What is Quantum Machine Learning (QML)?

It is using Quantum Computers in Machine Learning ;)

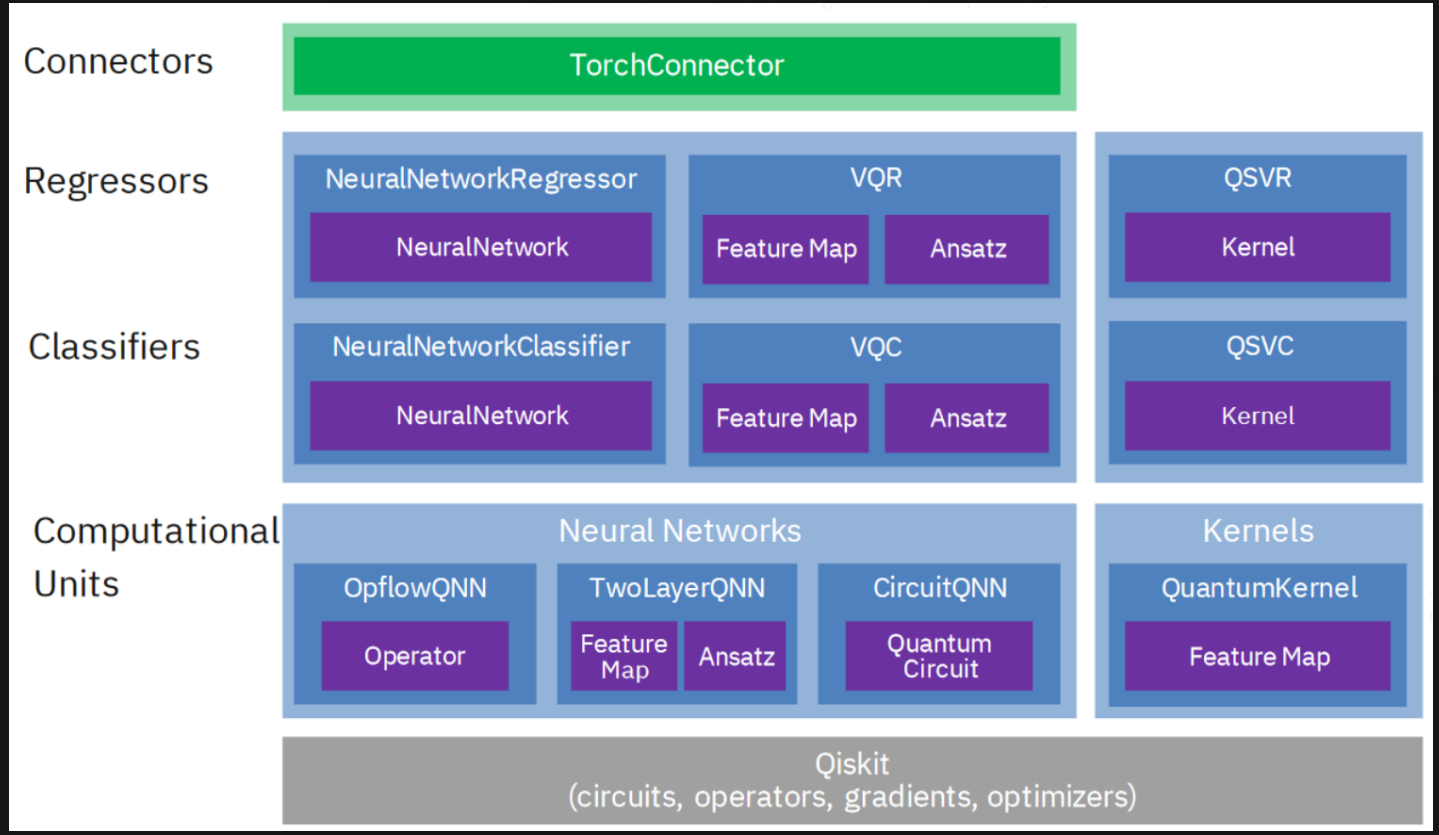
