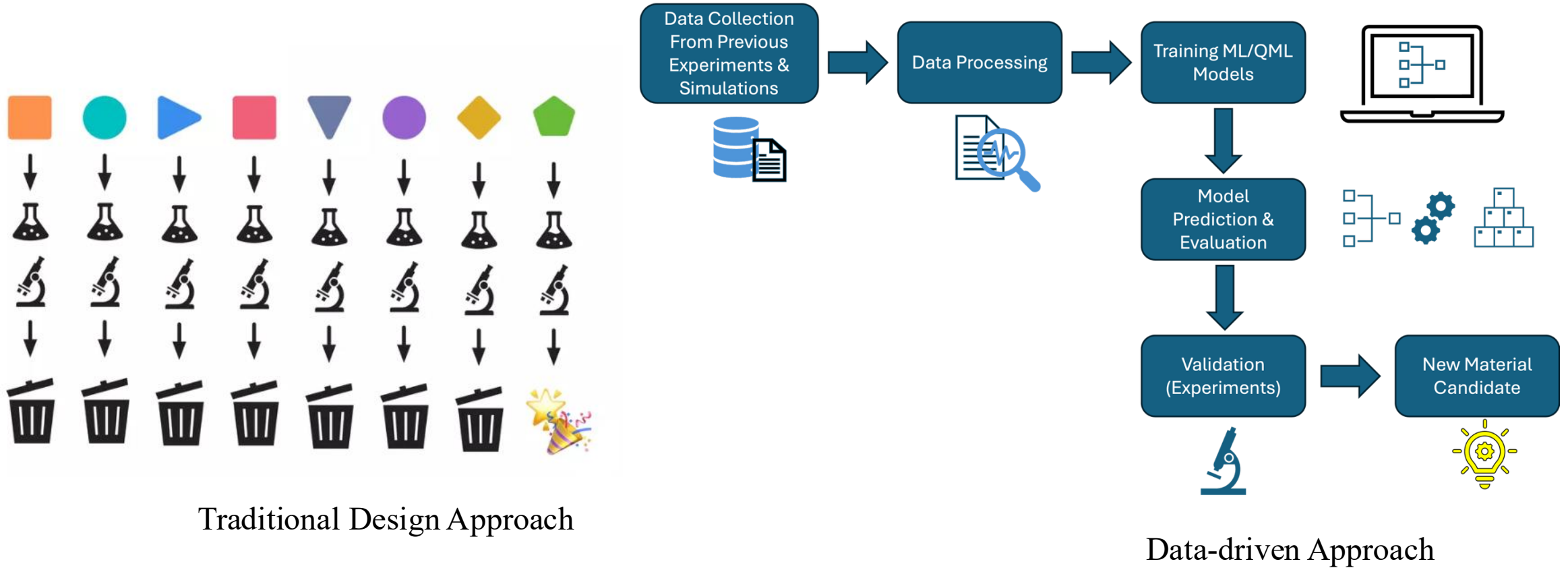

Quantum Machine Learning Applications in Material Science

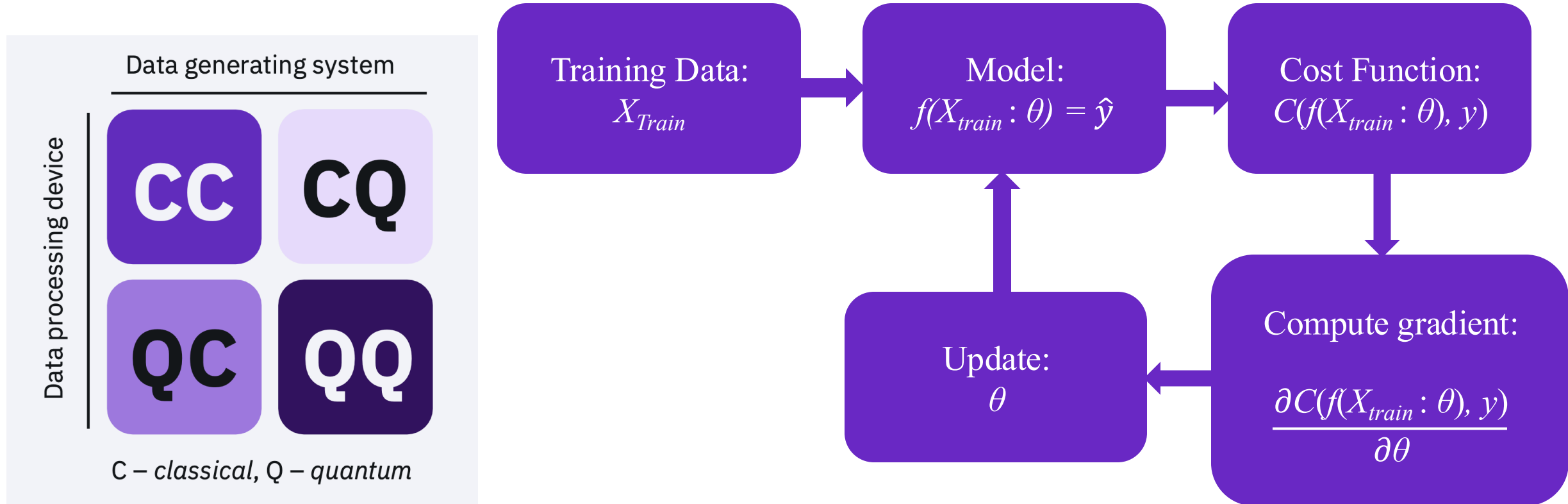
Data-driven discovery workflow



Common Machine Learning tasks in Material Science

- Property Prediction
 - Bulk Modulus
 - Band - gap energy
 - Thermo-electric properties (Thermal and Electrical Conductivities)
- Classification Task
 - Any screening tasks to identify the category of a material
- Generative Tasks
 - Create compositions, structures of a certain type of materials based on desirable properties

A General ML Workflow



Variational Circuit for ML Workflow

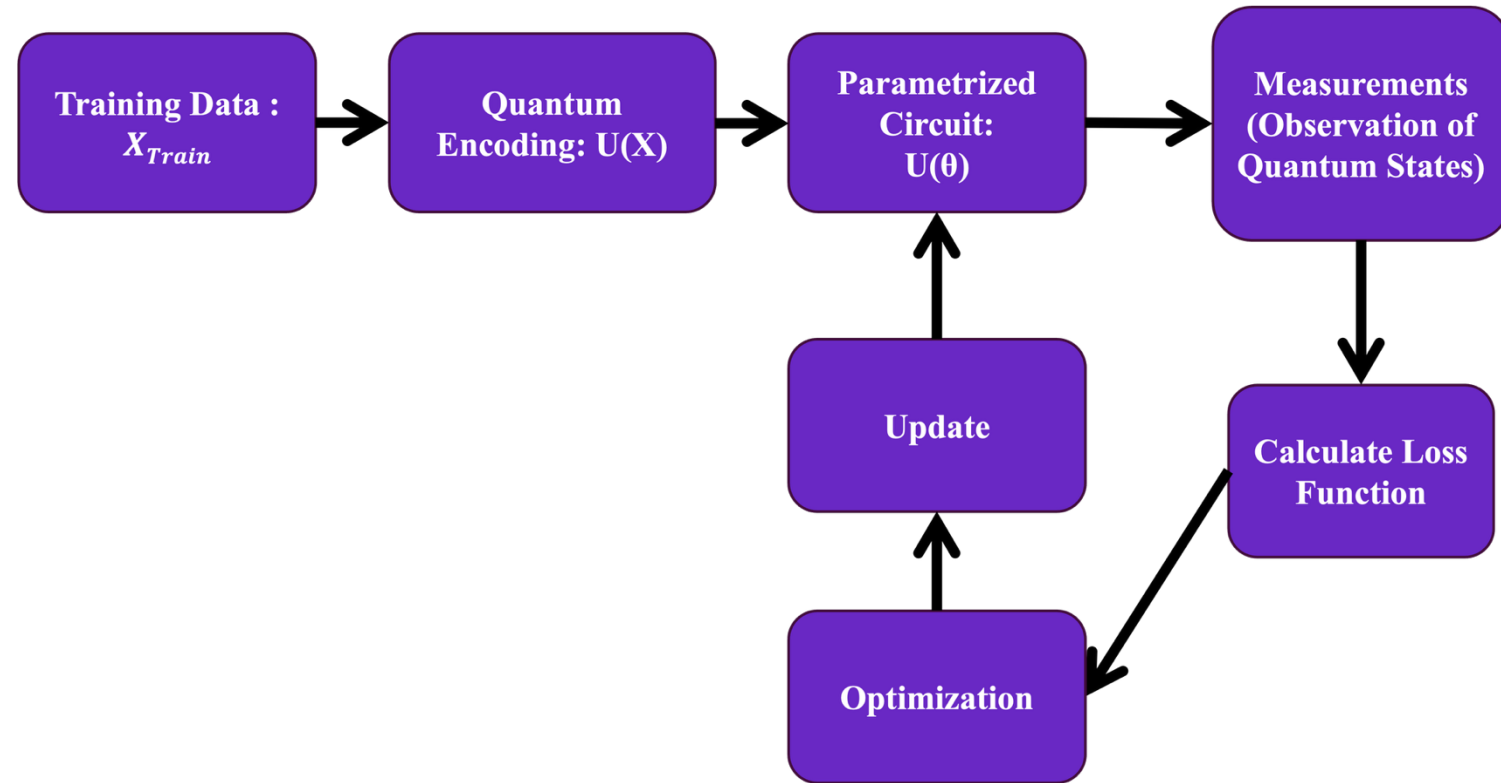
Objective: Train a quantum circuit on labeled samples in order to predict labels for new data

