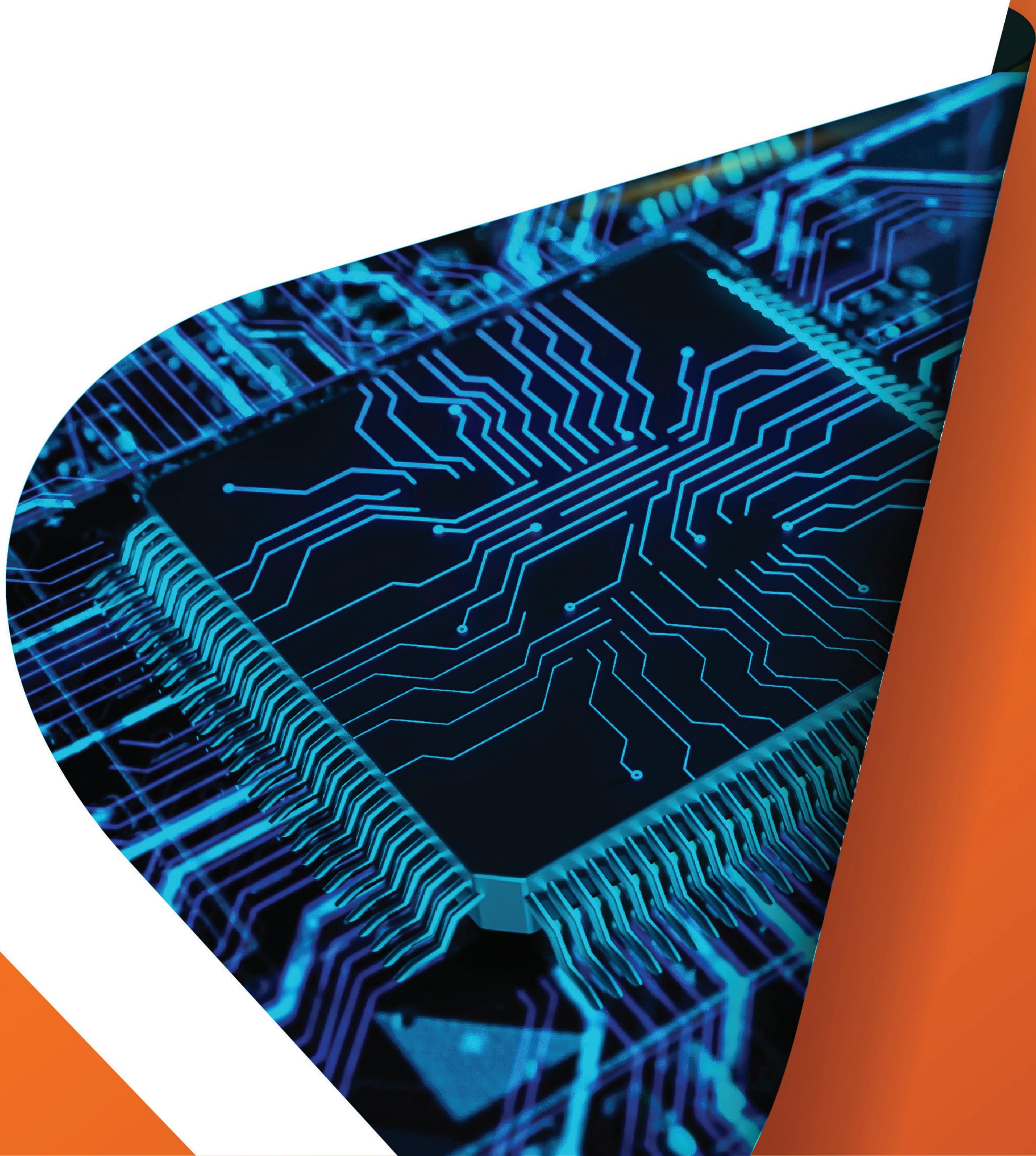
Centre for Outreach and Digital Education
Indian Institute of Technology Madras

IIT Madras CODE offers Certificate Program on

Quantum Computing

Cohort - 2



About the Course

Quantum computing has taken giant strides over the past decade, with companies like IBM, Google, IonQ and Quantinuum showcasing near-term quantum devices with hundreds of qubits. India has witnessed a spurt of related activity over the last few years, backed by government initiatives such as the National Mission on Quantum Technologies and Applications (NMQTA) and the Quantum-enabled Science and Technologies (QuEST) program.

Today, there is a widespread interest in quantum computing and information, both in academia and increasingly in industry. There is indeed a pressing need for a quantum-skilled workforce across academia and industry in India. Through this IITM CODE program we hope to introduce the fundamentals of quantum computing to a wider group of professionals and equip them with the necessary tools required to become an active part of the emerging quantum ecosystem.