QML libraries in the field

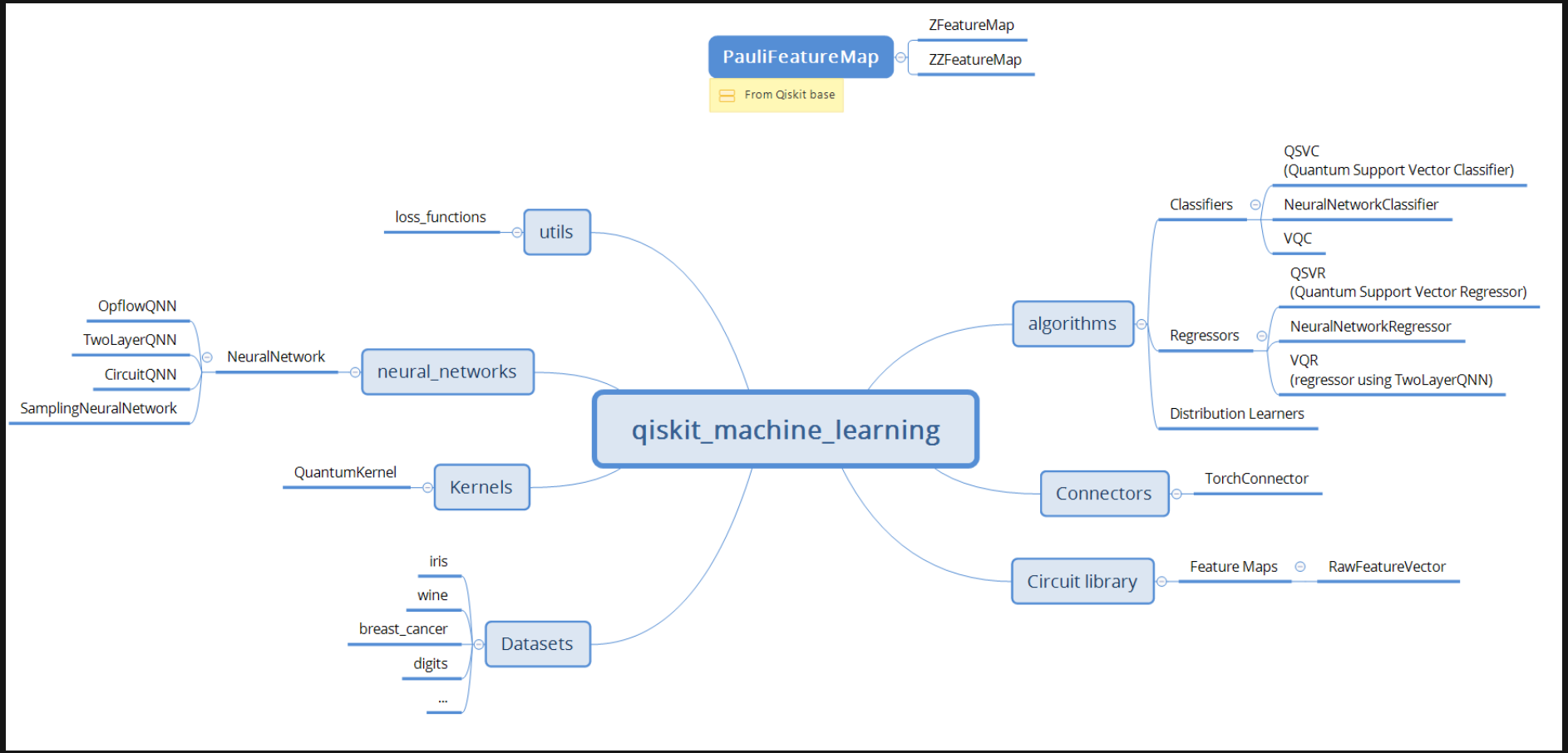
1. (IBM) Qiskit Machine Learning
2. (Xanadu) PennyLane
3. (Google) Tensor Flow Quantum

