GBS-Q SKILL MATRIX

Themes	Entry	Foundation	Experienced	Expert
Basic Mathematics	Linear Algebra I Fourier Series I Probability I Statistics I	Graph Theory I Linear Algebra II Fourier Series II Probability II Statistics II	Graph Theory II Stochastic Processes	Should be able to mathematically model any technical building block of a problem. Should be able to explain a difficult mathematical piece in any paper to an associate at a lower level. Should be able to teach a particular topic in mathematics to an associate at a lower level.
Quantum Mathematics	Quantum Computing I	Quantum Computing II	Quantum Computing III	Quantum Computing IV
Computer Science and Information Theory	Computer Science I Machine Learning I	Machine Learning II Deep Learning I	Deep Learning II	Deep Learning III Artificial Intelligence I
Quantum Algorithms	Quantum Algorithms I	Quantum Algorithms II	Quantum Algorithms III	
Programming	Programming I Qiskit I	Programming II Qiskit II	Programming III Qiskit III	

Basic Mathematics - Linear Algebra I

- Matrices
- Definition, Operations (Multiplication, Inverse)
- Special Matrices – Submatrix, Block Matrices
- Matrices over Complex Numbers
- Linear System of Equations
- Row Operations, Gauss Elimination
- Row Reduced Echelon Form of a Matrix, Gauss-Jordan Elimination
- Rank of a Matrix
- Determinant, Adjoint, Cramer's Rule
- Vector Spaces, Subspaces, Spanning Set, Linear Combinations, Linear Independence, Bases, Ordered Bases
- Basis, Dimensions
- Norms
- Eigenvalues, Eigenvectors and Diagonalisation, Diagonalisable matrices
- Jordan Canonical Form, Cayley Hamilton Theorem
- Classical and Quantum Computation of dual basis
- Linear Transformation, Isomorphism, Rank-Nullity Theorem
- Inner Product Spaces, Orthogonal and Orthonormal Basis, Cauchy-Schwarz Inequality, Gram-Schmidt Orthogonalisation, Orthogonal Projections

Basic Mathematics - Linear Algebra II

- SYSTEMS OF LINEAR EQUATIONS, Row-reduced Echelon Matrices and Non-homogeneous Equations, Invertible matrices - Non-homogeneous Equations
- DUAL SPACE, Linear Functionals, Dual Basis, Subspace Annihilators, Double Dual, Double Annihilator
- Direct Sum Decompositions and Projection Operators
- PRIMARY AND CYCLIC DECOMPOSITION THEOREMS, Jordan Decomposition
- INNER PRODUCT SPACES, QR Decomposition, Bessel's Inequality, Parseval's Indentity, Best Approximation
- Best Approximation: Least Squares Solutions, Orthogonal Complementary Subspaces, Orthogonal Projections, Projection Theorem. Linear Functionals
- ADJOINT OF A LINEAR OPERATOR, Properties of the Adjoint Operation. Inner Product Space Isomorphism
- SELF-ADJOINT, NORMAL AND UNITARY OPERATORS

Basic Mathematics – Fourier Series-I

- Fourier series
- Pointwise convergence of Fourier series
- Uniform convergence of Fourier series
- Bessel's Inequality and Parseval's Identity
- Complex Form of Fourier Series
- Half Range Series
- Solution by Transform Methods - Fourier Integral Representation, Fourier Transform and Inverse Fourier Transform, Applications, Fourier Cosine and Sine Transform

Basic Mathematics – Fourier Series-II

- Special kernels - Dirichlet kernel, Poisson kernel, Heat kernel
- Convolution theory
- Summability of Fourier series
- Applications of Fourier series
- Fourier transform, -on the Schwartz space, for L2-functions on R, for L1-functions on R
- Topics on Fourier transform - Poisson summation formula, Uncertainty principle
- Fourier analysis on Rn
- Fourier transform on Rn
- Hilbert spaces - Fourier expansion and Parseval's formula
- Banach spaces