IIT Madras CODE offers two 12-week courses in QUANTUM COMPUTING, offered in sequence. IIT Madras has active quantum research groups spread across the Physics, Electrical Engineering, Computer Science, Chemistry, Biotech and Management studies departments. We are also the first institute in the country to join the IBM Quantum Network as a partner and obtain preferential access to their current generation of quantum processors.

Course 1

"Introduction to Quantum Computing and Qiskit"

- Introduces the idea of a quantum bit and its properties and proceeds all the way to teaching and demonstrating basic quantum algorithms like search and factoring.
- This course is tailored in such a way as to be accessible to anyone with a basic knowledge of linear algebra and python.
- All the algorithms discussed here will be accompanied by demonstrations on current quantum hardware using IBM Qiskit.

Course 2

"Advanced Quantum Computing and Applications"

- Ventures into some of the key quantum algorithms that are being used in today's era of noisy intermediate-scale quantum (NISQ) devices.
- This includes the variational quantum eigensolver (VQE), quantum-inspired techniques for solving optimization problems and quantum machine learning.
- There is also a module on quantum error correction and quantum error mitigation which are crucial for the success of quantum algorithms in the NISQ era.
- Introduces the learner to emerging software tools such as qiskit runtime and transpiling quantum circuits.

Eligibility Criteria

We recommend basic knowledge in linear algebra and python from the participants

Course fees

Industry and Faculty	: Rs. 1,00,000 + 18% GST
Students	: Rs. 85,000 +18% GST

About CODE

Established in 1986, the Centre for Continuing Education (CCE) , now renamed as Center for Outreach and Digital Education (CODE), coordinates the outreach and online programs of IIT Madras. The centre's activities include coordinating the Web-enabled MTech programs; coordinating NPTEL and GIAN courses; coordinating IIT Madras' BS Degree programs; short-term skilling programs targeted towards Industry, Quality Improvement programs, meant for faculty in engineering institutions, support for conferences, book writing, etc. For more details, please refer https://code.iitm.ac.in/

To Register

CLICK HERE

QUANTUM COMPUTING

COURSE 1

Table of Contents for Course 1

Module 1

Mathematical Preliminaries

Instructor Profile

Prof. Prabha Mandayam

Department of Physics

IIT Madras

About the module

A brief review of the concepts from linear algebra that will be used in the course. This includes the concept of inner product, orthogonal states, eigenstates, eigenvalues and basis vectors. This module will also introduce the bra-ket notation that will be flowed throughout the course.

Learning outcomes of this module

Evaluate inner products between two vectors, identify orthonormal bases, evaluate eigenstates and eigenvalues, ability to work with bra-ket notation.

Applications of this module

Introduce the basic math concepts and notation required for understanding quantum bits and quantum computing.

Module 2

Quantum Mechanics Fundamentals

Instructor Profile

Prof. Prabha Mandayam
Department of Physics
IIT Madras

About the module

A quick introduction to quantum theory via two-level quantum systems. This module will discuss the postulates of quantum mechanics and describe quantum states, operators (unitary and Hermitian) and discuss the concept of measurement in quantum theory.

Learning outcomes of this module

Superposition Principle, action of Hermitian operators and unitary operators, Z-basis and X-basis measurements

Applications of this module

Gain comfort with the basic concepts of quantum theory required for quantum computing.

Module 3

Introduction to Qubits: Bloch sphere and Basic single-qubit gates

Instructor Profile

Prof. Prabha Mandayam
Department of Physics
IIT Madras

About the module

This module will introduce the idea of a quantum bit or qubit, geoemtric visualization of the qubit via the Bloch sphere and also discuss some of the logical operations on single qubits (X and Z gates and Hadamard gate)

Learning outcomes of this module

Identify states on the Bloch sphere, construct sinlge-qubit quantum circuits and evaluate their outputs.

Applications of this module

Design simple quantum circuits

Module 4

Two-qubit gates, Bell state circuit, No-cloning theorem and teleportation.

Instructor Profile

Prof. Prabha Mandayam
Department of Physics
IIT Madras

About the module

This module will introduce multi-qubit systems and the concept of entanglement. It will describe the no-cloning theorem and the quantum teleportation protocol.

Learning outcomes of this module

Tensor-product notation to describe multi-qubit states, understand why quantum states cannot be copied,understand the difference between product states and entangled states.

Applications of this module

The concept of entanglement, Bell-state circuits are widely used in quantum computation and quantum communication.

Module 5

Introduction to IBMQ, Physical realizations of qubits and Qiskit

Instructor Profile

Dr. Chandrashekar Radhakrishnan
Department of Physics
IIT Madras

About the module

Discussion on different physical architectures for implementing qubits, with a special focus on superconducting qubits. This module will also introduce the IBMQ platform and the qiskit simulator.

