Quantum Machine Learning

Gennaro De Luca, PhD
Arizona State University

Ira A. Fulton Schools of Engineering
Arizona State University

Overview

- Artificial Neural Networks for Deep Learning
- Introduction to Quantum Computing
- Quantum Programming
- Quantum Machine Learning

Quantum Machine Learning (QML)

Goals are identical to classical machine learning.

For supervised learning:

- Input data.
- Define model.
- Learn parameters to best fit data.
- Predict future (unknown) inputs.

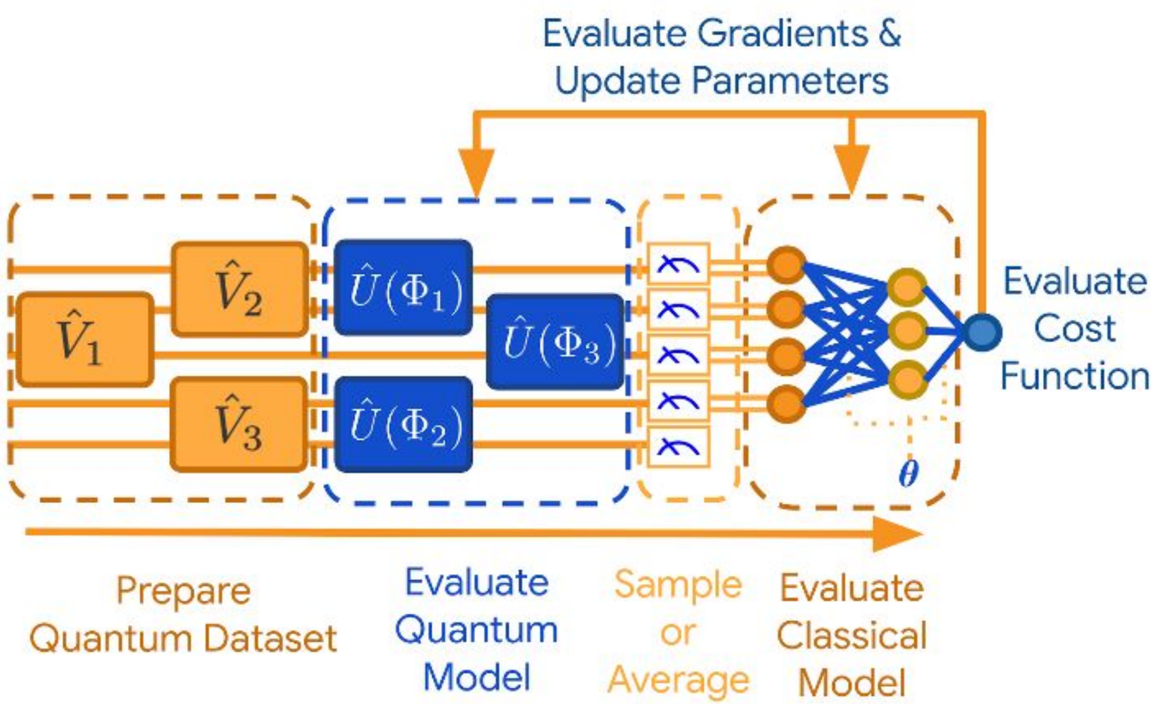
For unsupervised learning:

- Categorize data using some distance measure.
- Predict category of future data.

Quantum Machine Learning (QML) (cont'd)

Key Components:

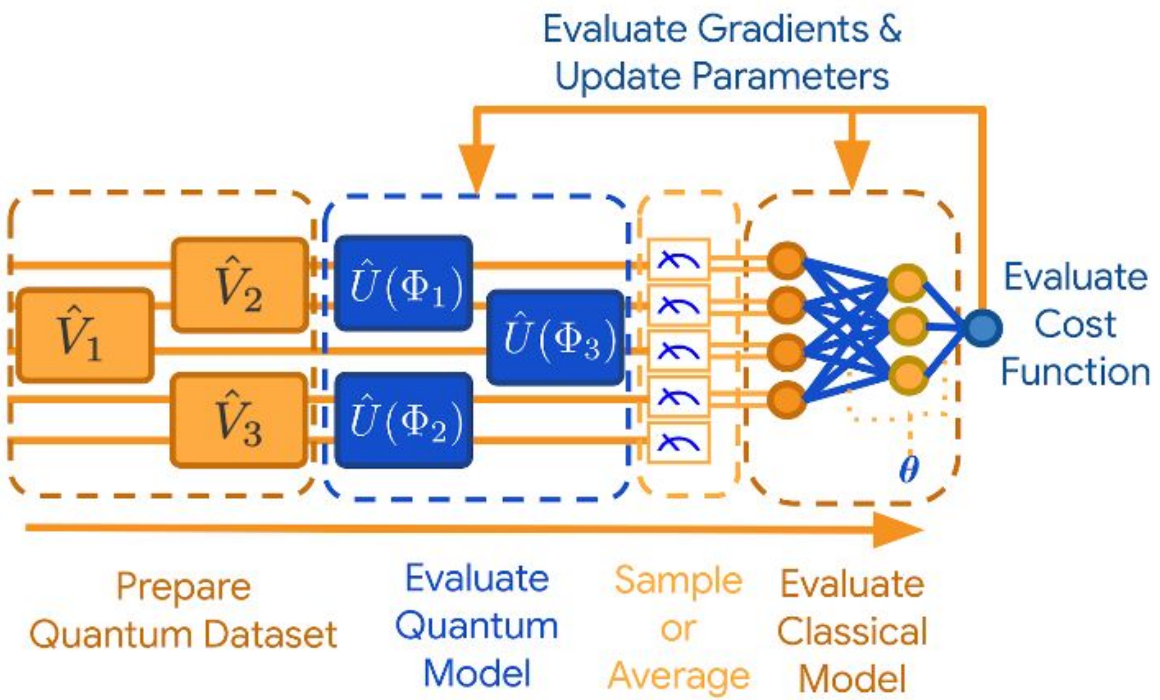
- Data embedding (store classical data in quantum states)
- Ansatz definition (similar to structure of neural network, including number and type of layers)
- Measurement (quasiprobability distribution or expectation values)



Quantum Machine Learning (QML) (cont'd)

Key Components:

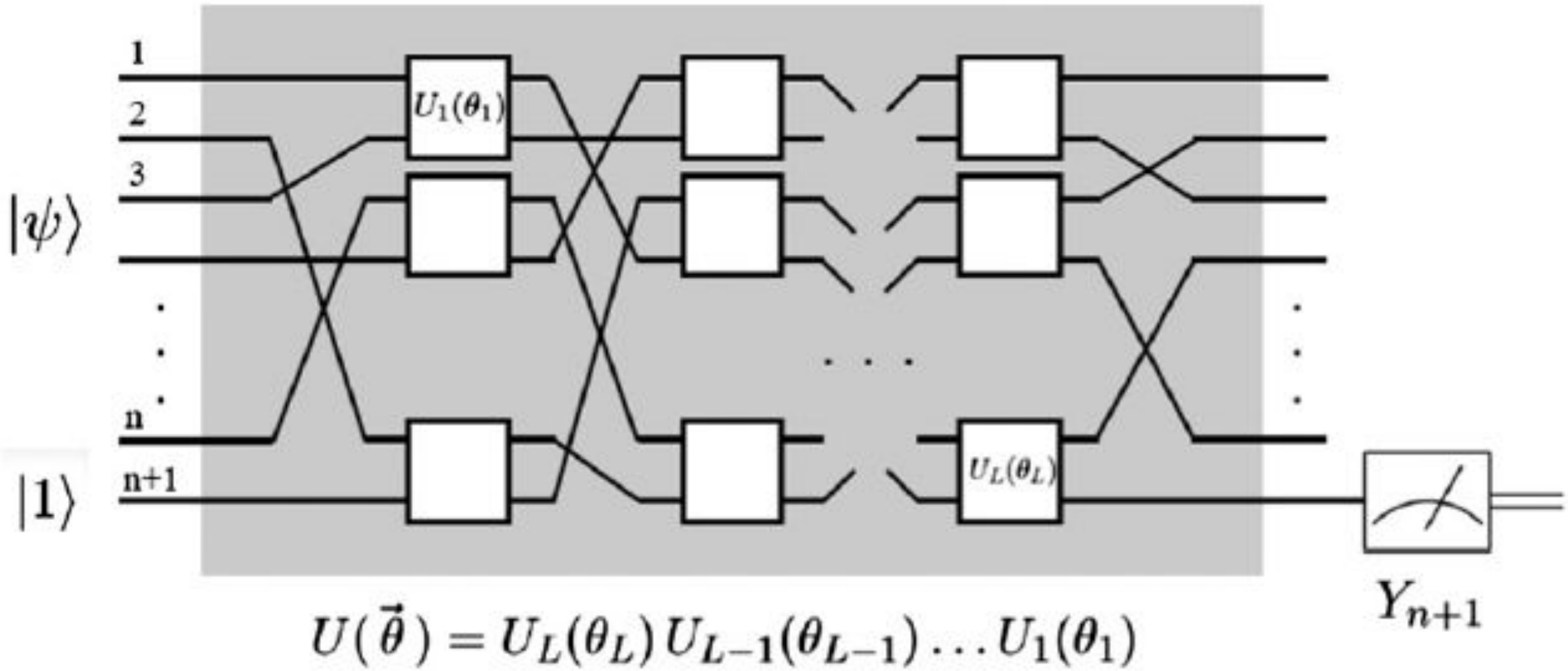
- Classical postprocessing (optional step, can use classical neural network)
- Optimization (cost function evaluation, gradient evaluation, and parameter updates)



Applications of QML

- **Supervised and unsupervised learning (similar to standard neural network)**
- **Natural Language Processing (similar to RNN)**
- **Image recognition (similar to CNN)**
- **Classical or quantum data processing**
  - Can process quantum data directly without embedding.