We'll use Qiskit ;)

Created in April 2021

Qiskit Machine Learning - overview

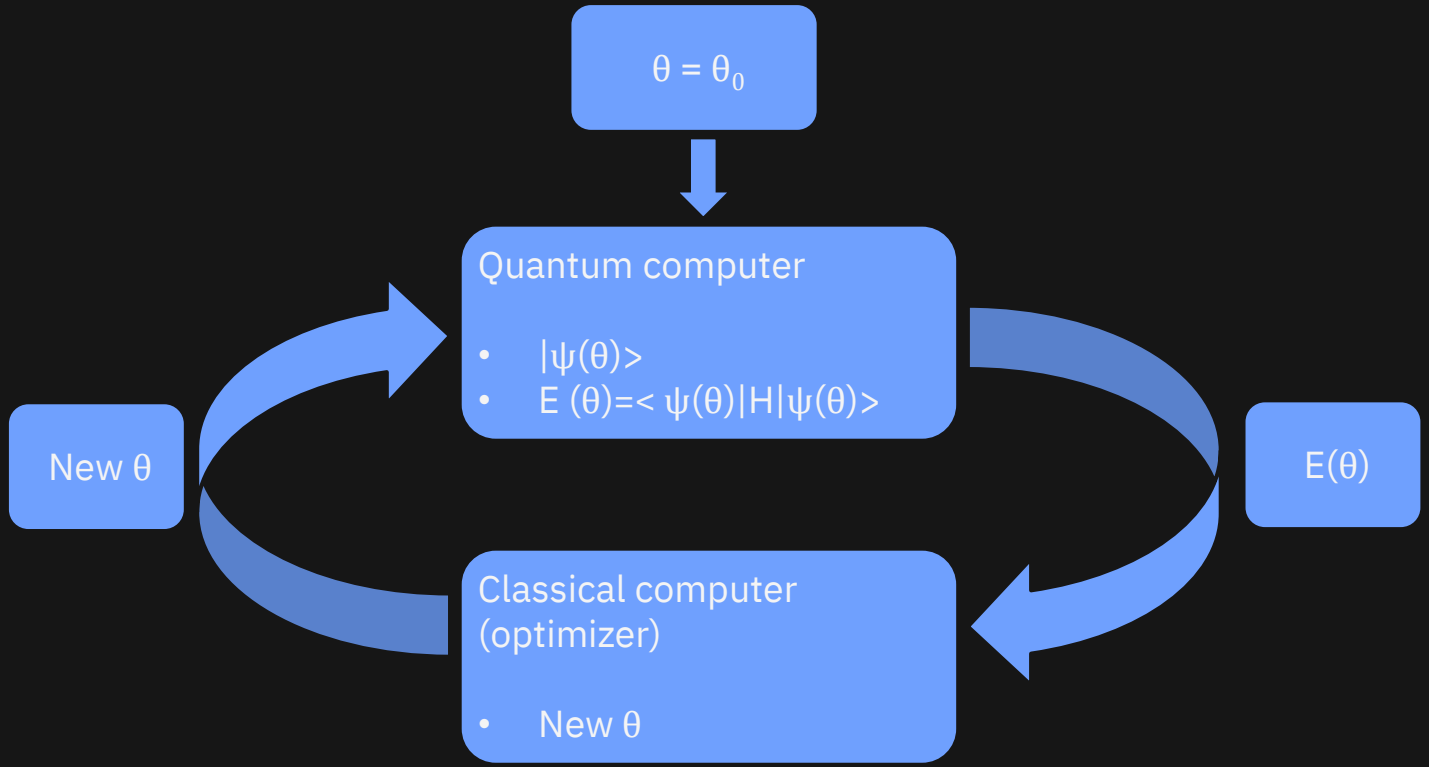

Connectors
TorchConnector
Regressors
NeuralNetworkRegressor
NeuralNetwork
VQR
Feature Map
Ansatz
QSVR
Kernel
Classifiers
NeuralNetworkClassifier
NeuralNetwork
VQC
Feature Map
Ansatz
QSVC
Kernel
Computational Units
Neural Networks
OpflowQNN
Operator
TwoLayerQNN
Feature Map
Ansatz
CircuitQNN
Quantum Circuit
Kernels
QuantumKernel
Feature Map
Qiskit
(circuits, operators, gradients, optimizers)


