Potential Project Themes

Course: Quantum Computation

February 13, 2024

Note: This document includes potential project themes and some references to asssist you select a final project topic for the Quantum Computation Course. The project comprises 50% of the course assessment, so leverage the provided resources to craft an ambitious project abstract. Merely copying algorithms or summarizing existing information won't make a *good* project. A good project, apart from literature review should also demonstrate something unique your team has done or explored. It's not mandatory to present entirely original results, but your project should offer some value. For instance, if you've explored a specific idea that didn't yield the expected outcome due to certain reasons, that is perfectly acceptable and can contribute to the project's merit. Also note, these are just suggestions to get you started, you're welcome to write an abstract on any quantum computing topic not mentioned in this document.

1. **Quantum Optimization**
   This is a vast theme in itself, there's a lot of topics that you can work on under this theme.

   - **Quadratic Unconstrained Binary Optimization (QUBO) problems:**
     QUBO problems are an interesting class of optimization problems that quantum computing can address. Finding the solution to a QUBO is equivalent to finding the ground state of a corresponding Ising Hamiltonian. Some Quadratic Programs can be converted to QUBO problems and for the latter, algorithms like Variational Quantum EigenSolver (VQE), Quantum Approximate Optimization Algorithm (QAOA), Grover Adaptive Search (GAS) etc are used. These are useful for certain combinatorial optimization problems like Max-Cut, TSP, Knapsack, etc which have practical interest in many fields.

     (a) Refer this and the intext citations in it for more on algorithms and potential applications.

     (b) You can pick a specific problem (could be a simple model problem) relevant to a field, convert it to a QUBO and use relevant quantum algorithms for optimization.

- **Quantum Annealing (QA) for optimization problems:**
  While QAOA runs on a gate-model of quantum computers, Quantum Annealers are purpose-driven quantum computers designed to solve optimization problems. Quantum annealing essentially performs an adiabatic evolution to optimise some function. In the NISQ-era, QA is found to significantly outperform QAOA, as it converges to optimality more rapidly.
  (a) Explore DWave,it builds quantum annealers, you can sign up for their cloud quantum service and some basic access to quantum computers.
  (b) Quantum Annealers could have applications in Machine Learning, refer this recent paper.

2. **Applications of Quantum Algorithms**
   Theme 1 was about certain Quantum Algorithms specifically for optimization. But Quantum Algorithms are also designed to tackle several other problems too, for which classical computers are computationally expensive. You can look for some applications here and the algorithms used in such applications. (you can use any SDK you want, this is just a reference for getting topic ideas)

3. **Quantum Machine Learning**
   Qiskit Textbook and Pennylane demos are some great places to learn about this topic Chose something specific to work on for your projects. Also this book is a great reference for supervised learning with QC.

4. **Quantum Games**
   - Quantum Gambling: Double or nothing game
   - You can build a quantum game which uses topics of quantum computation like entanglement, superposition, measurement etc. Refer here for some list of resources. You cannot copy an already existing game, you have to create a new one.

5. **Pedagogical animation of Stern-Gerlach Experiment and Quantum Spin**

6. **Some theoretical ideas**
   - From Schrodinger Equation to Dirac Equation and Quantum Spin
   - The Dirac equation as a quantum walk
   - Supersymmetric Quantum Computation
   - Black hole information Paradox