Quantum Neural Network Example



Data Embedding

Three straightforward strategies can be used to perform data embedding, though many advanced strategies also exist.

Basis Encoding:

- Treat qubits as binary bits.
- Requires $N * \tau$ qubits, where τ is the classical data's precision (e.g., 32-bit).
- Embedding time is $O(N * \tau)$.

Data Embedding (cont'd)

Amplitude Encoding:

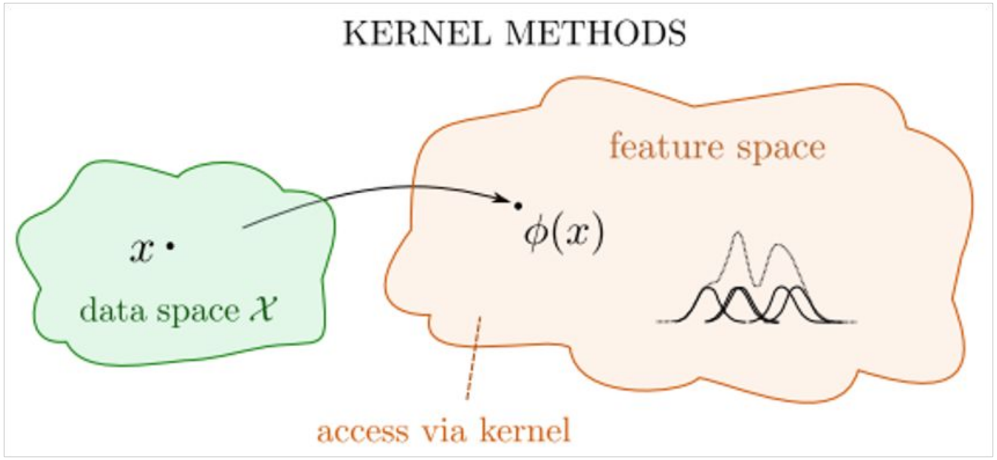
- Directly embed features as the normalized amplitudes of qubits.
- Requires log(N) qubits.
- Embedding time is $O(2^n/n)$, with n = number of qubits.

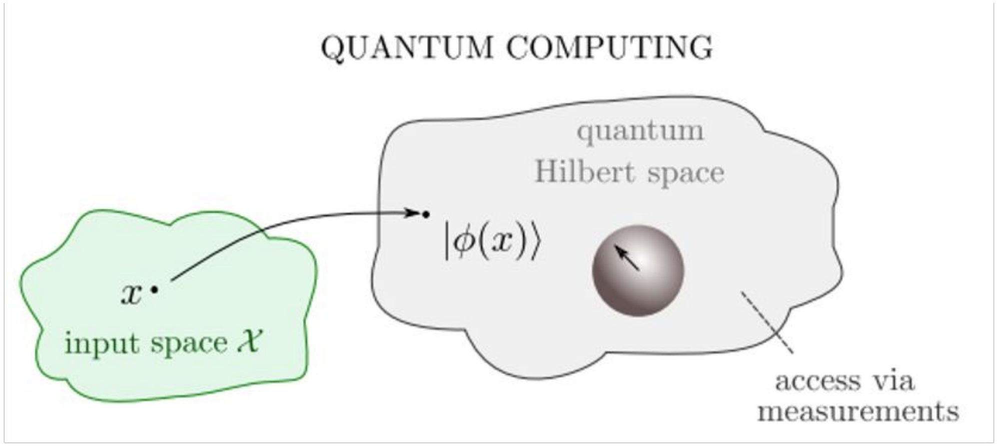
Rotation Embedding:

- Use qubit's spherical representation to embed data using rotations. (This approach is very easy for programmers.)
- Requires N qubits.
- Embedding time is $O(N)$.

Data Embedding (cont'd)

- Data embedding can be considered as a type of kernel method.
- The formula for the kernel can be directly derived from the embedding strategy.
- Changing embedding strategies can increase the model's expressiveness.



