**UCSD Spring School on Quantum Computation**
**May 19-22, UCSD**

# Indicative Syllabus

Below you will find a rough syllabus for topics that we intend to cover during the 3.5 days of lecture. Please note that the details are subject to change.

For the benefit of students with no exposure to the quantum formalism, we enclose a “cheat sheet” that covers basic notation and operations in quantum computation. The material in the cheat sheet does not constitute a prerequisite, and we will introduce each required concept as we go. Nevertheless, you may find it useful to take a look before the school, and keep a copy of the “cheat sheet” at hand during the first lectures.

## Day 1 (Monday): Introduction to QM and quantum computation

(9-10:30) **[Dorit]** Introduction

- Brief introduction to school
- Schrodinger's cat, the two slit experiment
- A qubit: quantum states and superposition
- Measurements.
- Schrodinger’s equation, Hamiltonians, and unitary evolution
- Hadamard gate and interference
- Two qubits, EPR state and the notion of entanglement

(11-12:30) **[Thomas]** The circuit model

- Definition of tensor products and n qubits
- The quantum circuit model
- Universal gate sets and the Solovay-Kitaev theorem. Clifford gates.
- The class BQP and its relation to BPP and NP.
- Error reduction

(lunch)

(2-3:30) **[David]** Basic quantum algorithms

- 1-bit Deutsch-Josza
- The Hadamard transform and its relation to QFT
- The Bernstein-Vazirani algorithm
- The Hidden Subgroup Problem, and specific instances (Simons, Shor, Graph Isomorphism)

(3:30-5) **[Jalex, Chinmay]** TA session

(5:30-6:30) **[Dorit]** The local Hamiltonian problem
- Recap: Hamiltonians, eigenstates, energies
- Definition of expectation values
- The Local Hamiltonian (LH) problem
- Relation between CSP and LH, and SAT as a special case
- QMA & QMA-completeness, statement of the quantum Cook-Levin theorem.

**Day 2 (Tuesday): Delegation, error correction, simulation**

(9:00-10:30) **[Dorit]** The quantum Cook-Levin theorem
- Statement and proof of Cook-Levin
- Containment + completeness
- The circuit-to-Hamiltonian construction, and history states.

(11:00-12:45) **[Thomas]** Delegating quantum computation
- Verifiability and blindness
- The quantum one-time pad
- Childs protocol for delegation of Clifford-gate circuit
- Fitzsimons-Morimae protocol

(lunch)

(2-3:30) **[David]** The adiabatic model
- Simulating Hamiltonian evolution on a quantum computer (30 min)
- The adiabatic model and how to simulate it (30 min)
- Adiabatic is universal (30 min)

(3:30-5:00) **[Jalex, Chinmay]** TA session

(5:00-6:30) **[Dorit]** Quantum error-correcting codes
- Definition and examples of quantum error-correcting codes
- Conditions for error correction
- Stabilizer codes and CSS codes
- Fault tolerance
- Open problems in quantum fault tolerance

**Day 3 (Wednesday): Quantum interactive proofs, models of quantum computation**

(9-11) **[Thomas]** Quantum games and self-testing
- Quantum XOR games

- The CHSH game and Tsirelson's bound
- Characterization of near-optimal strategies
- Approximate group representations and application to self-testing

(11:30-12:30) **[David]** Restricted models of computation I:
- Motivation:can we establish quantum versus classical separation with any restriction?
- Quantum advantage with shallow circuits

(lunch)

(2-3) **[Dorit]** The quantum PCP conjecture
- Statement of QPCP
- Thermalization
- The gap amplification version + random access formulations (equivalence under quantum reductions)
- The NLTS conjecture and connections to robustness of entanglement

(3-4:30) **[Jalex, Chinmay]** TA session

(4:30-6:30) **[David]** Restricted models of computation II
- Terhal-Divincenzo
- Boson sampling
- IQP circuits
- The QAOA algorithm

(8-10) **[All]** Party

**<u>Day 4 (Thursday):</u> Interactive proofs, stoquastic Hamiltonians**

(9-11) **[Thomas]** Interactive proofs with entangled provers
- The class MIP*
- The quantum games PCP conjecture
- Relation to Hamiltonian PCP conjecture
- The quantum linearity test and an exponential size quantum PCP

(11:30-12:30) **[David]** Stoquastic Hamiltonians
- Stoquasticity/ Perron Frobenius/thermal path integral
- Stoquastic local Hamiltonian is MA complete
- Simulation of stoquastic frustration-free Hamiltonians
- Prospects for simulating stoquastic adiabatic/quantum annealing

(12:30-3) **Lunch and discussion of open questions and challenges**