Learning outcomes of this module

Ability to create simple quantum circuits and run them on qiskit simulator as well as quantum hardware.

Applications of this module

Introduction to quantum software and hardware via IBM Q

Module 6

Quantum speed-up: Deutsch and DJ algorithms and Introduction to Computational complexity

Instructor Profile

Dr. Chandrashekar Radhakrishnan
Department of Physics
IIT Madras

Instructor Profile

Prof. Prabha Mandayam
Department of Physics
IIT Madras

About the module

Introduce ideas of computational hardness (classical and quantum). Discussion of a simple quantum algorithm to demonstrate quantum speed-up.

Learning outcomes of this module

Understand query complexity, implement Deutsch and Deutsch-Jozsa algorithms on qiskit

Applications of this module

The techniques learnt in the Deutsch algorithm will be applied in many quantum algorithms.

Module 7

Quantum Fourier Transform and Phase estimation

Instructor Profile

Prof. Prabha Mandayam
Department of Physics
IIT Madras

About the module

Discuss the circuit for implementing quantum Fourier tranform and show the polynomial scaling. Also discuss the phase estimation algorithm as a simple application of QFT.

Learning outcomes of this module

Understand how QFT can be performed using Hadamard and controlled rotation gates; implementation on qiskit.

Applications of this module

QFT and phase estimation are the basic steps in the quantum factoring algorithm

Module 8

Order Finding and Factoring

Instructor Profile

Prof. Prabha Mandayam
Department of Physics
IIT Madras

About the module

Discuss the order finding algorithm using phase estimation. Discuss Shor's factoring algorithm via order finding.

Learning outcomes of this module

Implement quantum factoring algorithm on qiskit.

Applications of this module

Integer factorization is used in public key cryptography

Module 9

Simons and Bernstein-Vazirani Algorithms

Instructor Profile

Prof. Prabha Mandayam
Department of Physics
IIT Madras

About the module

Discuss a few related quantum algorithms such as Simons and Bernstein-Vazirani

Learning outcomes of this module

Implement Simons and B-V algorithms on qiskit.

Applications of this module

Quantum algorithms for oracle-based problems, exmaple, hidden string problem.

Module 10

Grover Search

Instructor Profile

Prof. Prabha Mandayam
Department of Physics
IIT Madras

About the module

Explain the quantum search algorithm, the Grover iterate and demosntrate quadratic speed-up.

Learning outcomes of this module

Implement Grover search on qiskit.

Applications of this module

Quantum search over an unstructured database.

Module 11

Amplitude amplification and HHL algorithm

Instructor Profile

Mr. Dhiraj Madan
IBM Research, India

About the module

Explain amplitude amplification and use it to discuss the HHL algorithm for solving a system of linear equations.

Learning outcomes of this module

Implement HHL on qiskit.

Applications of this module

Quantum algorithm for solving linear systems of equations.

Module 12

Public key cryptography and Quantum Key Distribution (BB84)

Instructor Profile

Dr. Chandrashekar Radhakrishnan
Department of Physics
IIT Madras

About the module

Discuss the concept of (classical) public key cryptography and the RSA protocol. Introduce quantum key distribution (QKD) and discuss the BB84 protocol.

Learning outcomes of this module

Understand how quantum concepts like the uncertainty principle lead to unconditional security of publick key cryptography using quantum states.

Applications of this module

QKD protocols are at the heart of quantum communication networks.

QUANTUM COMPUTING

COURSE 2

Table of Contents for Course 2

Module 1

Quantum Machine Learning I : Introduction

Instructor Profile

Dr. Anupama Ray
IBM Research, India

About the module

After a brief introduction to classical machine learning, this module will discuss quantum machine learning (QML) techniques such as variational quantum classifier (VQC) and Quantum Support Vector Machines (QSVM).

Learning outcomes of this module

Understand and apply QML techniques like VQC, QSVM and quantum clustering.

Applications of this module

VQC and QSVM are essential QML tools for several data/image classification applications.

Module 2

Quantum Machine Learning II : Theory

Instructor Profile

Dr. Anupama Ray
IBM Research, India

About the module

After a brief introduction to classical machine learning, this module will discuss quantum machine learning (QML) techniques such as variational quantum classifier (VQC) and Quantum Support Vector Machines (QSVM).

Learning outcomes of this module

Understand and apply QML techniques like VQC, QSVM and quantum clustering.

Applications of this module

VQC and QSVM are essential QML tools for several data/image classification applications.

Module 3

Quantum Machine Learning III : Applications

Instructor Profile

Dr. Anupama Ray

IBM Research, India

About the module

After a brief introduction to classical machine learning, this module will discuss quantum machine learning (QML) techniques such as variational quantum classifier (VQC) and Quantum Support Vector Machines (QSVM).

