

Introduction to Variational Quantum Algorithms

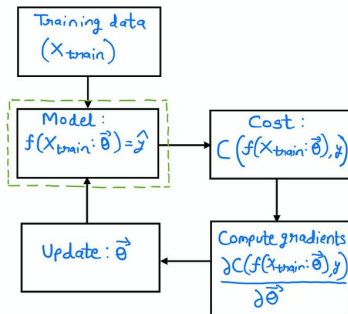
Sebastian Zając

Quantum Machine Learning Conference 2024

Machine Learning, Deep Learning

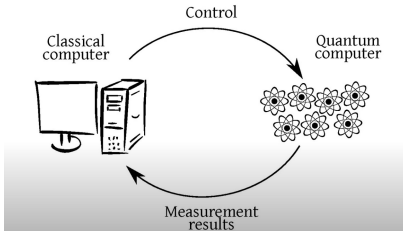
With ML, we aim to put a label onto a yet unlabeled thing. There are three main ways of doing it:

- **classification** - prediction of a discrete label,
 - **regression** - prediction of continuous output value
- segmentation** (partitioning the population into groups).

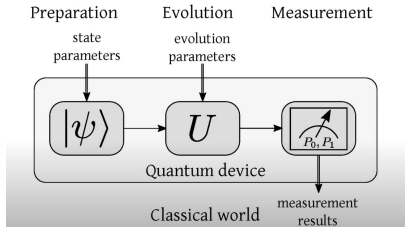


Quantum Computing process

Quantum computation control loop



Computation as experiment



Can we replace "model" with quantum computation which is beneficial or advantageous?

Variational Quantum Circuits

VQC are the practical embodiment of the idea:

„Let's train our quantum computers like we train neural networks”

Other names: parametrized quantum circuits, quantum neural networks, ...

Application

- Chemistry,
- optimization,
- solving equation,
- machine learning,
- ...

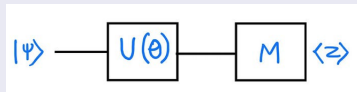
Parameterized Quantum Circuits as QML model

General Quantum Circuit:



where $|\psi\rangle$ is the initial state. U is the unitary operation (evolution). M is the measurement of the qubit.

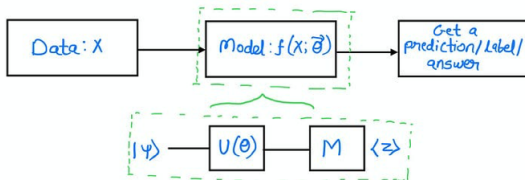
Variational Circuit



Unitary operations can depend on some parameters θ . The output is random - we get expected value of the output.

Variational Circuit as Classifier

Variational Circuit as Classifier:



- 1 Encode the classical data into a quantum state.
- 2 Apply a parameterized model (ansatz).
- 3 Measure the circuit to extract labels.
- 4 Use optimization techniques to update model parameters.

Example: VQE

For Variational Quantum Eigensolver (VQE):

1. A circuit ansatz

Unitary coupled-cluster singles & doubles (UCCSD)

2. A cost-function

The expectation value of a molecular Hamiltonian - the energy.

3. A training procedure

Gradient descent using the parameter-shift rule.

Example: QAOA

For Quantum Approximate Optimization Algorithm:

1. A circuit ansatz

repeated time evolutions of „cost” and „mixer” unitaries.

2. A cost-function

The expectation value of a „cost” Hamiltonian. Encoding a discrete optimization problem.

3. A training procedure

Gradient descent using the shots-frugal optimizer (e.g. Rosalin).

Variational Quantum Algorithm Zoo

Machine Learning

- Quantum GANs
- Quantum Classifiers
- Quantum Optical Neural Networks
- Quantum Graph Recurrent Networks
- Quantvolutional Neural Networks
- Quantum Convolutional Neural Networks

Math

- Variational Quantum Factoring
- Variational Quantum Linear Solver

Summary

Thanks for Your Attention!
sebastian.zajac@sgh.waw.pl