Presented by Saasha Joshi

July 31, 2025

INTRODUCTION TO QUANTUM MACHINE LEARNING

ABOUT ME

Staff Scientist in Quantum Computing at
CMC Microsystems, Canada

- Research in QML and quantum software development.

- MSc degree in Computer Science with a focus on QC from the University of Victoria.

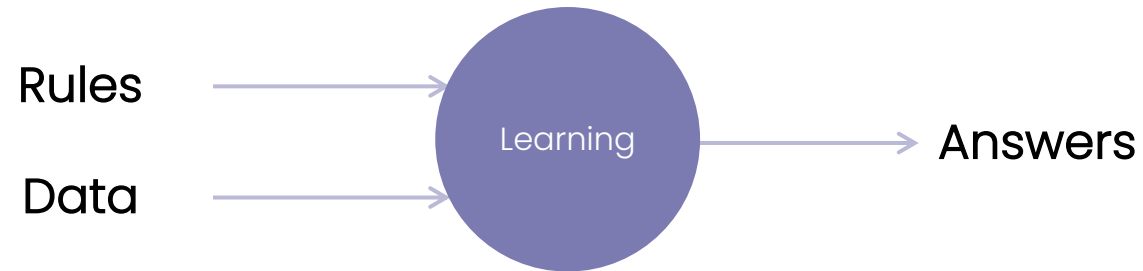- Actively involved in open-source development and educating and mentoring students.

CONTENT

1. Machine Learning

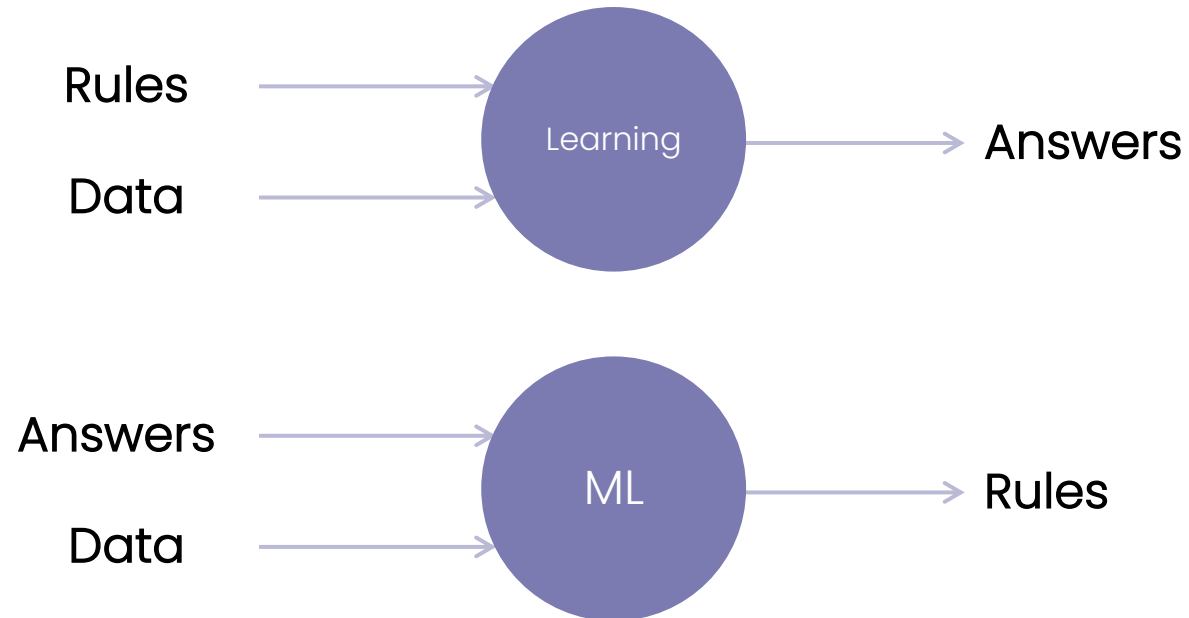2. Quantum Machine Learning
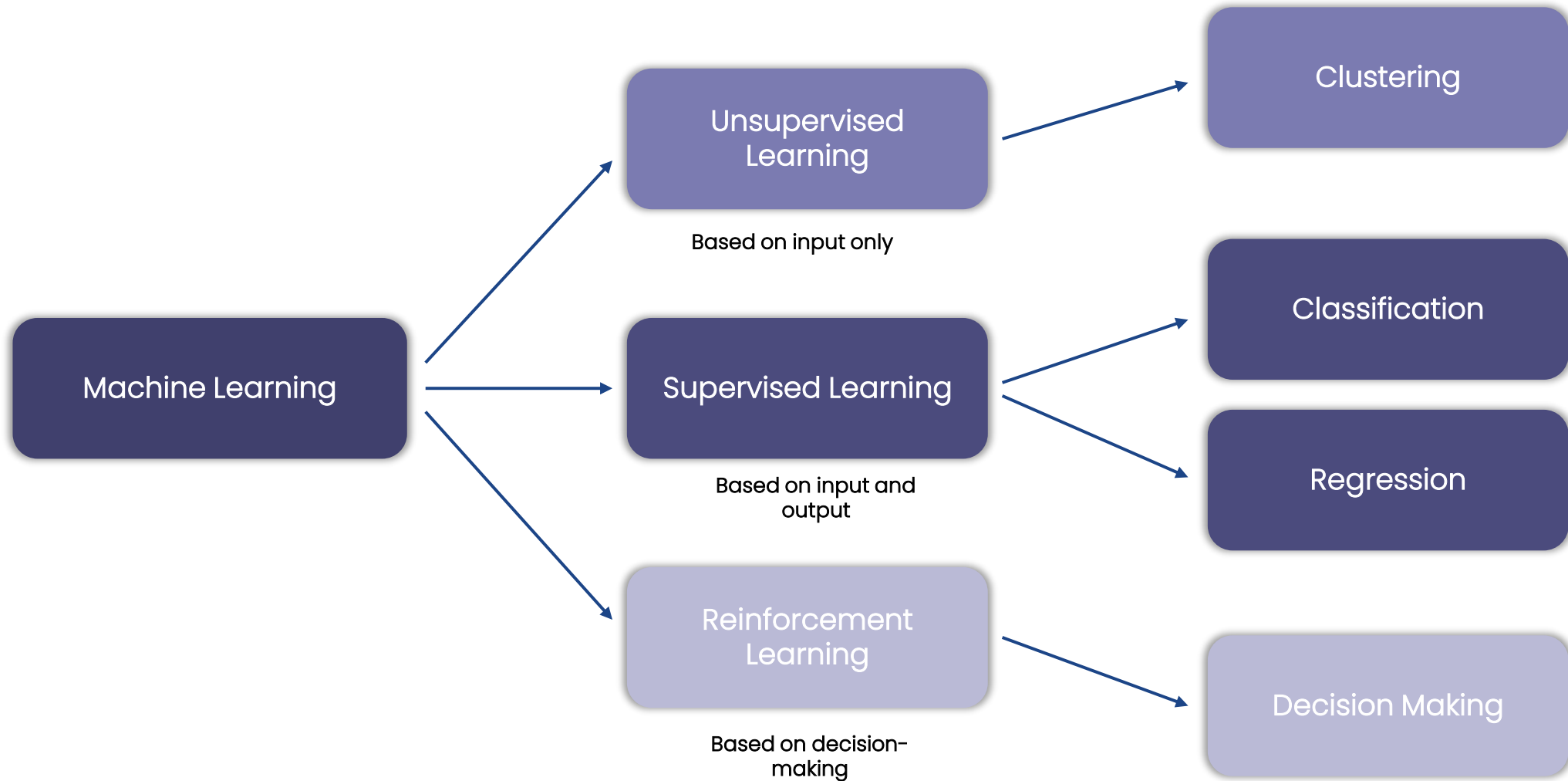
3. Types of QML Algorithms

