Research Plan: qDrift-Based Simulation of Non-Hermitian Quantum Dynamics

QIntern 2025 Mentor Application

Overview

The project focuses on implementing and analyzing a randomized Hamiltonian simulation algorithm (qDrift) tailored for non-Hermitian quantum systems. Non-Hermitian dynamics arise in open quantum systems and PT-symmetric systems, where the evolution is no longer unitary. The interns will study a recently proposed method that bounds the simulation error in terms of observable quantities rather than the trace norm, allowing efficient simulations when the full state is not required.

The goal is to prototype and benchmark this observable-bounded qDrift method using quantum simulators (e.g., Qiskit) and compare it against traditional Trotterization techniques. Interns will gain hands-on experience in quantum algorithm design, error analysis, and practical implementation.

Six-Week Work Plan

Week 1: Background and Foundations

- Study of non-Hermitian quantum mechanics and open systems.
- Review of qDrift and randomized compiling techniques.
- Introduction to quantum simulation methods (Trotter, LCU, etc.).
- Setup: Qiskit installation and tutorials on simulation tools.

Week 2: Paper Study and Codebase Preparation

- Deep dive into the reference work: *"Observable bound for qDrift on non-Hermitian dynamics"*.
- Interns prepare a summary of key mathematical results.
- Set up basic simulation templates for both Hermitian and non-Hermitian models.

Week 3: Initial Implementation

- Implement observable-bounded qDrift algorithm for a toy model.
- Validate sampling distribution and construct measurement circuits.
- Begin benchmarking against deterministic Trotterization.

Week 4: Error Analysis and Scaling

- Analyze observable errors under various sampling sizes.
- Compare resource overhead vs. accuracy across models.
- Study scaling behavior for larger non-Hermitian Hamiltonians.

Week 5: Extensions and Optimization

- Explore sampling optimizations (e.g., importance sampling).
- Investigate physical applications such as decay or PT-symmetric systems.
- Run experiments on cloud-based backends (if available).

Week 6: Documentation and Final Report

- Write detailed project report and present results.
- Open-source code with documentation and usage instructions (if any).
- Feedback session and discussion on future work.

Guidance and Supervision Plan

Weekly group meetings will be held to discuss progress, challenges, and next steps. I will provide direct feedback on implementation, error analysis, and scientific writing. Extra office hours will be scheduled by in-time communication.

Plans for Future Work

Following successful implementation, this work can be extended to:

- Multi-observable tracking in open-system dynamics.
- Resource estimation for fault-tolerant simulation of non-Hermitian systems.
- Publication based on results.