Step 1: Encode the classical data into a quantum state

Step 2: Apply a parameterized model

Step 3: Measure the circuit to extract labels

Step 4: Use optimization techniques to update model parameters



Step 1: Encoding Data

Types of encoding:

- Basis Encoding
- Amplitude Encoding
- Angle Encoding
- Higher Order Encoding

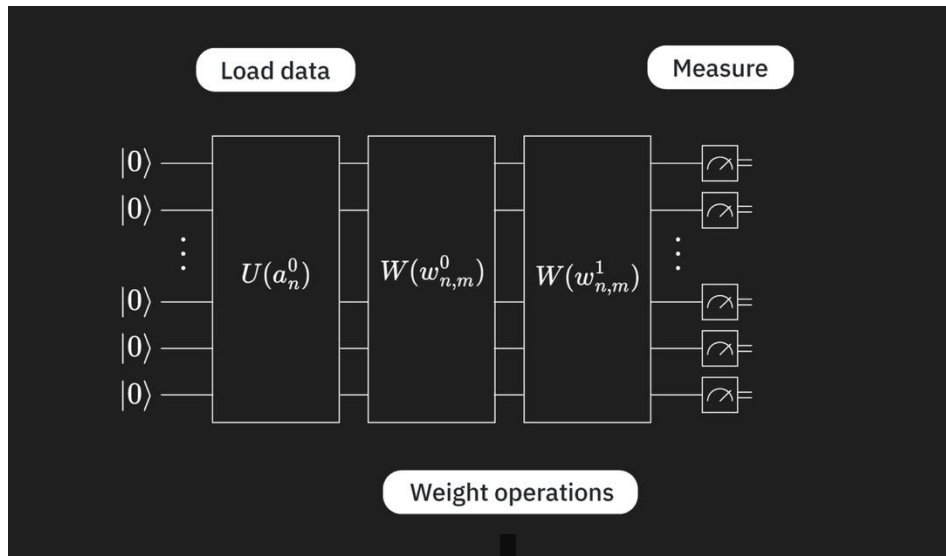
List of built-in feature maps provided by Qiskit:

- Z feature map
- ZZ feature map
- Pauli feature map

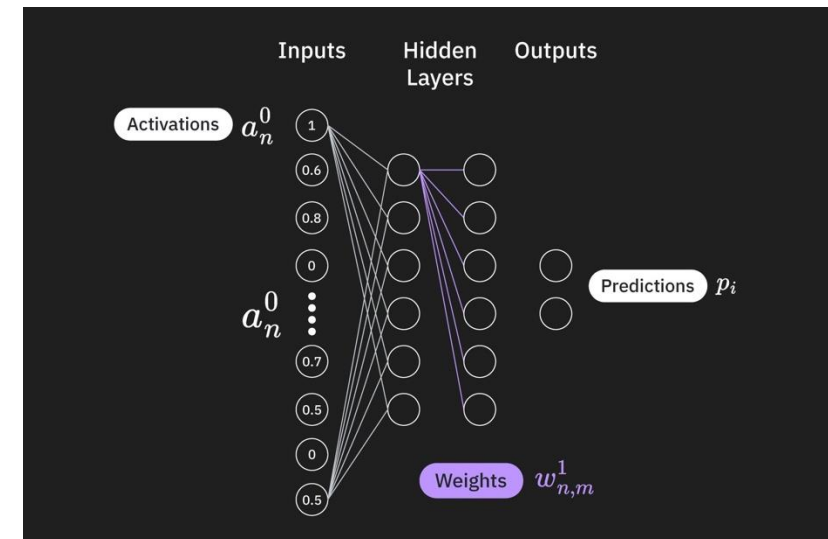
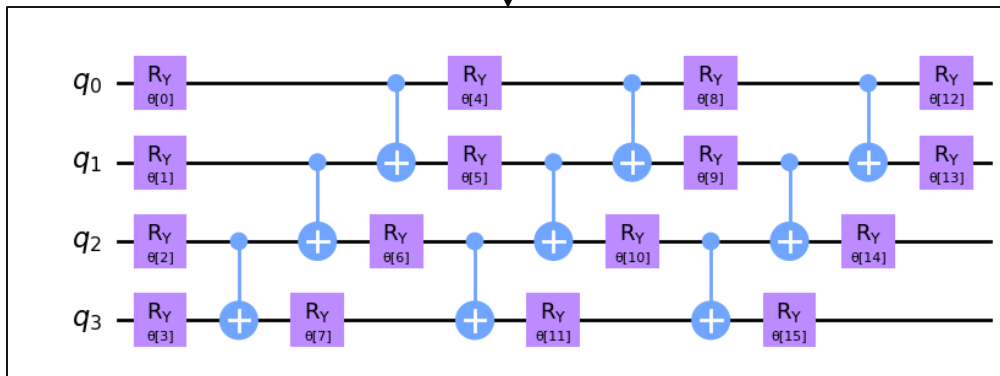
Qiskit also provides feature maps, which combine encoding with entanglement, to make more efficient use of qubits to represent a feature in a quantum state.

[Details about Data Encoding in QC](#)

Step 2: Applying variational circuit/ Ansatz



The picture shown is the variational circuit used in a QML classifier circuit, the encoded data is passed through Y rotation, and then entangled (partial/full), and repeated multiple times/ layers (mimics neural network layers for classical counterpart)



Step 3: Taking Measurements (Samplers and Estimators)

In QML, the final quantum state is measured using one of two [primitives](#):

- **Sampler:** Samples the output register from quantum circuit execution
- **Estimator:** Computes expectation values of observables with respect to states prepared by quantum circuits.

These primitives let us extract classical information from a quantum circuit efficiently. They run on both simulators and hardware.

Step 4: Optimization

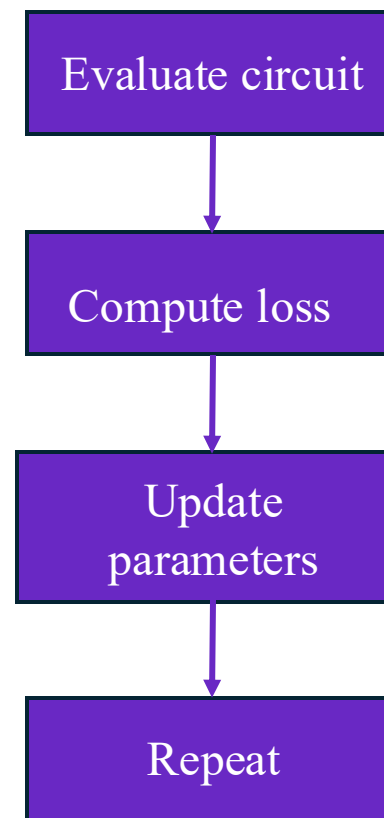
In QML, we use: (i) Classical Optimizers (ii) Quantum optimizers (Quantum Annealers, QAOA, etc.)

For this presentation we discuss and use classical optimizers with Quantum circuits.

Some classical optimizers: **COBYLA** (Gradient-free), **L-BFGS-B** (Gradient based), **SPSA**, etc.

