Indian Institute of Technology Kanpur
Department of Mathematics
Proposal for New Modular Elective Course

Title: Theoretical Foundations of Quantum Computing
Course No: MTH 7XX
Credits: 3-0-0-5 (L-T-P-C)
Semester: Any, Duration: Half Semester
Department: Mathematics
Proposer: B.V.R.Kumar
Prerequisite: MTH-308, MTH 522, MTH523A, MTH 409a, MTH698
No. of Students: ~ 15
Dept. to which course may be interesting: MATH/PHY/All Engineering Dept.

Course Objective:

Quantum computing is an emerging paradigm of computation that exploits the principles of quantum mechanics to process information in ways fundamentally different from classical computing. This modular course develops the mathematical and theoretical foundations of quantum computation, beginning with complex vector spaces, Hilbert spaces, tensor products, and linear operators. It introduces qubits, quantum states, unitary evolution, measurement, entanglement, and quantum circuits. Fundamental quantum algorithms, including Deutsch–Jozsa, Grover's search, and the Quantum Fourier Transform, are studied to illustrate quantum parallelism and computational speedup. The course also introduces quantum information, complexity, and the limitations of quantum computation.

Theoretical Foundations of Quantum Computing — 22 Hours

Module / Lecture	Course Content	Hours
M1: Mathematical Foundations		4
1. Mathematical Language	Vector spaces, Dirac notation, Hilbert spaces, operators, eigenvalues, unitary matrices	2
2. Tensor Products	Kronecker products, composite systems, multi-qubit states	2
M2: Quantum States & Operations		5
3. Qubits & Evolution	Qubits, superposition, Bloch sphere, unitary evolution, Pauli matrices	2
4. Measurement	Observables, Born's rule, projective measurement, density operators, POVMs	2
5. Entanglement	Bell states, separability, no-cloning, partial trace	1
M3: Quantum Circuits		4
6. Gates & Circuits	Single-qubit gates, controlled gates, CNOT, universal gate sets	2
7. Quantum Protocols	Interference, phase kickback, teleportation, superdense coding, quantum channels	2
M4: Quantum Algorithms		6
8. Early Algorithms	Deutsch, Deutsch–Jozsa, Bernstein–Vazirani, oracle computation	2
9. Grover's Algorithm	Search, oracle, amplitude amplification, geometric interpretation	2
10. QFT & Phase Estimation	QFT, phase estimation, order finding, Shor's algorithm	2
M5: Reliability & Complexity		3
11. Error Correction & Complexity	Quantum noise, error-correcting codes, complexity, research directions	3
Total		22

Textbooks and Reference Books

A. Textbooks

1. Nielsen, M. A., & Chuang, I. L. (2010). Quantum Computation and Quantum Information: 10th Anniversary Edition. Cambridge University Press.
2. Rieffel, E. G., & Polak, W. H. (2011). Quantum Computing: A Gentle Introduction. MIT Press.
3. Lipton, R. J., & Regan, K. W. (2014). Quantum Algorithms via Linear Algebra. MIT Press.
4. Yanofsky, N. S., & Mannucci, M. A. (2008). Quantum Computing for Computer Scientists. Cambridge University Press.

B. Reference Books

1. Preskill, J. (1998–present). Lecture Notes for Physics 229: Quantum Information and Computation. California Institute of Technology.
2. Kaye, P., Laflamme, R., & Mosca, M. (2007). An Introduction to Quantum Computing. Oxford University Press.
3. Wilde, M. M. (2017). Quantum Information Theory (2nd ed.). Cambridge University Press.
4. Watrous, J. (2018). The Theory of Quantum Information. Cambridge University Press.
5. Montanaro, A. (2024). Quantum Algorithms: An Overview. Selected research literature and lecture resources.

Date: 18.09.26

Signature of the Proposer: B. V. R. Kumar

Signature of DPGC Convener:

Course Approved/Not Approved

Signature of Chairman SUGC