PauliFeatureMap
ZFeatureMap
ZZFeatureMap
From Qiskit base
qiskit_machine_learning
utils
loss_functions
neural_networks
NeuralNetwork
OpflowQNN
TwoLayerQNN
CircuitQNN
SamplingNeuralNetwork
Kernels
QuantumKernel
Datasets
iris
wine
breast_cancer
digits
...
algorithms
Classifiers
QSVC
(Quantum Support Vector Classifier)
NeuralNetworkClassifier
VQC
Regressors
QSVR
(Quantum Support Vector Regressor)
NeuralNetworkRegressor
VQR
(regressor using TwoLayerQNN)
Distribution Learners
Connectors
TorchConnector
Circuit library
Feature Maps
RawFeatureVector

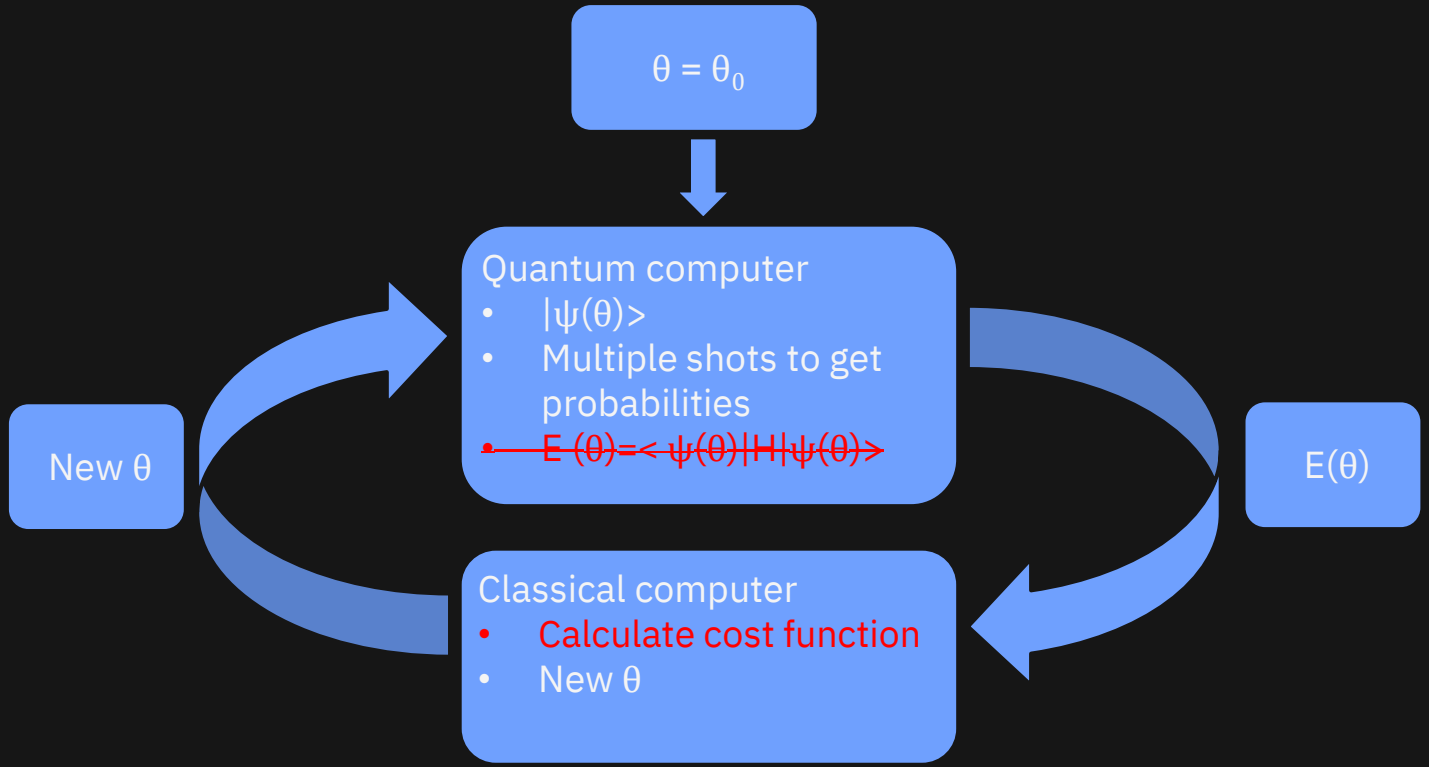
Example:

Variational Quantum Classification (VQC)

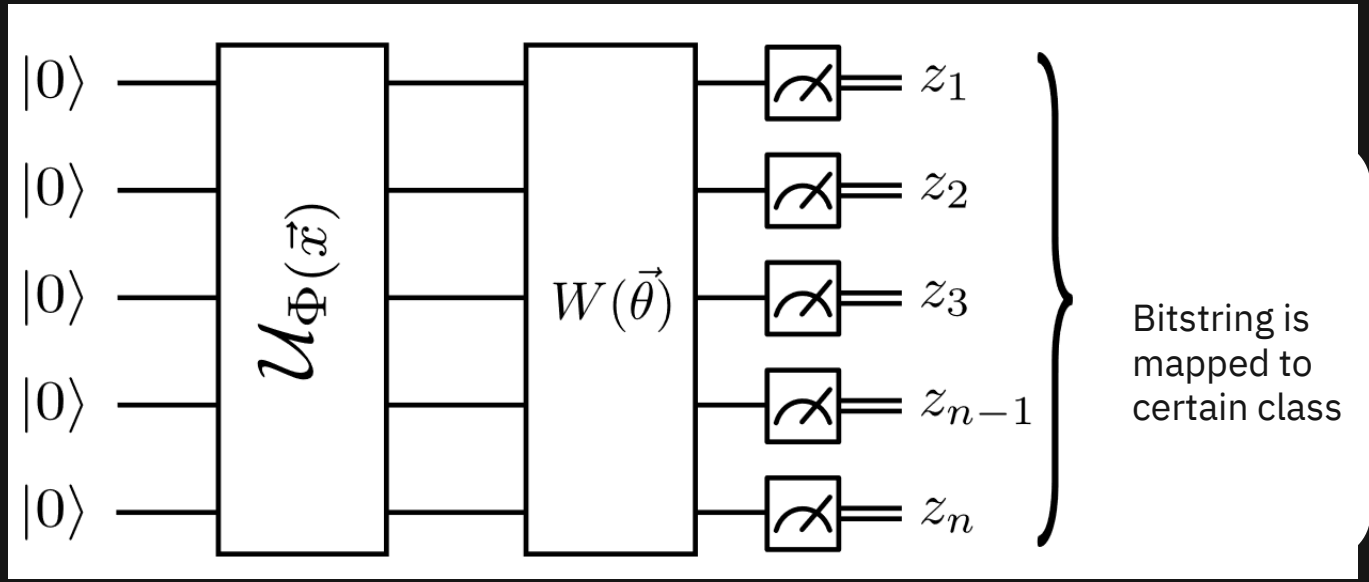
Concept of variational, hybrid algorithms



Variational Quantum Classifier



The circuit



https://arxiv.org/pdf/1804.11326.pdf

The algorithm

Loop until convergence:

for each data point:

for each circuit execution

- Encode point into feature map
- Append ansatz circuit
- Measure result and decode feature class