Basic Mathematics – Graph Theory-I

- Discovery of graphs, Pictorial representation, Matrix representations
- Isomorphic graphs
- Subgraphs
- Degree of a vertex
- Special graphs, Complements
- Larger graphs from smaller graphs, Union, Sum, Cartesian Product. Composition
- Connected graphs and shortest paths, Walks, trails, paths, cycles
- Connectivity
- Weighted graphs and shortest paths, Dijkstra's shortest path algorithm
- Trees, Cayley's formula, Kirchoff-matrix-tree theorem
- Special classes of graphs, Bipartite Graphs, Line Graphs Chordal Graphs
- Independent sets, coverings and matchings,
- Perfect matchings in graphs, Greedy and approximation algorithms
- Vertex Colorings, Cliques and chromatic number, Mycielski's theorem
- Edge Colorings, Gupta-Vizing theorem
- Planar Graphs, Euler's formula
- Planarity testing - D-M-P-planarity algorithm
- 5-Color-theorem
- Directed Graphs, Underlying graph, Out-degrees and in-degrees

Basic Mathematics – Graph Theory-II

- Cut-vertices and cut-edges, Blocks
- Floyd-Warshall shortest path algorithm
- Minimum spanning trees, Kruskal's algorithm, Prim's algorithm
- Eulerian Graphs, Fleury's algorithm, Chinese Postman problem
- Hamilton Graphs
- Matchings in bipartite graphs, Hall's Theorem, Konig's Theorem
- Vertex Colorings - Greedy coloring algorithm, Coloring of chordal graphs, Brooks theorem
- Edge Colorings - Class-1 and Class-2 graphs, Edge-coloring of bipartite graphs, Class-2 graphs, Hajos union and Class-2 graphs, Scheduling problem and equitable edge-coloring
- Planar Graphs - Polyhedrons and planar graphs, Subdivisions and Kuratowski's characterization, Minors and Wagner's theorem
- Directed Graphs – Isomorphism, Directed walks, paths and cycles, Connectivity in digraphs
- Orientation of a graph
- Eulerian and Hamilton digraphs
- Tournaments
- Graphic sequences, model of the LAN problem, Havel-Hakir... criterion, Realization of a graphic sequence, Erdos-Gallai criterion

Basic Mathematics – Complex Numbers & Complex Algebra

- Geometric Interpretation
- Algebraic Operations
- Bilinear form
- Conjugate of a Complex Number
- Modulus of a Complex Number
- Polar form
- Exponential form
- Powers of Complex Numbers
- Complex Functions
- Planar Sets
- Complex Functions
- Limits, Continuity, Differentiability
- Analytic Functions

Basic Mathematics – Stochastic Processes

- Introduction, basics, Classes of Stochastic Processes
- Discrete-Time Markov Chains, Classification of States, Stability
- Reducible Markov Chains
- Reversed and Time-Reversible Markov Chains
- Continuous-Time Markov Chains, Kolmogorov Equations, Limiting and Stationary Distributions, Poisson Processes, Birth-Death Processes, M/M/1 Queueing Model, Simple Markovian Queueing Models
- Martingales, Conditional Expectations, Generated ?-fields
- Martingales, Sub-martingales and Super-martingales
- Brownian Motion, Itô Integrals & Itô's Formula, SDEs and their Applications in Finance
- Renewal Processes, Renewal Function and Renewal Equation
- Generalized Renewal Processes and Renewal Limit Theorems
- Markov Renewal and Markov Regenerative Processes
- Non-Markovian Queues
- Branching Processes, Galton-Watson Process, Properties of GW Process, Markov Branching Process
- Stationary Processes

Basic Mathematics – Statistics I

- Variation in data, Absolute Deviation and Absolute Mean Deviation, Mean Squared Error, Variance and Standard Deviation, Coefficient of Variation
- Moments, Association of variables, Raw and Central Moments, Sheppard's Correction, Absolute Moments and Computation of Moments, Skewness and Kurtosis
- Simple linear regression analysis
- Multiple linear regression analysis
- Model adequacy checking, Correcting model inadequacies through transformation and weighting
- Tests for leverage and influential points
- Generalized and weighted least squares estimation
- Indicator variables
- Multicollinearity
- Autocorrelation
- Polynomial regression models
- Variable selection and model building
- Logistic and Poisson regression models
- Generalized linear model
- Sampling Theory, Basics
- