Full-stack quantum machine learning on hybrid quantum-classical platforms

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UNIVERSITÀ
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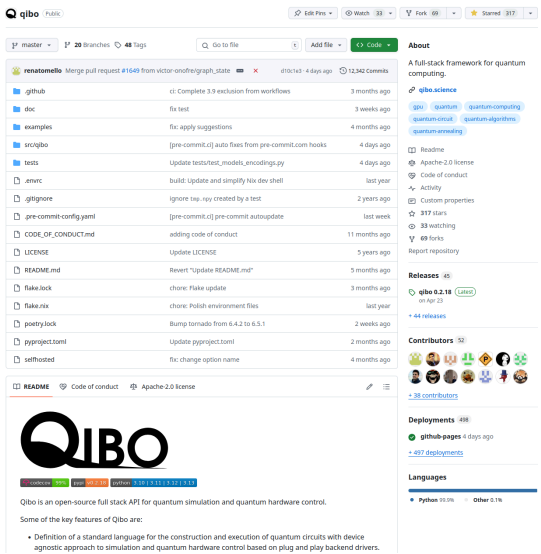
DI MILANO

QIBO

A worldwide open source collaboration



"Qibo: a framework for quantum simulation with hardware acceleration"

Efthymiou et al, 2020.

The Quantum Computer

CQT

SG NSCC SINGAPORE National Supercomputing Centre

Agency for Science, Technology and Research SINGAPORE

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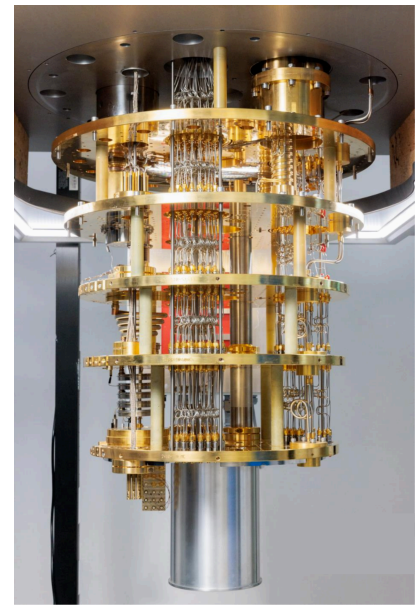
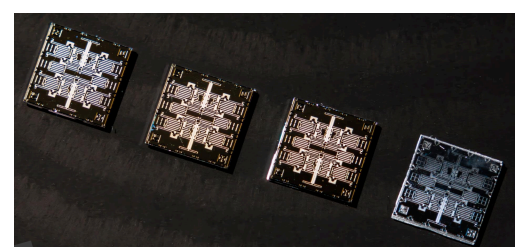
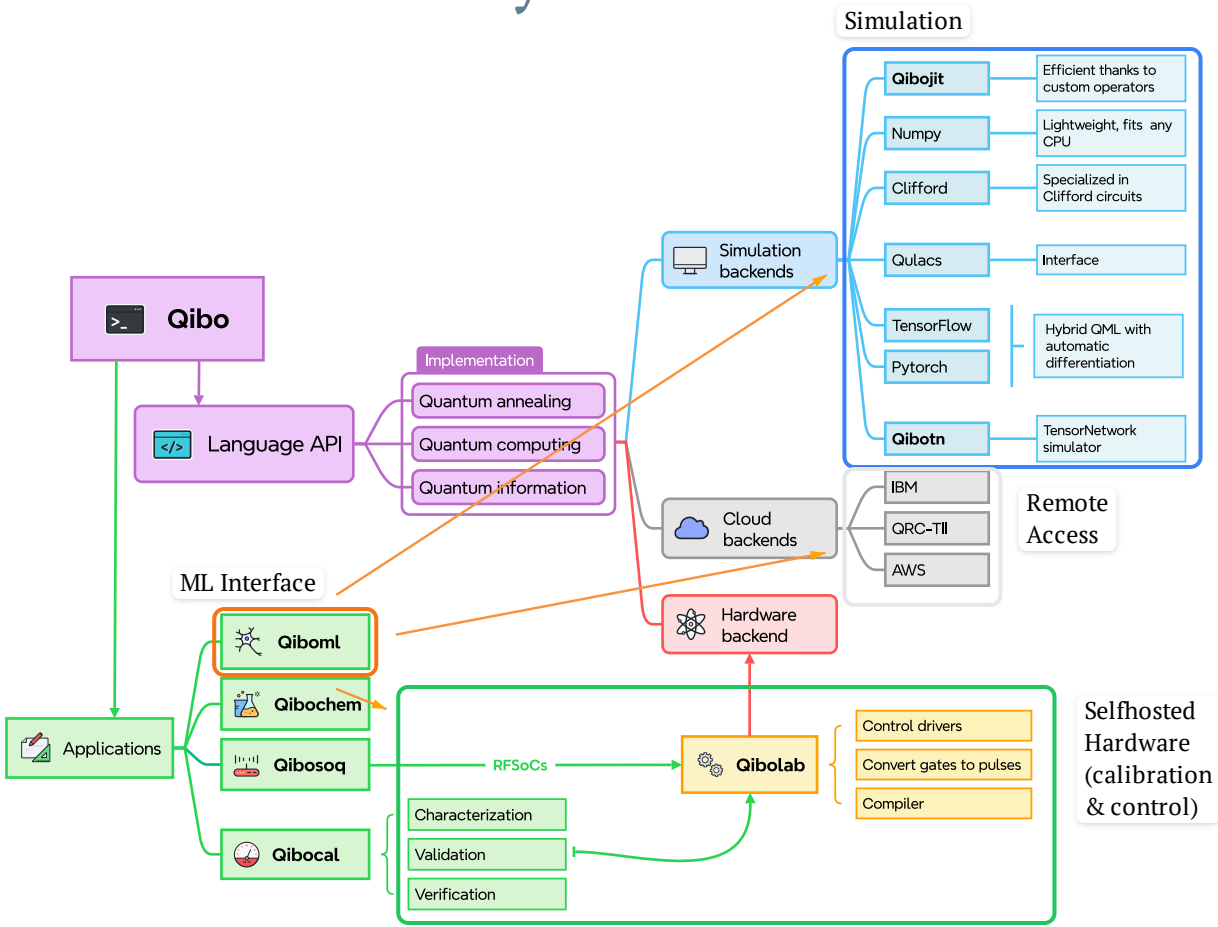
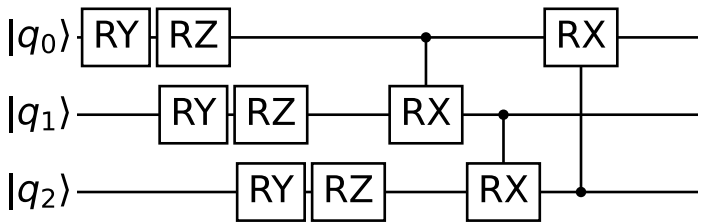