MACHINE LEARNING

TRADITIONAL VS MACHINE LEARNING

Rules →

Learning

Data →

→ Answers

TRADITIONAL VS MACHINE LEARNING

Rules   →

Data   →

Learning   → Answers

Answers   →

Data   →

ML   → Rules

MACHINE LEARNING

Machine Learning

Unsupervised Learning

Based on input only

Clustering

Supervised Learning

Based on input and output

Classification

Regression
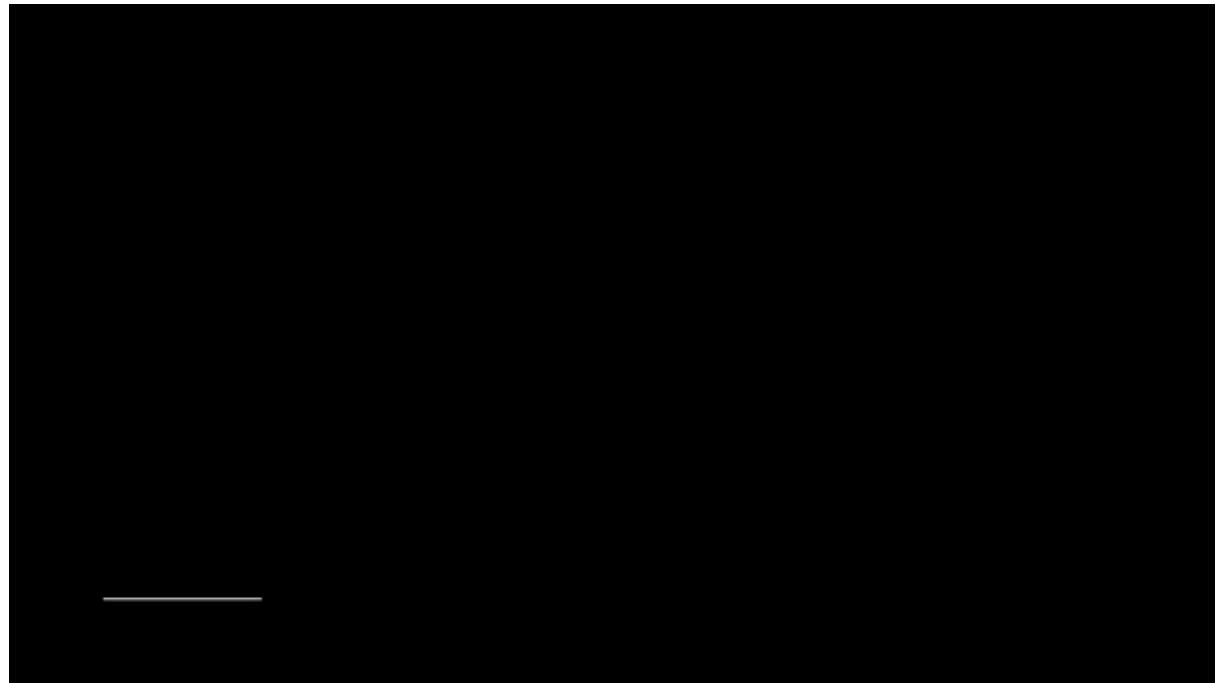
Reinforcement Learning

Based on decision-making

Decision Making

SUPERVISED LEARNING: CLASSIFICATION

- The model helps in the classification of unseen data.
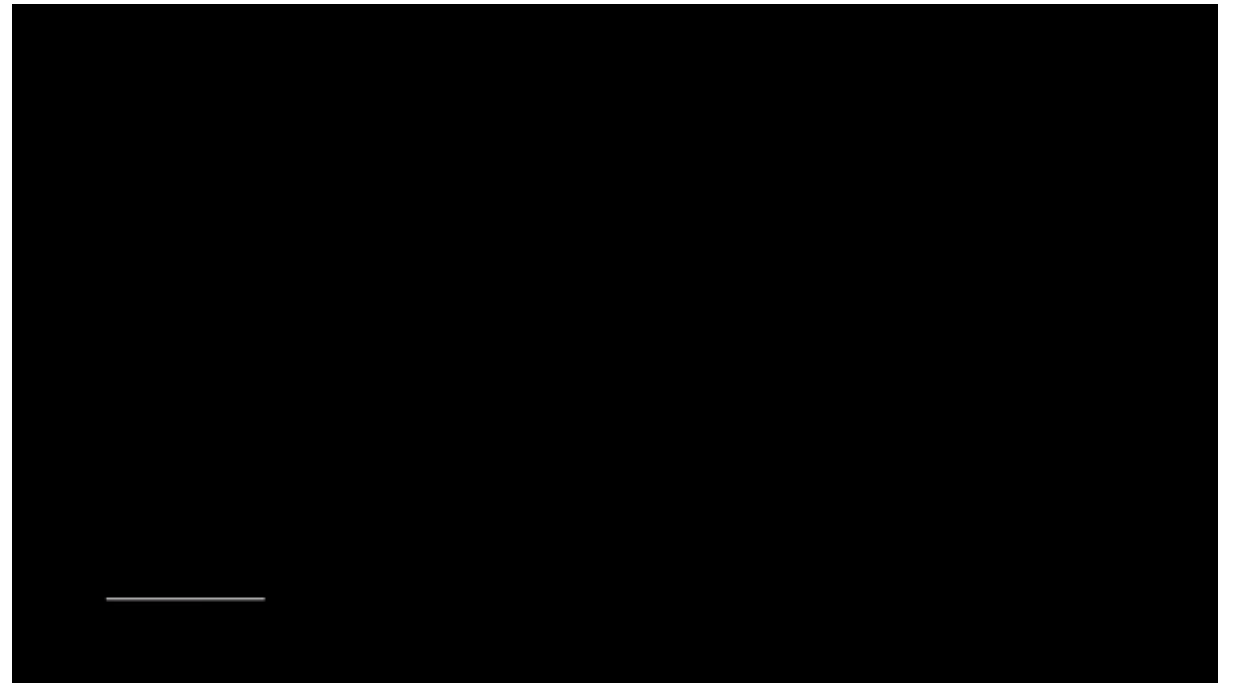
SUPERVISED LEARNING: CLASSIFICATION