Create statistics of probability of every class

Calculate contribution to cost function

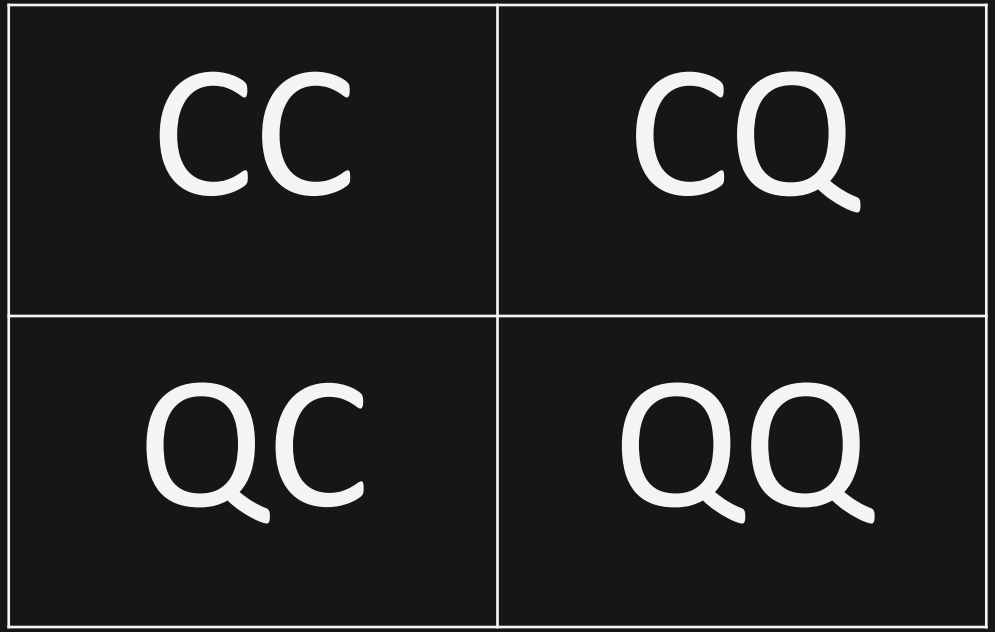
Use classical optimizer to propose new circuit parameters

Reading/references:

- Supervised learning with quantum enhanced feature spaces
- Classification with Quantum Neural Networks on Near Term Processors
- Quantum Machine Learning
- Recent advances for quantum classifiers

What other ideas to consider?

1. QCs can do the linear algebra in large dimensions
2. Multiple data points encoded simultaneously
3. Applications beyond binary classifications
4. Modelling quantum data instead of classical data
5. Quantum-inspired classical algorithms


CC
CQ
QC
QQ

Encoding data on quantum computers

Name	Favorite color
Eve	red
Bob	yellow
Alice	blue
Jane	green

one-hot

Name	Prefers red	Prefers green	Prefers blue	Prefers yellow	Prefers pink
Eve	1	0	0	0	0
Bob	0	0	0	1	0
Alice	0	0	1	0	0
Jane	0	1	0	0	0

Name	Favorite color
Eve	10000
Bob	00010
Alice	00100
Jane	01000

binary

Name	Favorite color
Eve	$0_{10} = 000_2$
Bob	$3_{10} = 011_2$
Alice	$2_{10} = 010_2$
Jane	$1_{10} = 001_2$

domain wall

Name	Favorite color
Eve	0000
Bob	1110
Alice	1100
Jane	1000

Some QML concepts

- Parametrized quantum circuit can work as NN
- Variational quantum algorithms can be realized on current NISQ computers and used in ML tasks – finding NN weights analog to finding optimal circuit parameters
- Quantum computers can work in exponentially higher-dimensional spaces ➔ we can create new models to improve accuracy
- Quantum computers create a new potential avenue to increase power of ML models in the situation of quickly growing dimensions
- Kernel function estimation can be easy for QC while very complex for classical
- Hybrid quantum-classical models
- Potential of providing quadratic or even exponential speedups over classical algorithms
- Bottleneck – loading large datasets into quantum computer (basis embedding, amplitude embedding, …)