Quantum Kernel Expressivity Research – Executive Summary

Overview

This document summarizes a novel research direction identifying time evolution under Hamiltonian dynamics as a primary axis of expressivity in quantum learning systems. Unlike depth or qubit scaling, temporal frequency modulation alone induces measurable phase transitions in kernel spectra, model separation, sample complexity, and stability under noise.

Research Deliverables

• Hybrid classical dataset generated via entangled two-qubit evolution
• Frequency parameterized encoding applied to a quantum kernel SVM
• Spectral expressivity metrics (entropy, eigenshape, rank) derived analytically
• Performance benchmarking against variational and classical baselines
• Robust reproducibility pipeline with CI execution validation

Key Finding

A quantifiable transition emerges between low-frequency embeddings (feature collapse) and mid-frequency embeddings (high curvature and separability), after which entropy plateaus while accuracy remains stable. This identifies time as a capacity-limiting instrument that is tunable without architectural scaling.

Direct Applications

- Noise-aware quantum encoding policies
- Spectral diagnostics for QML model selection
- Optimization of frequency-based sampling strategies
- Analytical profiling of emerging QML training regimes

Next Steps

Formalizing closed-form spectral evolution curves under perturbed Hamiltonians, constructing temporal-entropy learning bounds, and extending benchmarking to live backends.