If gradients are needed → uses **Parameter Shift Rule**

[More about optimizers](#)



Let's move to the Jupiter Notebook



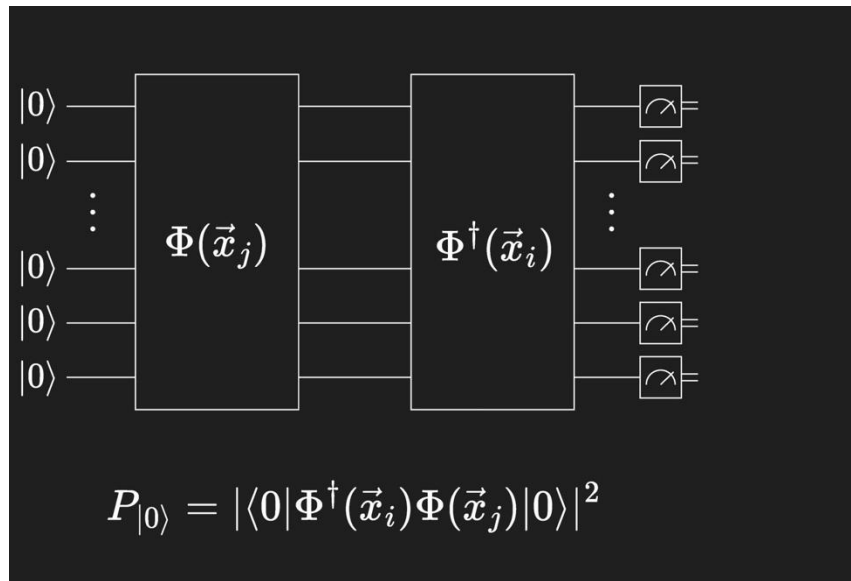
Things to remember while using Real Quantum Hardware

- Experiment different feature maps and choose the best fit for your dataset (there is no size fits all option)
- Same goes for building the variational circuit. Most of the part in building variational circuit is heuristic.
- Selection of backend (tend to choose the least busy options)
- Use a pass manager to transpile both the circuit and the observables to the architecture of the chosen backend.

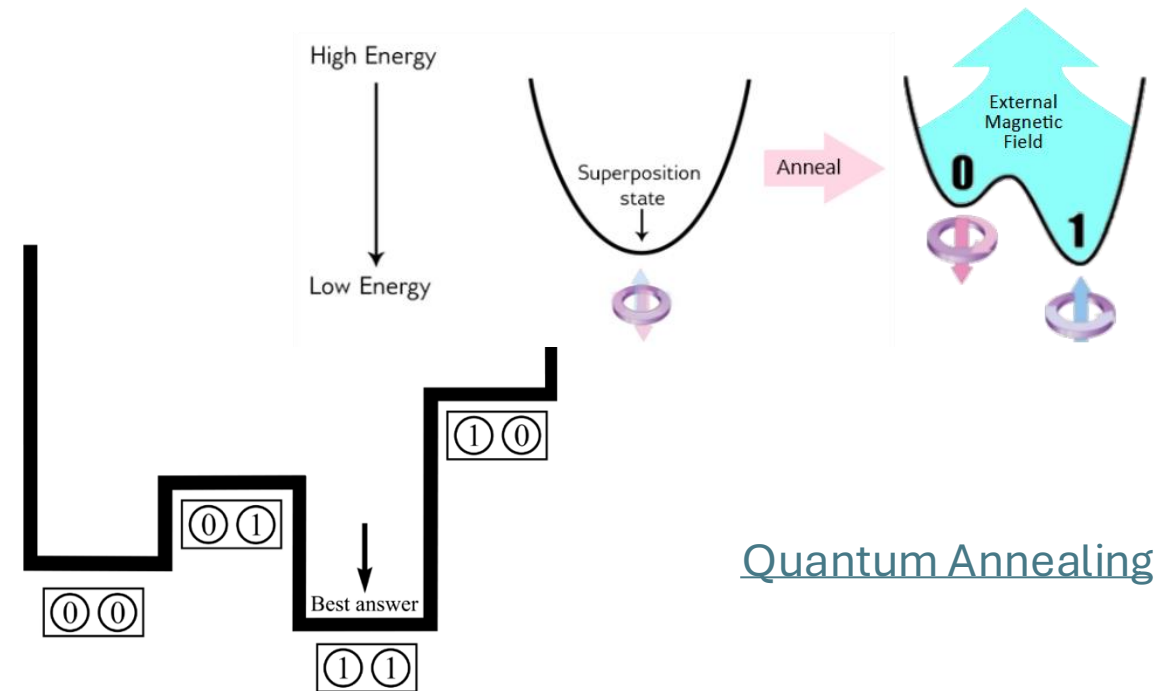
[Generate a basic preset pass manager](#)

Different QML Techniques

- Quantum Kernels technique: Mapping the data to a higher dimension, used for Clustering, and classification applications
- Quantum Optimization: Using Classical ML techniques with a quantum optimizer



Quantum Kernels



Quantum Annealing

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Thank You!