- The model helps in the classification of unseen data.

Given training labelled data,

$$\chi = (x_i, y_i)$$

Supervised model learns a function that generalizes to unseen data.
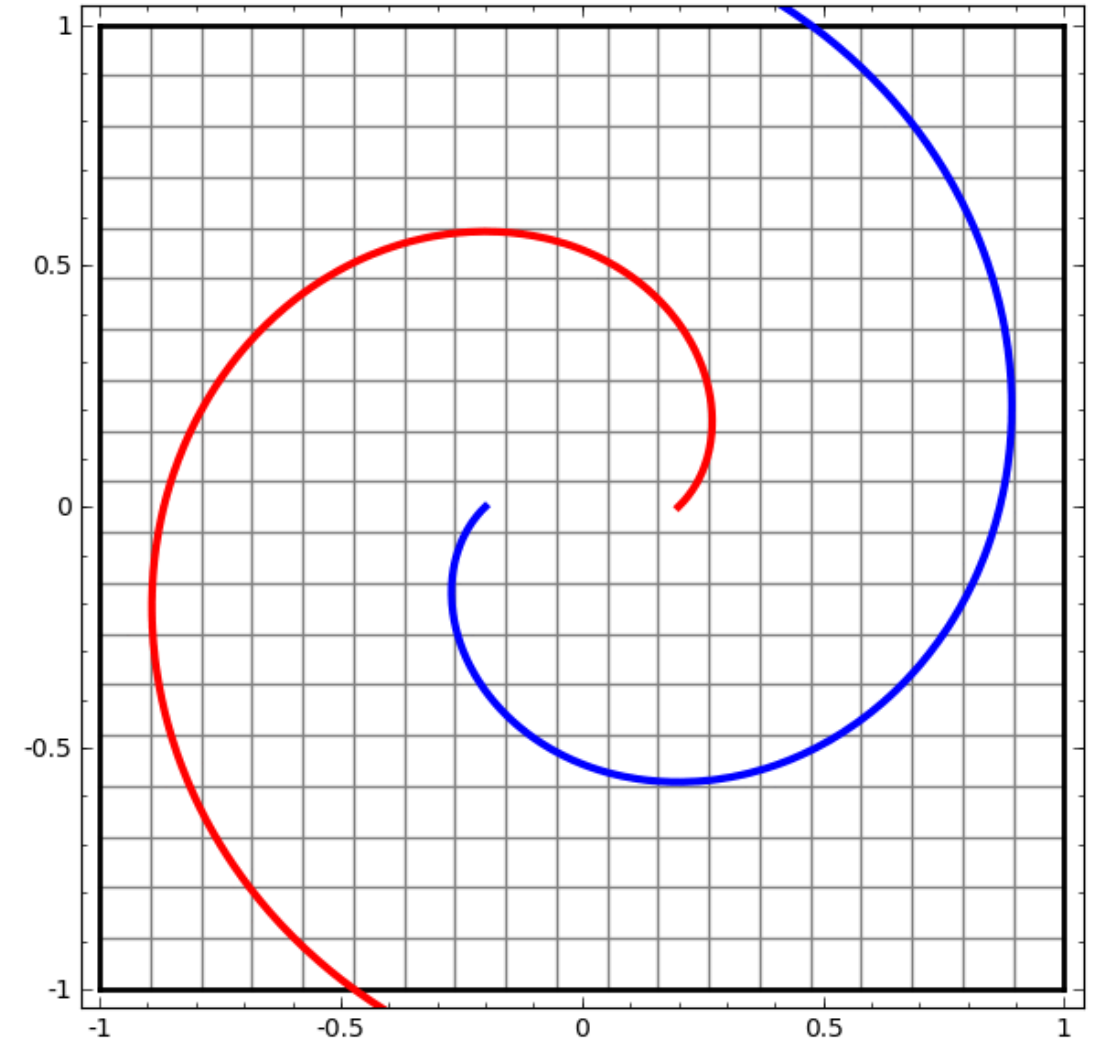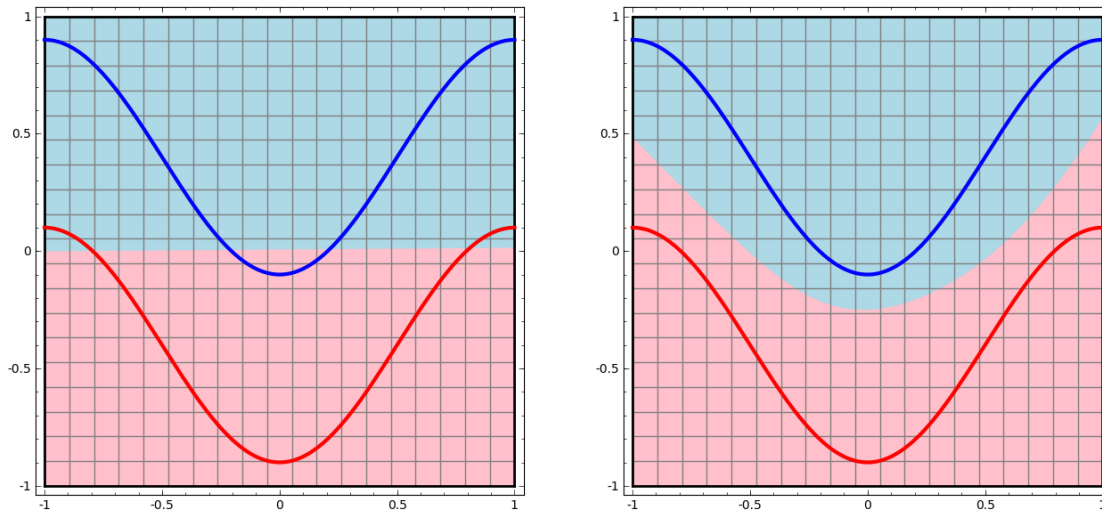
$$f : x \mapsto y$$

WHAT HAPPENS IF DATA IS NON-LINEAR?

