Google Summer of Code @ ML 4 SCI Machine Learning for Science

Task III: Open Task

Please comment on quantum computing or quantum machine learning. You can also comment on one quantum algorithm or one quantum software you are familiar with. You can also suggest methods you think are good and you would like to work on.

Familiar Quantum Software (In decreasing order of experience):

- **Cirq**
- **Pennylane**
- **Qiskit**

Familiar Quantum Algorithms:

I possess a solid mathematical and intuitive understanding of quantum algorithms like **Shor's Algorithm, Deutsch's Algorithm, the Deutsch-Jozsa Algorithm, Quantum Fourier Transform, Quantum Phase Estimation and the Bernstein-Vazirani Algorithm.**

Apart from these theorems, a concept/algorithm that I had studied for an ***open assignment as a part of my Graph Theory course*** this semester was **Quantum Walks**.

Simply put, quantum walks are the quantum versions/alternatives of the already-known classical walks to move from one point to another (typically from the source to the destination) within a graph.

Quantum walks can be classified into two parts:

- **Discrete-time Quantum Walks**: Step-by-step evolution on |position, state> (let's call it psi) using unitary transformations with a coin state. The walker exists in a quantum superposition of multiple psi and the two main components of it are:
    1. Coin State (|c>): To determine the direction of the walk (using qubits like |0> or |1> for instance in a single qubit system). Coin gates are used for the matter (which can be a Hadamard coin or a Grover coin).
    2. Shift Operation (|s>): Based on the current coin state, move the walker to a new state.
- **Continuous-time Quantum Walks**: Evolution on a continuous-time domain using a Hamiltonian and Schrödinger's Equation (requiring no coin space).

One of the most prominent examples of the algorithm lies in Photosynthesis.

Photosynthesis is the biological process used majorly by autotrophs, some algae, and bacteria to produce chemical energy stored in the form of Glucose and other organic molecules from light energy (from the Sun). Energy transfers to reaction sites using classical walks contained the problem of energy losses. Quantum walks, specifically Continuous-time Quantum Walks (CTQW), are faster and more efficient, due to the superposition of excited electrons (called excitons) which explore multiple paths, and the path with maximum interference is followed while destructive interference prevents energy losses.

Inspiration/ Motivation to study Quantum Machine Learning (and Experience):

My first encounter with Quantum Physics was rather funny when I saw a meme on Schrödinger's Cat in Grade 7. Upon searching the word "Schrödinger" on Google and seeing the bulky equation, my eyes bawled out—the scary equations surely got me interested in understanding them someday!

Cut to 2021–2023, when I was preparing for JEE Advanced (an examination to enter the most prestigious engineering colleges in India), I gained some intuition about the quantum realm after studying Wave Optics and Modern Physics. Later, in my freshman year, I took the Engineering Physics course, where I got to understand quantum phenomena more deeply.

However, I wanted to complement my theoretical knowledge with some programming, so I took the Quantum Computing Tutorial by FreeCodeCamp in the summer of 2024 and coded simple quantum circuits in Cirq.

I have been working on various Machine Learning and Deep Learning problems for the past two years and possess a strong grip on all the fundamentals. I believe ML4SCI QMLHEP projects involving Quantum Machine Learning provide me with a perfect platform to work on both topics at their intersection, given my interest in particle physics and experience in programming.

Preference for QMLHEP projects to work on for Google Summer of Code ‘25:

- Quantum Kolmogorov-Arnold Networks for High Energy Physics Analysis at the LHC
- Learning quantum representations of classical high-energy physics data with contrastive learning
- Q-MAML - Quantum Model-Agnostic Meta-Learning for Variational Quantum Algorithms for High Energy Physics Analysis at the LHC

References:

1. Quantum Walk and Its Application Domains: A Systematic Review - Karuna Kadian, Sunita Garhwal, and Ajay Kumar (2021)
2. Quantum biology - Wikipedia