Learning outcomes of this module

Understand and apply QML techniques like VQC, QSVM and quantum clustering.

Applications of this module

VQC and QSVM are essential QML tools for several data/image classification applications.

Module 4

Quantum Machine Learning IV : Applications

Instructor Profile

Dr. Anupama Ray
IBM Research, India

About the module

After a brief introduction to classical machine learning, this module will discuss quantum machine learning (QML) techniques such as variational quantum classifier (VQC) and Quantum Support Vector Machines (QSVM).

Learning outcomes of this module

Understand and apply QML techniques like VQC, QSVM and quantum clustering.

Applications of this module

VQC and QSVM are essential QML tools for several data/image classification applications.

Module 5

Variational Quantum Algorithms

Instructor Profile

Dr. Yamijala Chaithanya Sharma
Department of Chemistry
IIT Madras

About the module

This module will discuss the class of variational quantum algorithms, with special focus on the variational quantum eigensolver (VQE).

Learning outcomes of this module

Understand and implement VQE on qiskit.

Applications of this module

VQE is widely applied in quantum chemistry.

Module 6

Noise and Quantum Error Correction

Instructor Profile

Prof. Prabha Mandayam
Department of Physics
IIT Madras

About the module

Describe the theory of noise in quantum devices and introduce ideas of quantum error correction.

Learning outcomes of this module

Understand different noise models like bit-flip, phase-flip, depolarizing and T1/T2 processes. Implement a basic QEC code on IBM Qiskit.

Applications of this module

A basic understanding of noise and QEC is essential for working with today's noisy quantum hardware.

Module 7

Error mitigation for NISQ devices

Instructor Profile

Dr. Ritajit Majumdar
IBM Research, India

About the module

Introduce error mitigation techniques such as Zero Noise Interpolation and Probabilistic Error Cancellation.

Learning outcomes of this module

Incorporating error mitigation while programming NISQ hardware like IBM Q.

Applications of this module

Quantum error mitigation is widely used to reduce the effects of noise on quantum algorithms in current generation NISQ hardware

Module 8

Qiskit runtime, Transpling, Circuit Cutting

Instructor Profile

Dr. Dhinakaran Vinayagamurthy
IBM Research, India

About the module

Discuss quantum software techniques such as Qiskit Runtime and Transpling on IBM Q

Learning outcomes of this module

Ability to transpile quantum circuits on IBM Q and understand the use of qiskit runtime.

Applications of this module

Transpling and Qiskit Runtime are important tools in the IBMQ software stack.

Module 9

Quantum Communication Protocols

Instructor Profile

Dr. Chandrashekar Radhakrishnan
Department of Physics
IIT Madras

About the module

This module will introduce two important quantum communication protocols: quantum teleportation and super-dense coding.

Learning outcomes of this module

Understand the teleportation circuit and super-dense coding protocol; implement them on IBM Qiskit

Applications of this module

Teleportation and super-dense coding are two important applications of quantum entanglement. These are widely used in quantum communication theory.

Module 10

Introduction to Pulse Programming

Instructor Profile

Dr. Chandrashekar Radhakrishnan

Department of Physics

IIT Madras

Instructor Profile

Dr. Ritajit Majumdar

IBM Research, India

About the module

Introduce the idea of Pulse Programming with a simple example on IBMQ hardware.

Learning outcomes of this module

Understand the concept of programming quantum hardware via pulse programming routines.

Applications of this module

Pulse programming is used to optimize the performance of quantum hardware, and make it more resilient to the effects of noise.

Module 11

Solving Optimization Problems on a Quantum Computer (Part 1)

Instructor Profile

Prof. Anil Prabhakar
Department of Electrical Engineering
IIT Madras

About the module

Introduce techniques such as Quantum Integer Programming (QuIP) to solve optimization problems efficiently on quantum devices.

Learning outcomes of this module

Solve quadratic unconstrained binary optimization (QUBO) problems on IBMQ and quantum annealers like D Wave.

Applications of this module

QUBOs are widely used for practical problems such as bin-packing, optimal routing including traveling salesman problems.

Module 12

Solving Optimization Problems on a Quantum Computer (Part 2)

Instructor Profile

Prof. Anil Prabhakar
Department of Electrical Engineering
IIT Madras

About the module

Introduce techniques such as Quantum Integer Programming (QuIP) to solve optimization problems efficiently on quantum devices.

Learning outcomes of this module

Solve quadratic unconstrained binary optimization (QUBO) problems on IBMQ and quantum annealers like D Wave.

Applications of this module

QUBOs are widely used for practical problems such as bin-packing, optimal routing including traveling salesman problems.

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