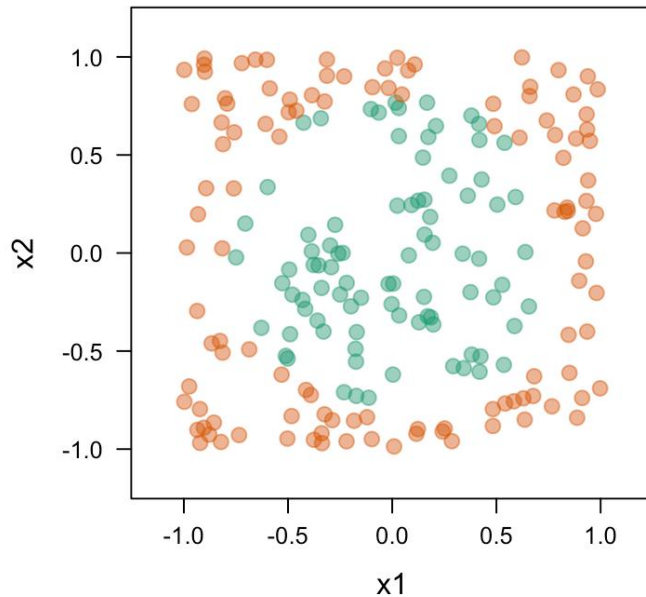Fix: High-dimensional feature mapping.

REAL WORLD DATA

Refer: https://colah.github.io/posts/2014-03-NN-Manifolds-Topology; https://cs.stanford.edu/people/karpathy/convnetjs//demo/classify2d.html;
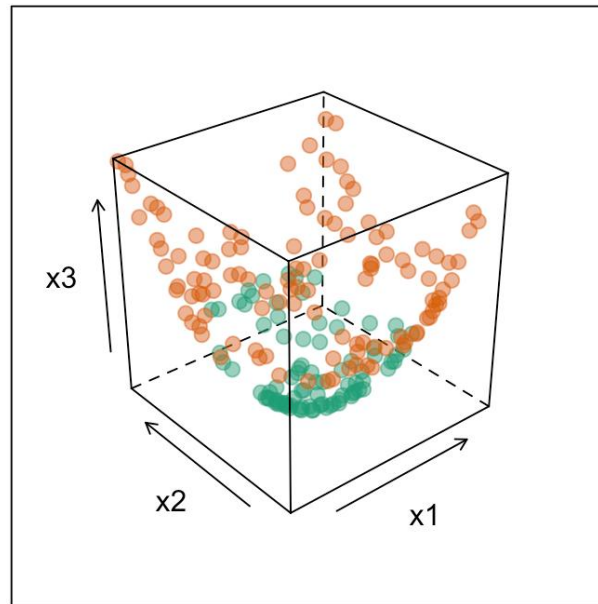https://colah.github.io/posts/2014-03-NN-Manifolds-Topology/img/spiral.1-2.2-2-2-2-2-2.gif

SUPPORT VECTOR MACHINE

- The data is non-linearly mapped to a high-dimensional space, called the *feature space*, where a hyperplane is constructed to separate the samples.

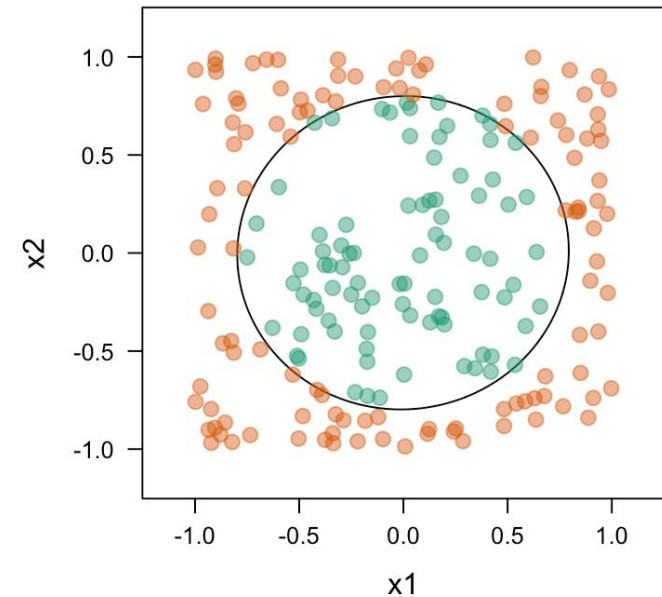- SVM utilizes *kernels* and the *kernel trick* to build this hyperplane.
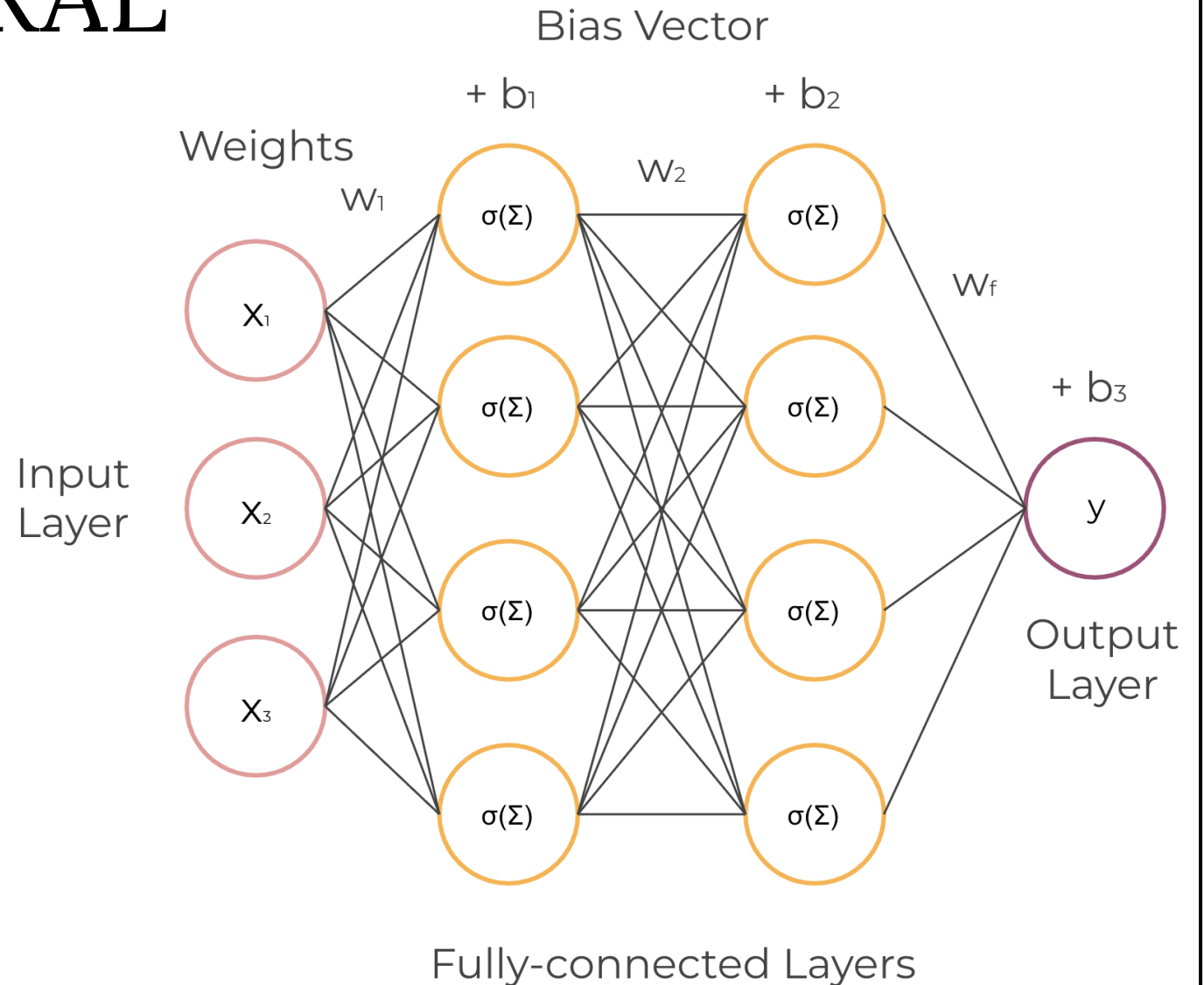

