CSCI 4140
Mid Term Review

Mark Green

Faculty of Science

Ontario Tech

Math Background

- Complex numbers, modulus, complex conjugate
- Bra-ket notation, inner product, outer product, tensor product
- Conjugate transpose of a matrix, Hermitian and Unitary matrices, special property of unitary matrices -> preserve the inner product
- Tensor product of matrices

Qubits and Gates

- Model of quantum program:
  - Initialize qubits
  - Perform computation – gates
  - Measure
- Qubit representation, 2D vectors, computational basis, matrix representation of gates, Bloch sphere, measurement
- Global and local phase, X basis, Pauli gates, Hadamard gate
- $R_{\phi,}$ S and T gates, U1, U2, and U3 gates
- With 1 qubit we can only do rotations

Qubits and Gates

- Multiple qubits, tensor products of qubits, CNOT gate, Bell state, entanglement, phase kickback
- Constructing circuits using Qiskit, circuit simulators
- Eigenvalues and eigenvectors, special properties of unitary and Hermitian matrices
- Mathematical explanation of phase kickback

Quantum Algorithms

- Quantum teleportation -> two classical bits send one qubit
- Superdense coding -> one qubit sends two classical bits
- Both applied a sequence of gates to entangled pair
- Quantum key distribution, use measurement in different basis to detect interception of message, basic algorithm steps, probability of detecting interception
- Deutsch-Josza algorithm, detect if a function is constant or balanced
- Bernstein-Vazirani algorithm, determine the value of s in $f(x) = s \cdot x \; mod \; 2$

Quantum Algorithms

- Simon's algorithm – determine if f() is one-to-one or two-to-one, determine the period of the function, distance b between repeated values, need classical computer to solve system of equations
- Notion of an oracle – black box that computes a function or checks a result
- Quantum Fourier transform – linear space to angular space, successive controlled rotations be smaller angles, CROT gate, inverse quantum Fourier transform
- Implementation of QFT and inverse QFT

Quantum Algorithms

- Quantum phase estimation, for an unitary U determine θ in $U|\psi\rangle = e^{2\pi i\theta}|\psi\rangle$, use of inverse QFT, basic structure of the algorithm, need to construct powers of U – this is the difficult part
- Shor's algorithm – compute factors of large numbers, can break common cryptography algorithms, period finding for $f(x) = a^x mod\ N$, difficulty of computing U^{2^i}
- Find the factors of 15, why?
- Grover's algorithm – unstructured search, construction of oracle, basic structure of algorithm, amplitude amplification

Quantum Hardware

- Qubit representation and mobility, coherence, gate times, error rates, universality, cryogenics, control, NISQ
- Compilation, hardware can perform limited set of gates, need to translate into this set, need to move qubit states around
- Performance, many factors, quantum volume, HOG
- Laser cooling, slow down the motion of atoms