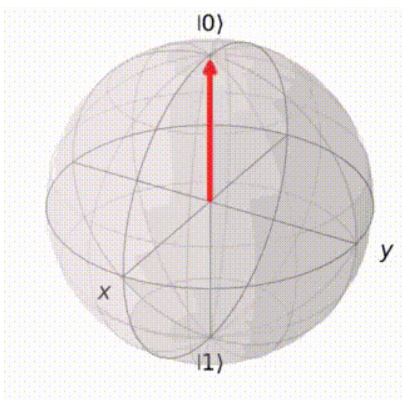


A flexible full-stack ecosystem



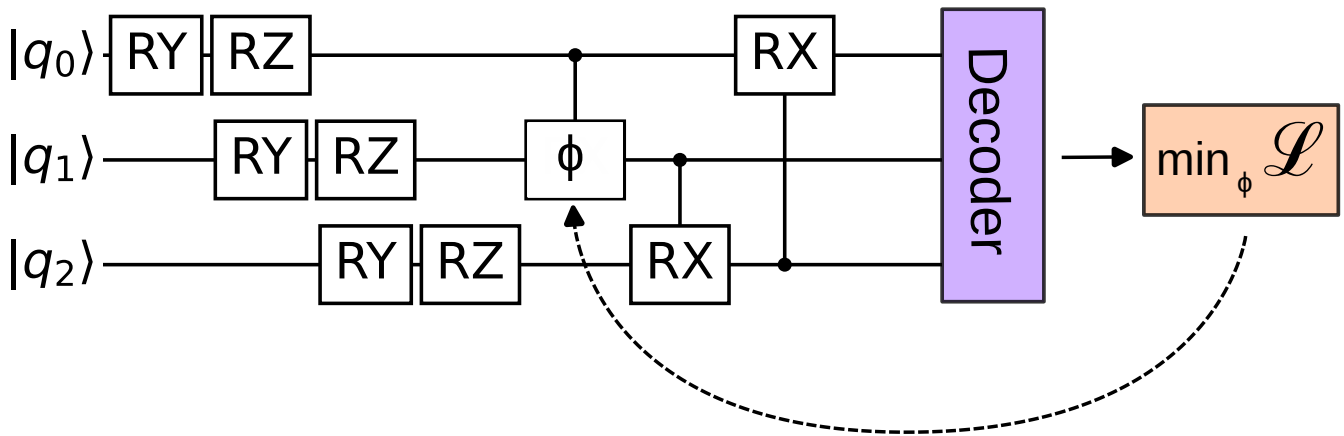
Quantum Computation through circuits





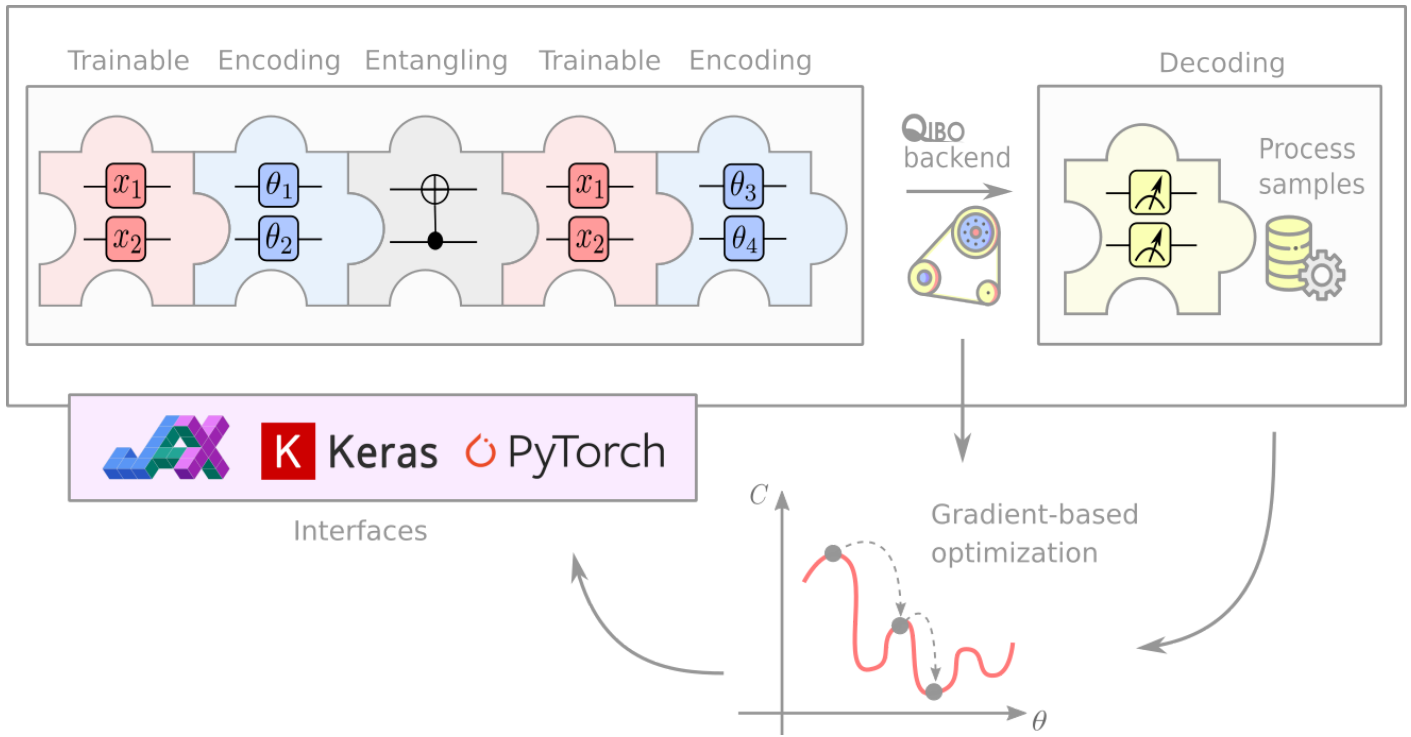

```python
import numpy as np
from qibo import Circuit, gates

# Construct the circuit
circuit  = Circuit(3)
# Add the gates
for q in range(3):
  circuit.add(gates.RY(q=q, theta=np.random.randn()))
  circuit.add(gates.RZ(q=q, theta=np.random.randn()))
  for q in range(3):
    circuit.add(gates.CRX(
      q%3, (q+1)%3, theta=np.random.randn())
    )
# Execute the circuit and get the final state
result = circuit()
print(result.state())
```

Quantum Machine Learning (QML)



- Decode the quantum information contained in the final state
- Compute the loss
- Update the gates' parameters to minimize the loss

The Qiboml pipeline



QML models made easy

Interface agnostic

```
from qiboml.models.encoding import PhaseEncoding
from qiboml.models.decoding import Expectation

# Encoding layer
encoding = PhaseEncoding(3, encoding_gate=gates.RX)
structure = []
# Alternate encoding and trainable layers
for _ in range(5):
    structure.extend([encoding, circuit.copy()])
# Decoding layer
decoding = Expectation(3)
# Prepare some data
x = np.random.uniform(
  0, 2, 300
  ).reshape(100, 3) * np.pi
y = np.sin(x).sum(-1)
```

Keras interface

```
from qiboml.interfaces.keras import QuantumModel
import tensorflow as tf

# This is a keras.Model
q_model = QuantumModel(structure, decoding=decoding)
# you can train it as you normally do for keras
# models
q_model.compile("adam", "mean_squared_error")
q_model.fit(
  tf.convert_to_tensor(x),
  tf.convert_to_tensor(y),
  batch_size=1,
  epochs=10
)
```

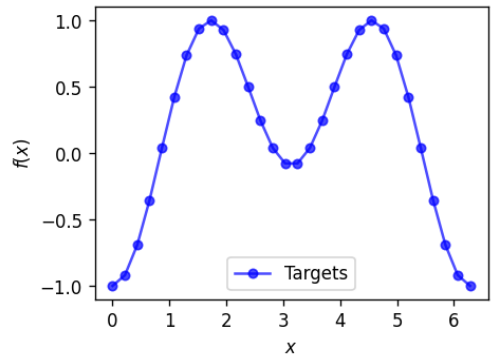
Deploy on any device: even selfhosted QPUs!

- *Just In Time* (JIT) CPU
- GPUs
- Cloud Providers
- Selfhosted QPUs

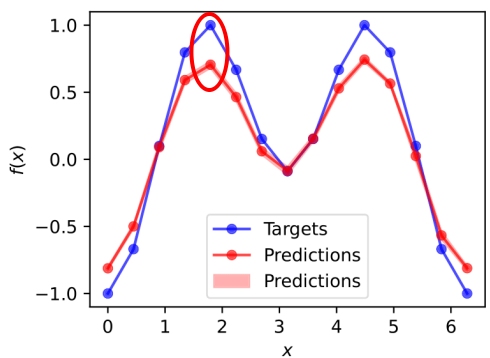

```python
from qibo import set_backend

# Use your selfhosted device through qibolab!
set_backend("qibolab", platform="my_local_platform")
```

Fitting functions on Quantum Hardware

```python
# Target function
def f(x):
    return torch.sin(x) ** 2 - 0.3 * torch.cos(x)
# Training Dataset
num_samples = 30
x_train = torch.linspace(
  0, 2 * np.pi, num_samples
  ).unsqueeze(1)
y_train = f(x_train)
```




```python
# Using qibolab at NQCH
set_backend("qibolab", platform="sinq-20")
# Define the transpiler
glist = [gates.GPI2, gates.RZ, gates.Z, gates.CZ]
natives = NativeGates(0).from_gatelist(glist)
transpiler = Passes([Unroller(natives)])
# Decoding layer
decoding = Expectation(
  nqubits=1,
  wire_names=[19], # select the qubit to use
  nshots=1024, # set the number of shots
  transpiler=transpiler
)
```



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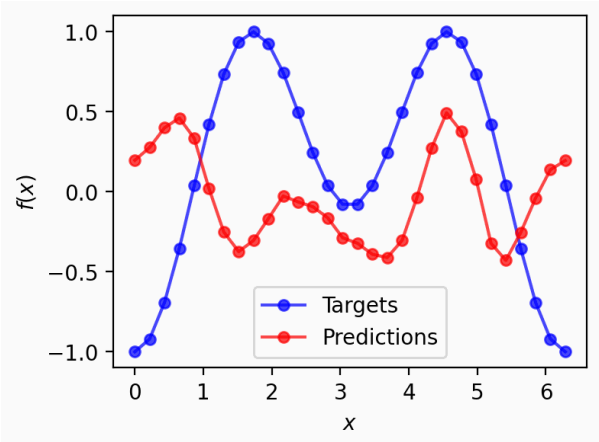
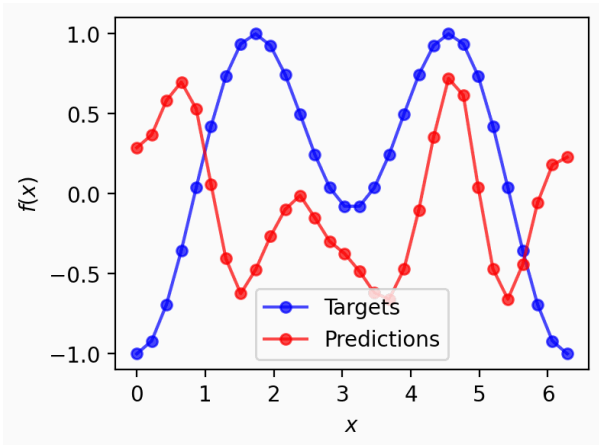
Mitigating Errors

Simulated Pauli Noise

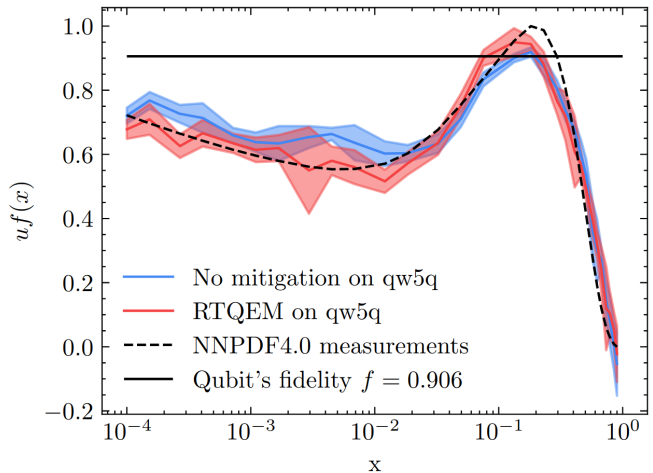


CDR mitigation




```
decoding = Expectation(
    nshots=5000,
    nqubits=1,
    mitigation_config={
    "real_time": True,
    "method": "CDR",
    "method_kwargs": {"n_training_samples": 50}
  }
)
```

Surpassing qubit fidelity

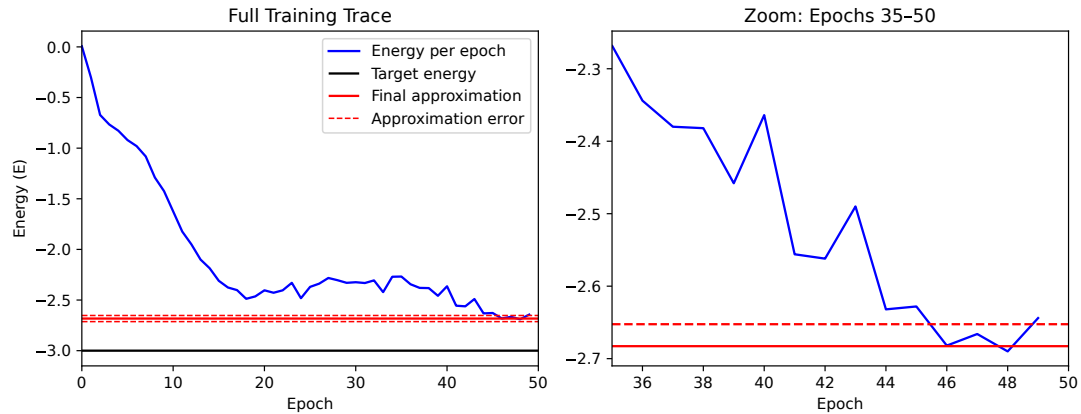


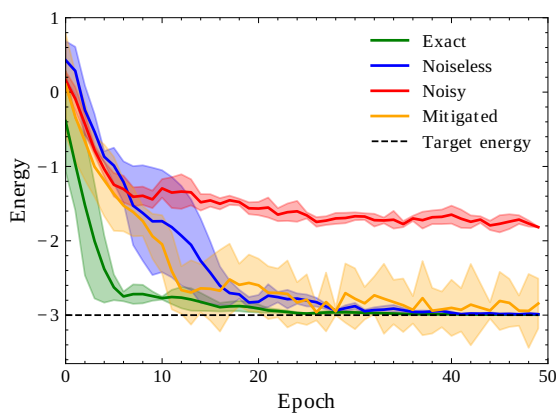
"Real-time error mitigation for variational optimization on quantum hardware"

Robbiati et al.

Finding ground states through VQEs

```
# by default this computes:
# <H> = <Z0 + Z1 + Z2>
# any observable can be used though
decoder = Expectation(
  nqubits=3,
  wire_names=[8, 3, 13],
  nshots=1000,
  transpiler=transpiler
  )
circuit = HardwareEfficient(3, nlayers=2)
model = QuantumModel([circuit,], decoder)
optimizer = torch.optim.Adam(
  model.parameters(),
  lr=0.25
  )
for epoch in range(50):
  optimizer.zero_grad()
  cost = model()
  cost.backward()
  optimizer.step()
```





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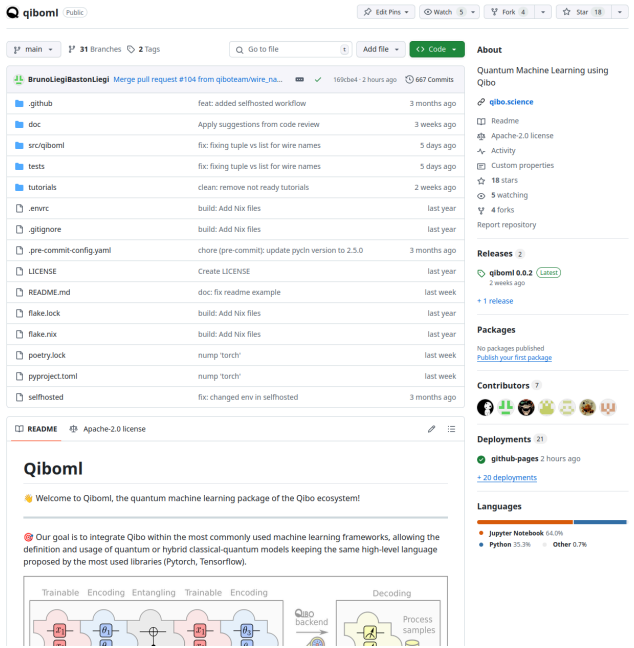
(Simulation)

Accelerating QML research

- Qiboml: an opensource library for QML applications
- Interfaces Qibo to popular ML frameworks (torch, keras, jax/flax?)
- Deploy on any Qibo-compatible backend:
  - *jit* CPU
  - GPU
  - cloud
  - selfhosted QPU!
  - Tensor Network (quimb and matchatea)?
- Mitigate errors in real time (RTQEM)!



Thank you for your attention!