Original feature space   **Enlarged feature space**   **Non-linear decision boundary**

Image source: https://bradleyboehmke.github.io/HOML/svm.html

CLASSICAL NEURAL NETWORK

- With each layer, the neural network transforms the data, creating a new *representation*.

CLASSICAL NEURAL NETWORK

- With only one input layer, you can visualize the network as it attempts to separate the data by drawing a line through it.

- More hidden layers learn a representation such that the data is linearly separable.

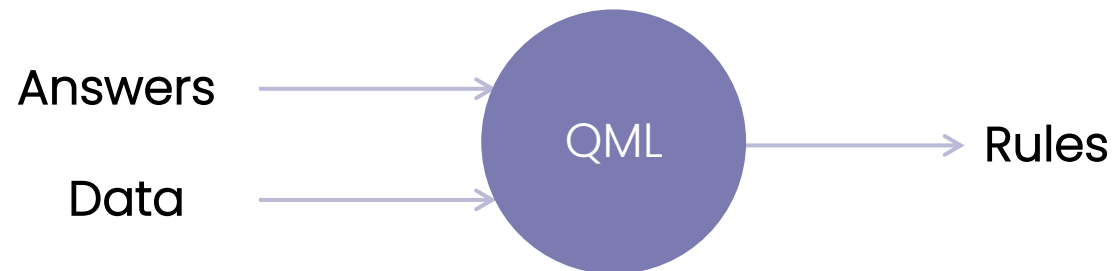- Each hidden layer corresponds to increase in the dimension.

Refer: https://colah.github.io/posts/2014-03-NN-Manifolds-Topology
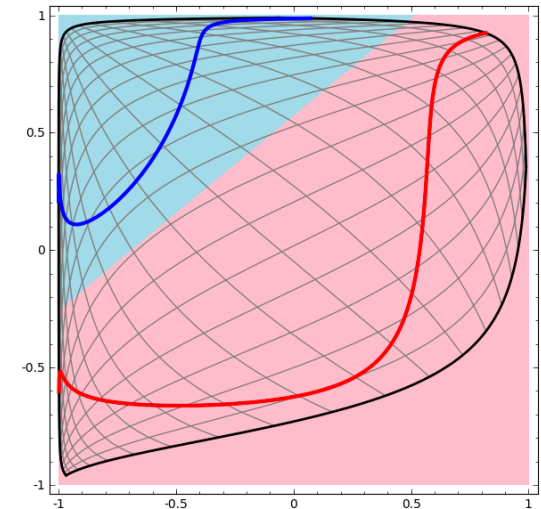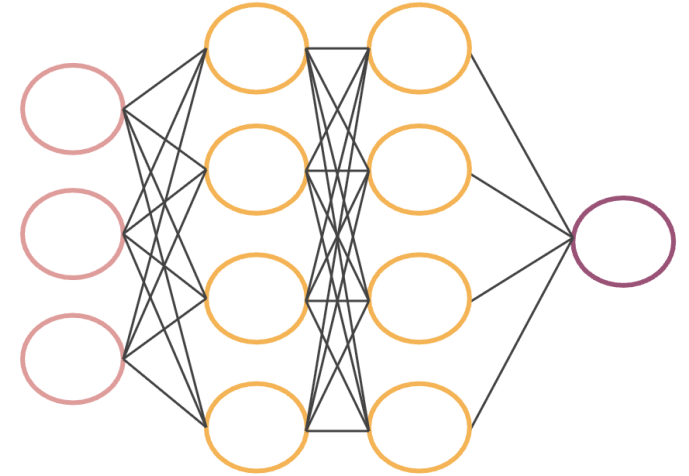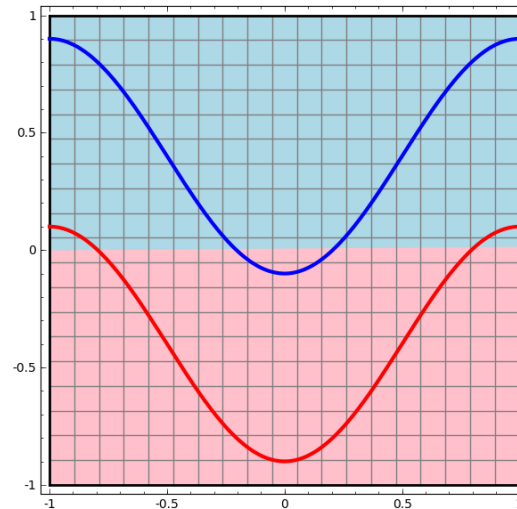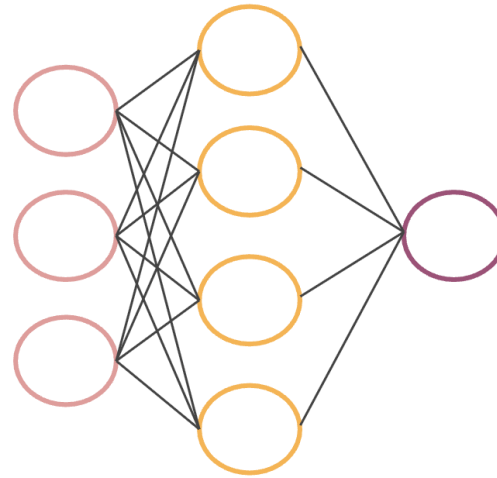
QUANTUM MACHINE LEARNING
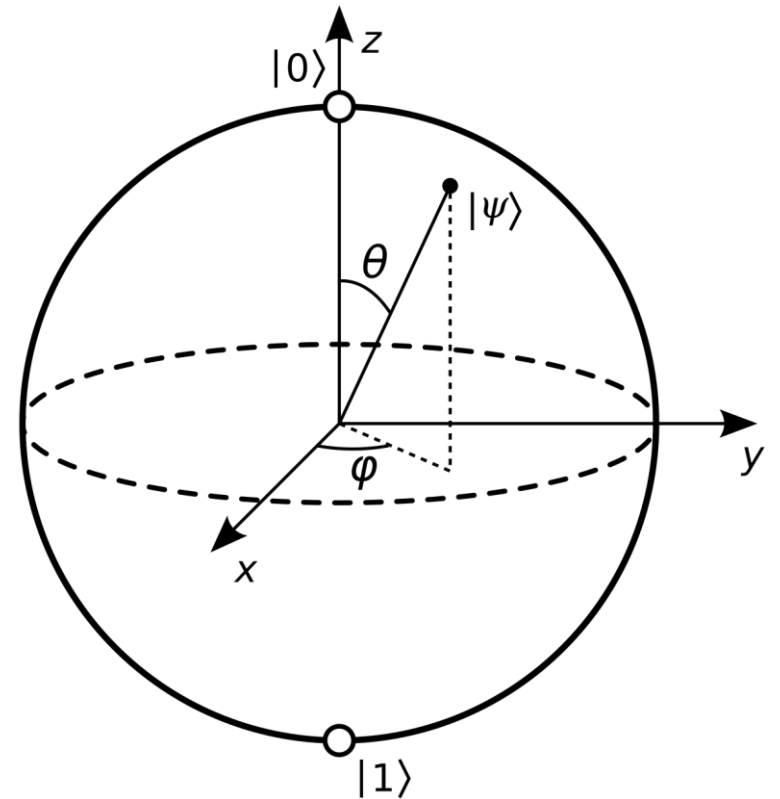
QUANTUM MACHINE LEARNING

- QML lies at the intersection of quantum information and machine learning.

- It leverages quantum mechanical properties such as *superposition, entanglement, and interference*.

Answers →

Data → QML → Rules

WE ALREADY HAVE A HIGHER-DIMENSIONAL SPACE!

- With quantum computers, we can map classical data to high-dimensional quantum states.

$$x \mapsto |\phi(x)\rangle$$
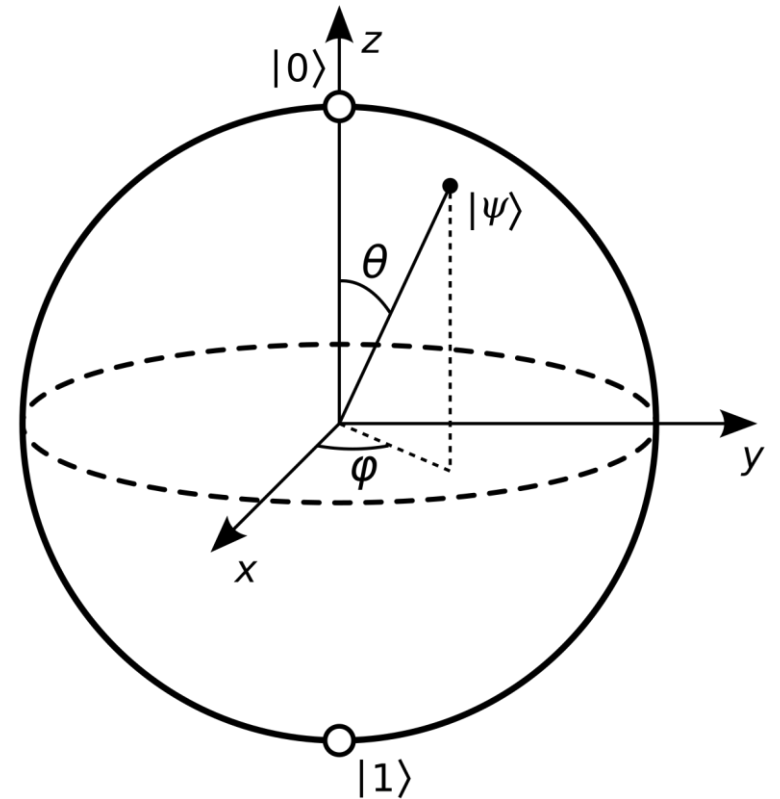
WE ALREADY HAVE A HIGHER-DIMENSIONAL SPACE!

- With quantum computers, we can map classical data to high-dimensional quantum states.

