The Nuts and Bolts of Quantum Computing

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Course Summary

This is a broad course which will introduce students to the world of quantum computing. We will cover the nuts and bolts of qubits, entanglement and quantum algorithms along with the necessary physics and mathematics background, including, linear algebra, probability, complex numbers, and partial differential equations. Through projects, the students will have the opportunity to explore potential advantages of quantum computing in areas such as Finance, Medicine, Logistics and Machine Learning. Through the lab part of the course, students will gain hands-on experience using quantum SDKs and implementing quantum algorithms, enhancing their practical understanding of the subject matter.

Course Prerequisites

- None: Open to all those interested.

Reference Books

The course will not follow any one particular text book. All essential course related material will be shared on LMS.

Assessments

The course assessment will be as follows:

1. Biweekly Assignments : 50%
2. Final Project and Presentation: 50%

Tentative Course Plan:

1. Week 1
    1.1. Lecture 1: Introduction to the course
    1.2. Lecture 2: The nature of spin
    1.3. Lab 1 : **Introduction**
        1.3.1. Quantum Computing Ecosystem- Simulators vs Quantum Computers
        1.3.2. Setting up necessary installation/accounts and Getting started
2. Week 2
    2.1. Lecture 3: Quantum state, Complex amplitudes
    2.2. Lecture 4: Review vector spaces
    2.3. Lab 2: **Classical vs Quantum Systems**
        2.3.1. Classical Coins vs Quantum Coins
        2.3.2. Visualizing Quantum states
3. Week 3
    3.1. Lecture 5: Classical and Quantum Bits
    3.2. Lecture 6: Quantum Measurements, Gates
    3.3. Lab 3: **Quantum Operations- 1**
        3.3.1. First Quantum programs with IBM's Qiskit
        3.3.2. Understanding how quantum gates work
4. Week 4
    4.1. Lecture 7: Rotations, Mobius transformations
    4.2. Lecture 8: Unitary, Hermitian Matrices
    4.3. Lab 4: **Quantum Operations- 2**
        4.3.1. Quantum Circuit Implementation- Simulators vs Quantum computers
5. Week 5
    5.1. Lecture 9: Photon Polarization
    5.2. Lecture 10: Time evolution
    5.3. Lab 5: **Exploring Quantum Softwares- 1**
        5.3.1. Exploring Cirq: Google's Quantum SDK
6. Week 6
    6.1. Lecture 11: System of two particles
    6.2. Lecture 12: Tensor products and Entanglement
    6.3. Lab 6: **Quantum Operations- 3**
        6.3.1. Circuits with Multipartite qubit states
        6.3.2. Entanglement and Multiple Control Constructions
7. Week 7
    7.1. Lecture 13: Einstein-Podolsky-Rosenberg (EPR)
    7.2. Lecture 14: Bell's Inequality
    7.3. Lab 7: **Quantum Communication- 1**
        7.3.1. Superdense coding
        7.3.2. Quantum Teleportation
8. Week 8
    8.1. Lecture 15: Bell's Inequality continued

- 8.2. Lecture 16: More on quantum gates
- 8.3. Lab 8: **Quantum Communication- 2**
    - 8.3.1. Entanglement and Protocols- BB84 & E-91 Cryptographic Protocols

9. Week 9
    - 9.1. Lecture 17: Fourier Transforms
    - 9.2. Lecture 18: Fourier Transforms Continued
    - 9.3. Lab 9: **Exploring Quantum Software Landscape- 2**
        - 9.3.1. Applications of Quantum Computing
10. Week 10
    - 10.1. Lecture 19: Quantum Fourier Transforms
    - 10.2. Lecture 20: Quantum Fourier Transforms Continued
    - 10.3. Lab 10: **Quantum Fourier Transform**
        - 10.3.1. Circuit implementation of QFT
        - 10.3.2. Application in Quantum Phase Estimation
11. Week 11
    - 11.1. Lecture 21: Quantum states in one dimension
    - 11.2. Lecture 22: Position and Momentum States
    - 11.3. Lab 11: **Quantum Games**
12. Week 12
    - 12.1. Lecture 23: Spin-position coupling
    - 12.2. Lecture 24: Quantum Random Walk
    - 12.3. Lab 12: **Exploring Quantum Software Landscape- 3**
        - 12.3.1. Applications of Quantum Computing
13. Week 13
    - 13.1. Lecture 25: Quantum Random Walk Continued
    - 13.2. Lecture 26: Continuum Limit Quantum Walk, Dirac Equation
    - 13.3. Lab 13: **Implementing Quantum Random Walk**
14. Week 14
    - 14.1. Lecture 27: Quantum Algorithms
    - 14.2. Lecture 28: Deutsch's Algorithm
    - 14.3. Lab 14: **Quantum Algorithms- 1**
        - 14.3.1. Phase Kickback
        - 14.3.2. Implementing Deutsch- Jozsa and Bernstein-Vazirani Algorithms
15. Week 15
    - 15.1. Lecture 29: Shor's Algorithm
    - 15.2. Lecture 30: Grover's Algorithm
    - 15.3. Lab 15: **Quantum Algorithms- 2**
        - 15.3.1. Implementing Grover's Algorithm
        - 15.3.2. Solving Max-Cut Problem using Grover's problem
16. Week 16
    - 16.1. Lecture 31: Buffer
    - 16.2. Lecture 32: Buffer
    - 16.3. Lab 16: **Quantum Algorithms- 3**
        - 16.3.1. RSA encryption
        - 16.3.2. Implementing Shor's Algorithm