

Course Title: Quantum Machine Learning

Credit Hrs: 3

Prerequisite: Linear Algebra and Probability Theory, basic knowledge of classical machine learning

Course Description:

It merges quantum computing with machine learning to create more powerful algorithms. Quantum computing concepts like superposition and entanglement, and the application of quantum algorithms to enhance classical machine learning tasks. Quantum Boltzmann Machines, Quantum Generative Adversarial Networks (QGANs), Applications to synthetic data generation.

Course Objectives:

- Introduce the principles of integrating quantum computation with machine learning.
- Explore quantum data representations and quantum feature spaces.
- Implement and analyze quantum machine learning (QML) algorithms using modern frameworks.
- Understand variational, hybrid, and kernel-based quantum learning methods.
- Evaluate performance and scalability of QML models on simulators and NISQ hardware.

Course Learning Outcomes: Upon completion, students will be able to:

- Explain theoretical foundations of QML and its relationship to classical ML.
- Encode and process classical data on quantum states.
- Design and implement QML algorithms (e.g., quantum classifiers, QNNs, QGANs).
- Analyze performance, complexity, and noise sensitivity of QML models.
- Apply QML to practical domains such as optimization, chemistry, and finance.

Course Contents:

Week	Contents
1-2	Quantum Computing & ML Foundations: Review of quantum computation principles (qubits, gates, measurements), Overview of classical ML pipeline, Quantum advantage in learning tasks
3-4	Quantum Data Encoding & Feature Maps: Quantum data loading challenges, Amplitude, angle, and basis encoding, Quantum feature maps

- and kernel estimation
- 5–6 Quantum Linear Algebra for ML: Quantum linear systems (HHL algorithm), Quantum principal component analysis (qPCA), Applications to dimensionality reduction
 - 7–8 Variational & Hybrid Quantum Models: Variational Quantum Classifier (VQC), Quantum Neural Networks (QNN), Quantum Gradient Descent and backpropagation
 - 9–10 Quantum Kernel Methods: Quantum kernel estimation, Support Vector Machines with quantum kernels, Performance comparison: QML vs classical ML
 - 11–12 Quantum Generative Models: Quantum Boltzmann Machines, Quantum Generative Adversarial Networks (QGANs), Applications to synthetic data generation
 - 13 Quantum Reinforcement Learning: Quantum agents and environments, Hybrid policies and exploration strategies
 - 14 Noise, Optimization, and Error Mitigation: Noise effects on learning performance, Parameter optimization in noisy circuits, Error mitigation and robustness techniques
 - 15 QML on NISQ Devices: Practical implementations on IBM Quantum / IonQ, Case studies of QML applications
 - 16 Current Research & Future Directions: Quantum advantage benchmarks in ML, Emerging architectures and hardware-aware learning, Student project presentations

Textbooks/ References:

- *“Quantum Machine Learning: What Quantum Computing Means to Data Mining”* — Peter Wittek (2nd Ed., 2020)
- *“Quantum Computation and Quantum Information”* — Nielsen & Chuang (2010)
- Schuld, M., & Petruccione, F. *“Supervised Learning with Quantum Computers”* (Springer, 2018)
- Biamonte, J. et al. *“Quantum Machine Learning”*, *Nature*, 549, 195–202 (2017)

- Qiskit Machine Learning Documentation
- PennyLane Tutorials and Quantum TensorFlow guides

Assessments:

- Assignments: 10%
- Quizzes: 10%
- Midterm Exam: 30%
- Final Exam: 50%