$$x \mapsto |\phi(x)\rangle$$

- Formally, a *Quantum Feature Map* is defined as a function that,

$$x \mapsto \rho(x)$$

$$\rho(x) = |\phi(x)\rangle\langle\phi(x)|$$

TYPES OF DATA EMBEDDING

- Basis Encoding

$$\Phi : x \mapsto |x_3 x_2 x_1\rangle \qquad x_i \in [0, 1]$$

- Angle Encoding

$$\Phi : x \mapsto U(x)|\psi_0\rangle$$

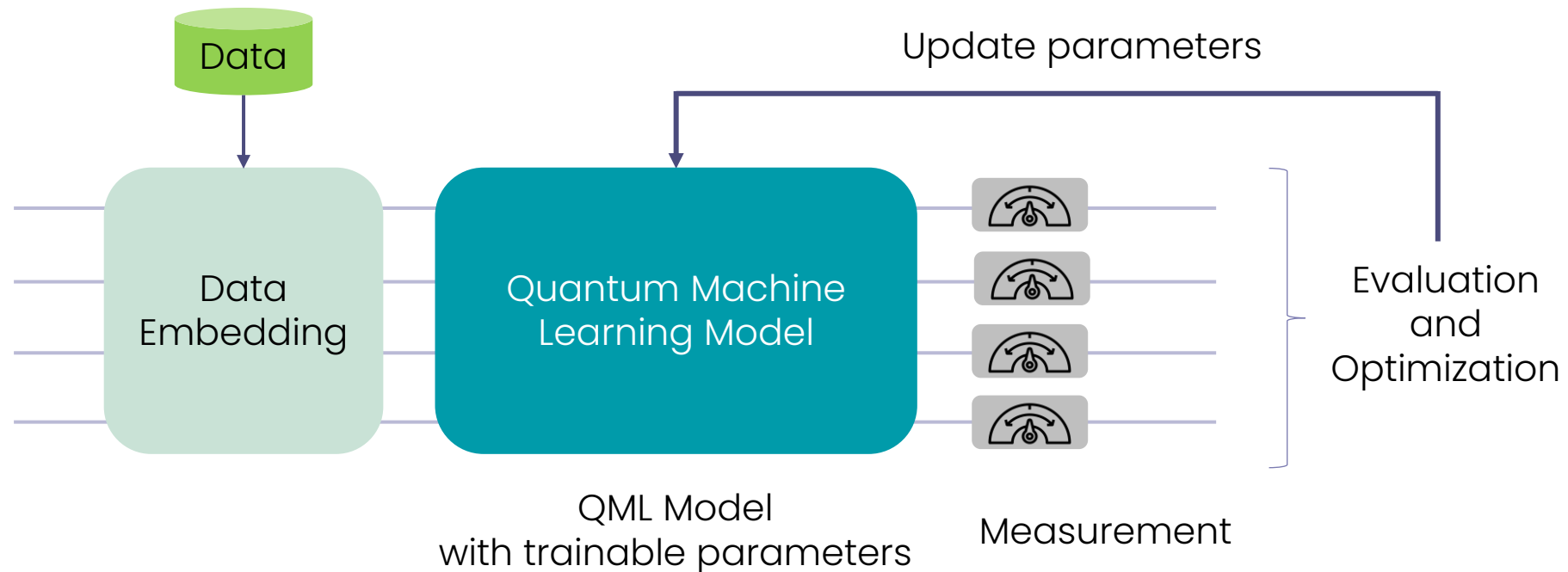- Amplitude Encoding

$$\Phi : x \mapsto \sum_i x_i |i\rangle$$

- And other feature maps

  - ZZ Feature Map $\quad U_{\phi(x)} = \exp\left(i \sum_{S \subseteq [n]} \phi_S(x) \prod_{i \in S} Z_i \right)$
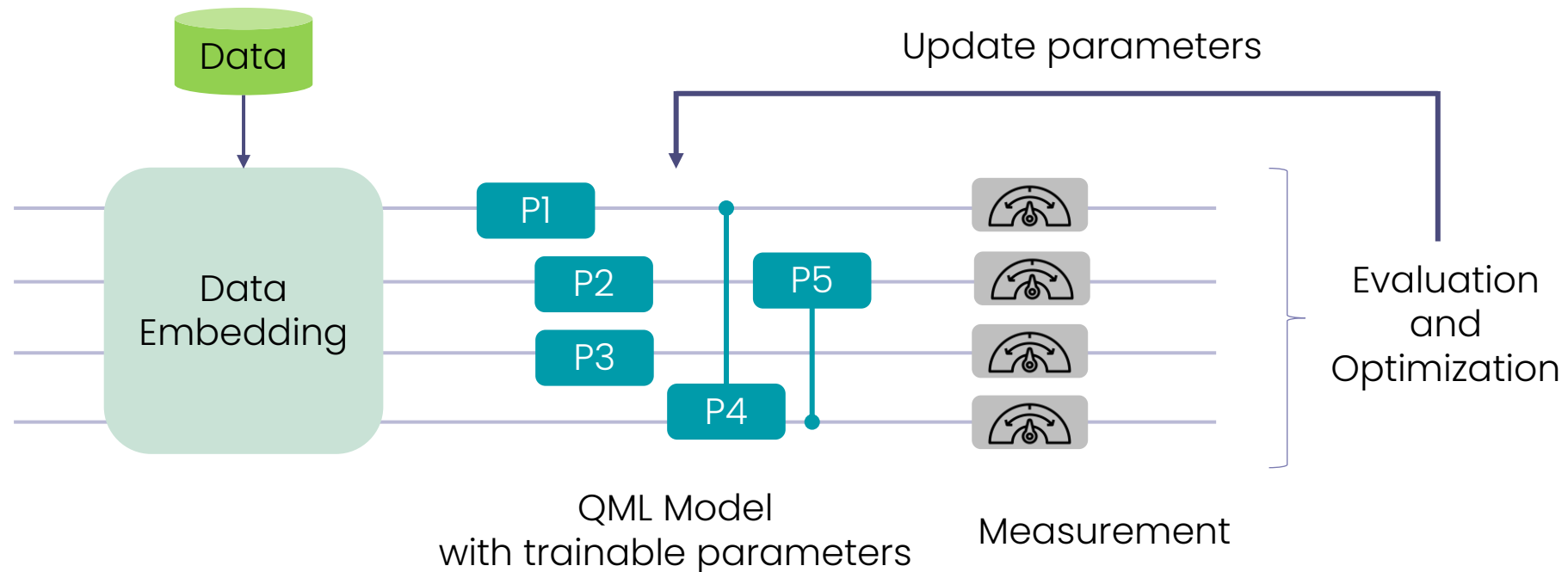
TYPES OF QML ALGORITHMS