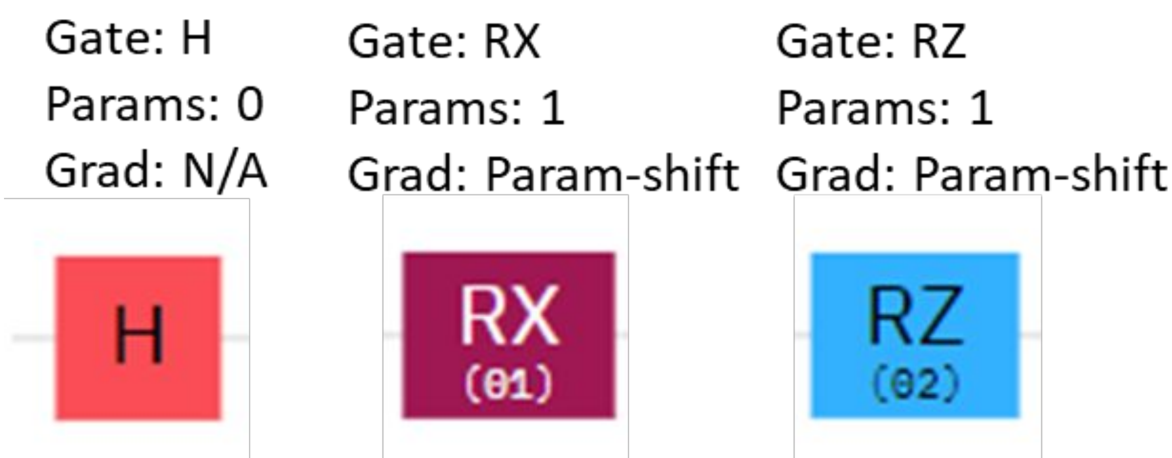


Ansatz Definition

- The ansatz definition is open to significant experimentation.
- Many "standard" ansatzes are available for testing.
- The ansatz should typically incorporate entanglement (e.g., CNOT) and parameterized gates (e.g., rotation gates).

Measurement and Optimization

- QML faces the same issues as classical ML, such as the barren plateau problem.
- QML optimization runs on a classical computer using classical optimization methods (e.g., AdamOptimizer).
- The method used for gradient computation can be experimented with, though most platforms can do it automatically (e.g., parameter-shift rules).

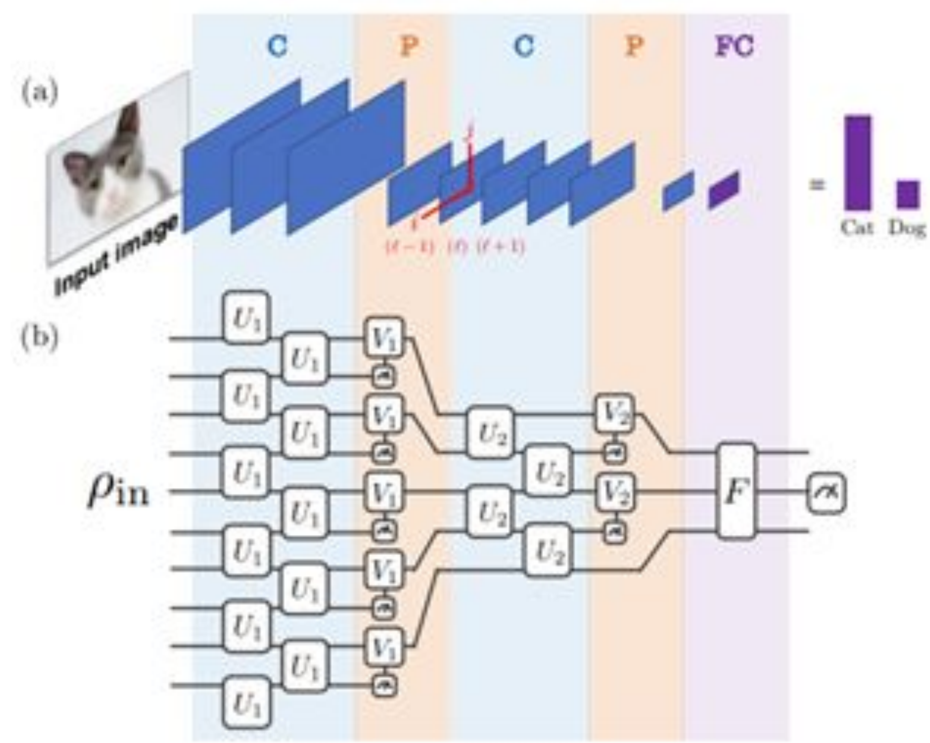


QML Application Example

- It is possible to develop quantum versions of existing classical methodologies (e.g., a quantum CNN – QCNN for image processing).

Classical CNN

QCNN



Summary

Artificial Neural Networks for Deep Learning

– Neurons → Qubits

Introduction to Quantum Computing

– Bits vs. Qubits

Quantum Programming

– Various Quantum programming libraries and environments

Quantum Machine Learning

– CNN vs. QCNN