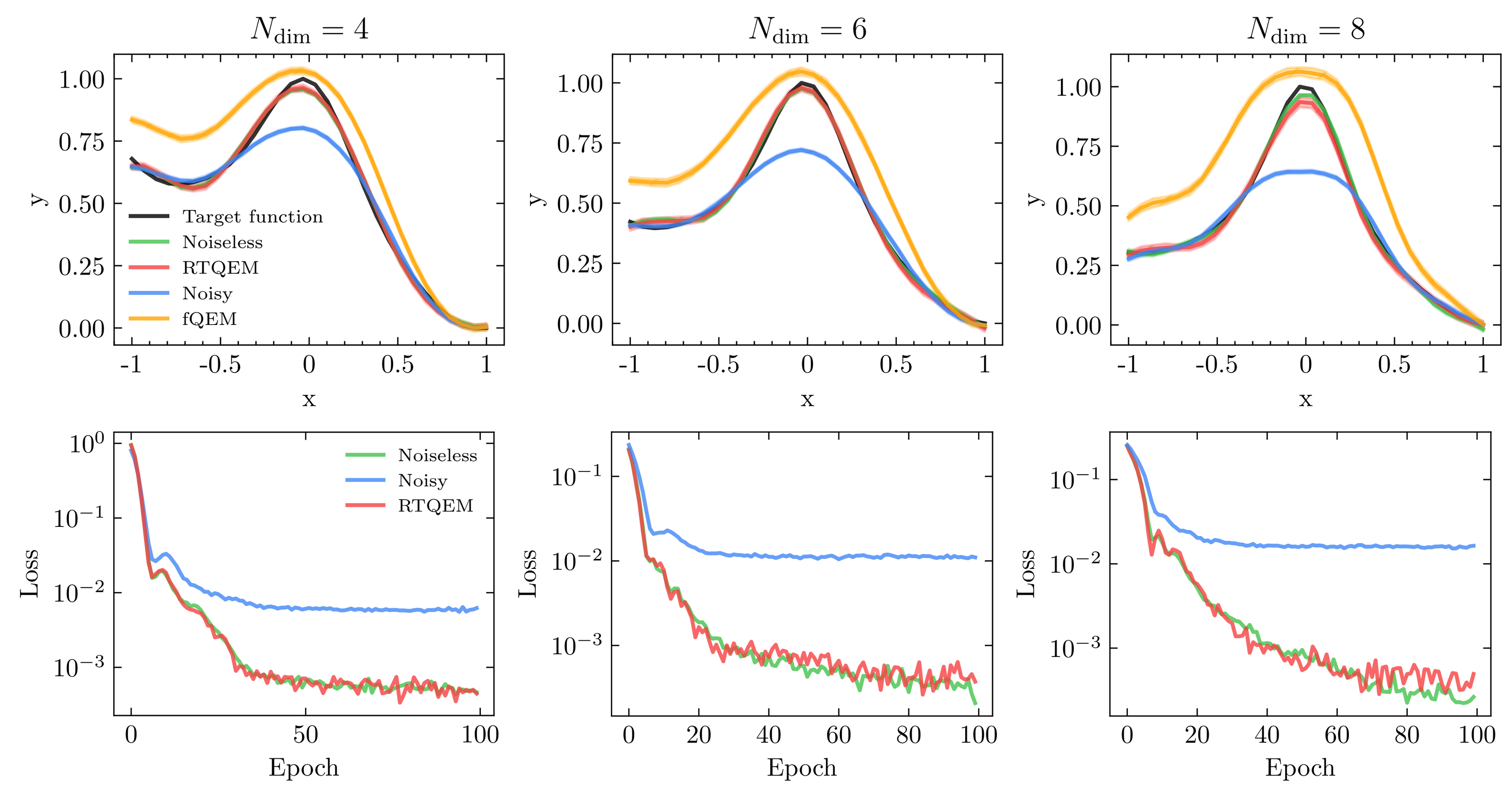
Simulation 1-dim: u-quark PDF

We firstly use a single-qubit circuit to fit the u-quark Parton Distribution Function (PDF).



Simulation n-dim

We then tackle a simple multi dimensional target to scale up with the number of qubits.



References