VARIATIONAL QUANTUM ALGORITHMS

Variational quantum algorithms consist of tunable unitary operations called Parameterized Quantum Circuits (PQC).
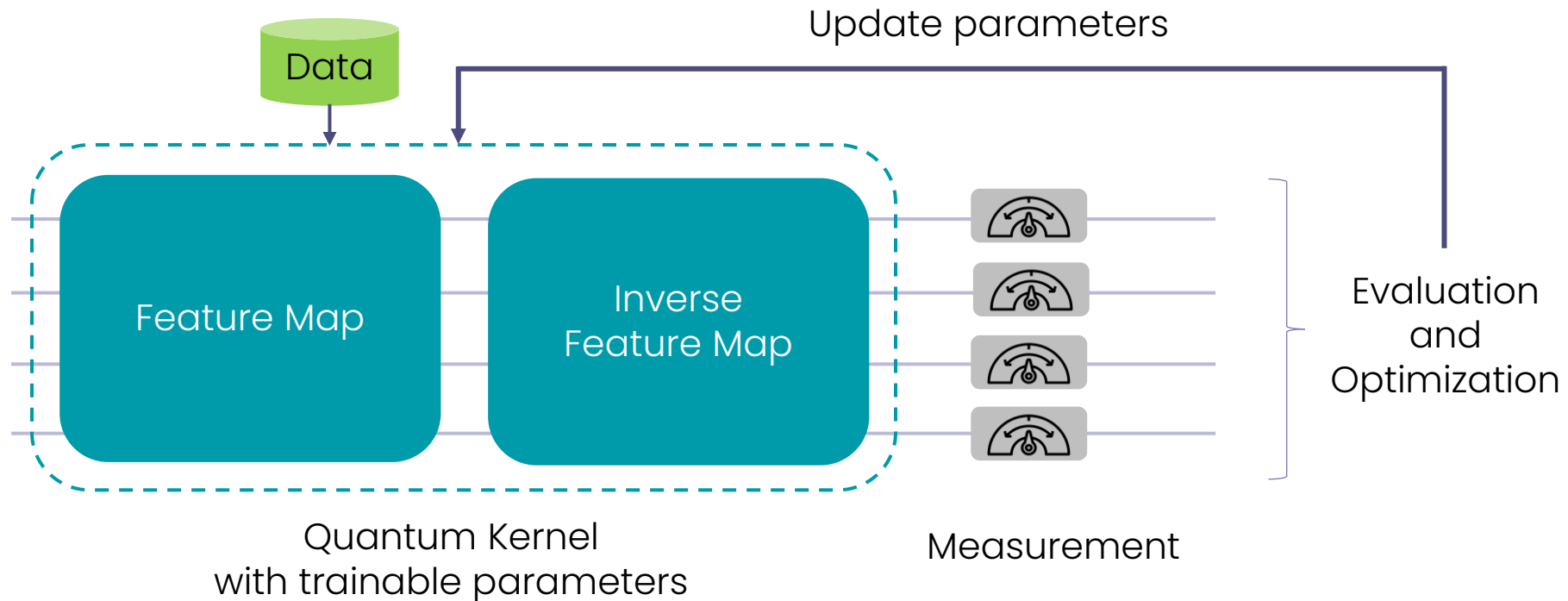
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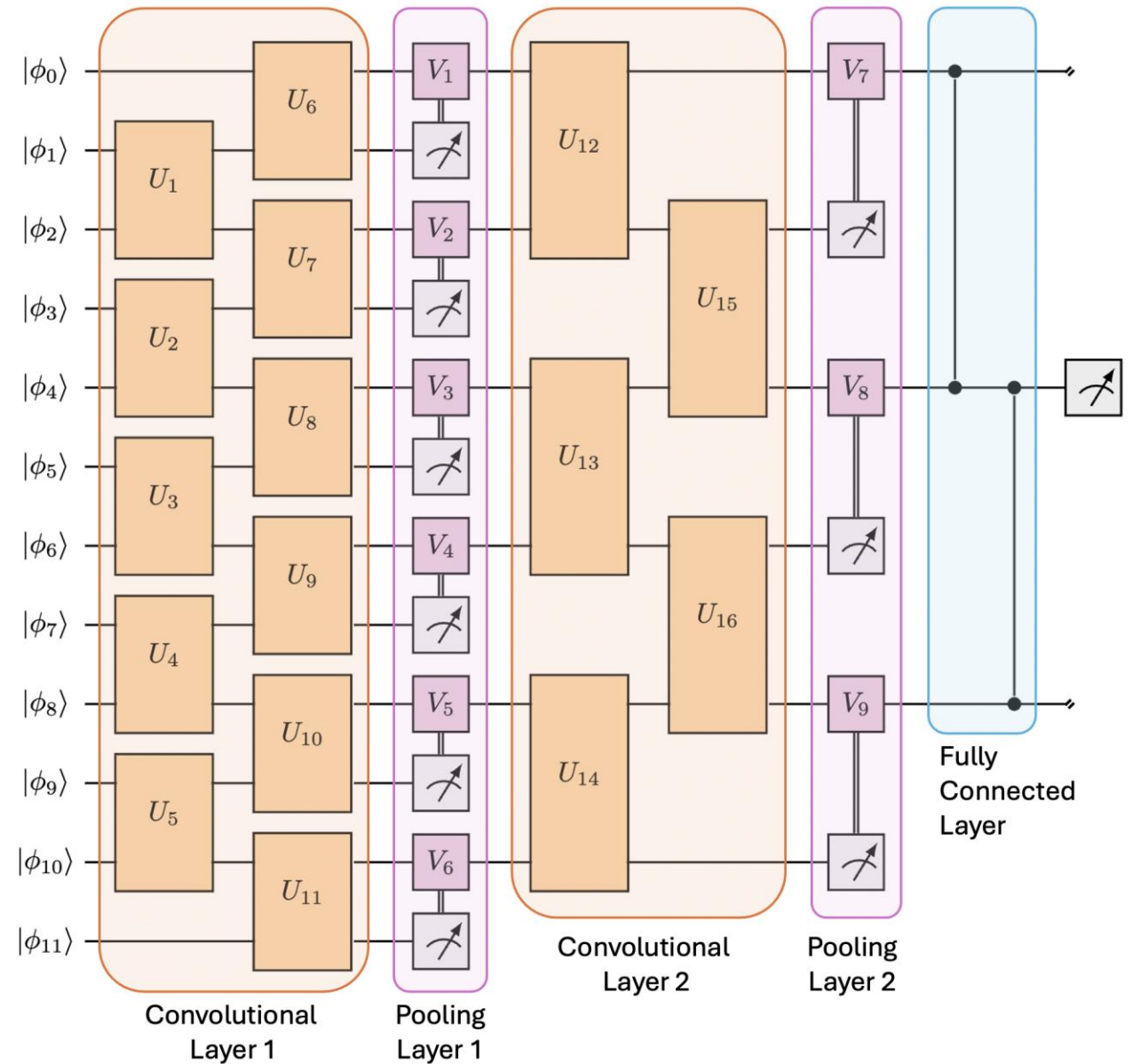
QUANTUM KERNEL METHODS

Kernel methods provide a similarity measure between data features. This similarity measure is expressed as the inner product of the data features, known as the kernel.

QUANTUM NEURAL NETWORKS

Quantum counterpart of classical neural network architecture.

For example, a quantum convolutional neural network.

THANK YOU

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