

# Indian Institute of Technology Kanpur

## Proposal for a New Course

1. Course Number: CSXXX
2. Course Title: **Programming Language Aspects of Quantum Computing**
3. Course Structure: Per Week Lectures (L): 3 hrs, Tutorial (T): None, Laboratory (P): None, Additional Hours (A): None  
Credits (3L + 2T + P + A): **9**  
Duration of Course: **Full Semester**
4. Proposing Department / IDP: **Computer Science and Engineering**  
Other Departments / IDPs interested: EE, PHY  
Other faculty members interested in teaching:
5. Proposing Instructor(s): **Subhajit Roy**
6. **Course Description**
  - A) Objectives**
    - Understand quantum computation models (qubits, gates, circuits)
    - Gain a programming languages-centric view of quantum computing
    - Explain quantum circuit compilation pipelines
    - Design abstractions for quantum programming languages
    - Reason about correctness using quantum program verification techniques
    - Connect PL concepts (types, semantics) to quantum computation
  - B) Contents**

**Module 1: Introduction to Quantum Computing** [10 lectures]

    - Classical vs quantum computation
    - Popular physics experiments that demonstrate quantum phenomenon
    - Mathematics for quantum computing, Dirac Notation
    - Quantum gates (Pauli, Hadamard, CNOT)
    - Measurement and probabilistic behavior
    - Quantum circuits as a computational model

- Quantum Algorithms: Deutsch–Jozsa, Grover’s search algorithm, Shor’s factoring algorithm, Quantum advantage and complexity class BQP

### **Module 2: Quantum Circuit Compilation** [10 lectures]

- Overview of quantum computer hardware
- Comparison with classical compiler pipelines
- Circuit model vs alternative models
- Circuit representations (DAGs, gate lists)
- Quantum IRs (e.g., QASM, MLIR extensions)
- Gate decomposition and universal gate sets
- Optimization passes (cancellation, commutation, circuit rewrite synthesis)
- Hardware mapping (qubit mapping and routing, optimized SWAP insertion)
- Noise-aware compilation

### **Module 3: Quantum Circuit Simulation** [6 lectures]

- Feynman’s algorithm for path integral formulation based simulation
- State vector simulation
- Hybrid simulation
- Density matrix simulation
- Tensor network methods
- Stabilizer simulation (Clifford circuits)

### **Module 4: Quantum Programming Languages** [7 lectures]

- Overview of low-level and high-level quantum languages
- Embedded vs standalone languages
- Linear types and no-cloning constraints
- Control flow in quantum programs
- Classical-quantum interaction
- Semantics of Quantum Programs: operational semantics, denotational semantics (superoperators), axiomatic semantics (Quantum Hoare Logic)
- Type Systems for Quantum Computing: linear type systems, resource tracking, effect systems for measurement, ensuring reversibility (ancilla bits and uncomputation)

### **Module 5: Quantum Program Verification** [7 lectures]

- Deductive Verification using Hoare logic for quantum programs
- Abstract Interpretation for quantum programs
- Dataflow analysis for safety and correctness of quantum programs
- Model checking approaches for quantum programs
- Program equivalence

**C) Pre-requisites** (e.g., course codes or equivalent background)

- Discrete Mathematics
- Linear Algebra
- Basic Probability Theory
- Programming Languages/Compilers (recommended)

The course will involve programming assignments/projects, and hence, students should be capable of programming in languages like Python or C.

**D) Short Summary** (For inclusion in Courses of Study booklet)

This course explores quantum computing from a *programming languages (PL)* perspective. It introduces the mathematical and computational foundations of quantum computing, followed by a deep dive into quantum program representation, compilation, simulation, language design, and verification.

**7. Recommended Books**

**Textbooks:**

There is no textbook for the course. The material will primarily be drawn from current literature.

**Reference Books:**

- Nielsen and Chuang, *Quantum Computation and Quantum Information*. Cambridge University Press.
- Mermin, *Quantum Computer Science: An Introduction*. Cambridge University Press.
- R. Shankar. *Principles of Quantum Mechanics*. Springer.
- Noson S. Yanofsky, Mirco A. Mannucci. *Quantum Computing for Computer Scientists*. Cambridge University Press.
- Chuck Easttom. *Quantum Computing Fundamentals*. Pearson Education.

**8. Any Other Remarks:** None

Dated: \_\_\_\_\_ Proposer: \_\_\_\_\_

Dated: \_\_\_\_\_ DUGC/DPGC Convener: \_\_\_\_\_

**The course is approved / not approved**

Chairman, SUGC/SPGC

Dated: \_\_\_\_\_