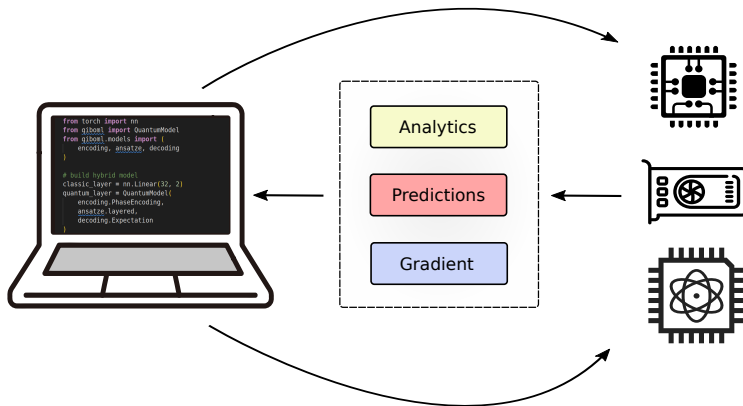


A few slides on full-stack QML

November 21, 2024

Quantum Machine Learning challenges

We aim to involve quantum process units into Machine Learning pipelines.

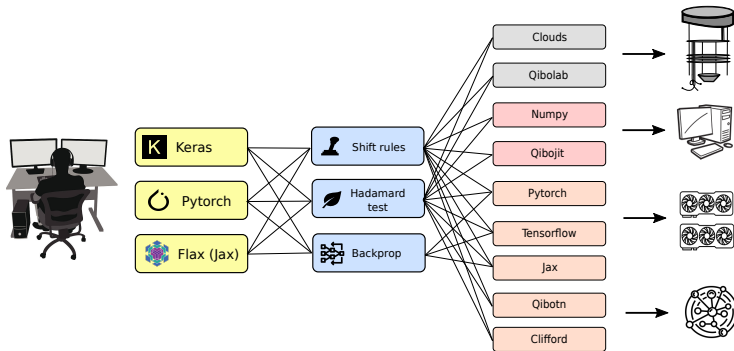


Classical and quantum components have to be executable on CPUs, GPUs and QPUs to fulfill the whole potential of an hybrid quantum-classical cluster.

Qibo as a modular playground

To do so, Qibo stands as an intriguing playground thanks to its modularity.

Once a favourite ML framework is chosen, a quantum circuit can be built with Qibo and included into the pipeline.



The circuit can then be executed onto the desired Qibo backend (quantum or classical).

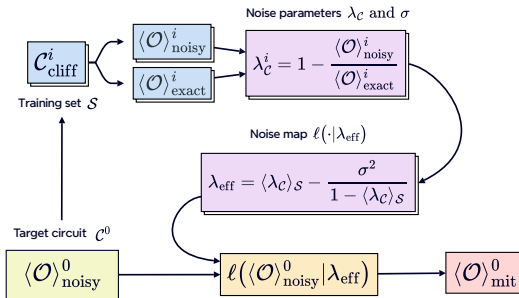
A practical example of an hybrid quantum-classical pipeline with Qibo

We want to learn the Parton Distribution Function of the *up* quark in the proton with a superconducting qubit.

In doing so, we want to mitigate the noise of the quantum device using a learning-based error mitigation technique.

The method requires:

1. efficient classical simulation tools;
2. easy access to the quantum hardware;
3. ability to easily make quantum and classical outputs interact;
4. access to GPUs clusters if the process is part of a ML pipeline (optionally).



High level API: Qibo

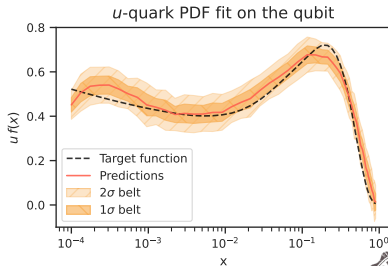
</> define **prototypes** and models;
 </> **simulate** training and noise.

Calibration: Qibocal

⚙️ **calibrate** qubits;
 ⚙️ generate **platform configuration**;

Execution: Qibolab

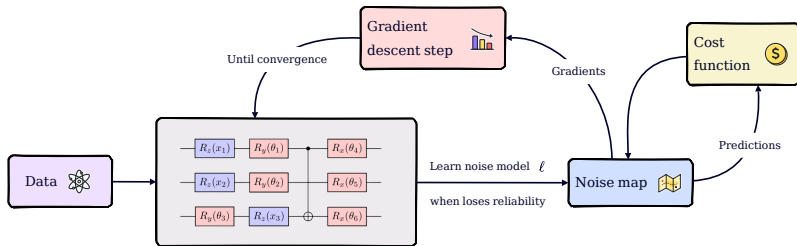
⚙️ allocate **calibrated** platform;
 ⚙️ **compile** and **transpile** circuits;
 ⚙️ execute and return **results**.



Parameter	Value
N_{data}	50
N_{shots}	500
MSE	$\sim 10^{-3}$
Electronics	Xilinx ZCU216
Training time	$\sim 2\text{h}$

Real-time quantum error mitigation

We define a Real-Time Quantum Error Mitigation (RTQEM) procedure.

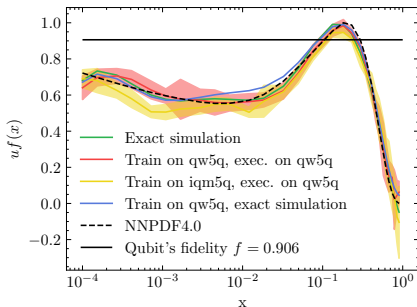


1. consider a Variational Quantum Algorithm trained with gradient descent;
2. learn the noise map ℓ every time is needed over the procedure;
3. use ℓ to clean up both predictions and gradients.

This procedure requires real-time interaction between quantum and classical devices: the former returns the output of the quantum system, the latter mitigate the noise.

We perform a gradient descent on two different quantum devices (and noises!)

Parameter	N_{train}	N_{params}	N_{shots}	Epochs
Value	15	16	500	100



- ⚙️ qw5q from QuantWare and controlled using Qblox instruments;
- ⚙️ iqm5q from IQM and controlled using Zurich Instruments.

Train.	Epochs	Pred.	Config.	MSE
qw5q	100	qw5q	RTQEM	0.0013
iqm5q	100	qw5q	RTQEM	0.0037
qw5q	100	sim	RTQEM	0.0016

All the hardware results are obtained deploying the θ_{best} on qw5q.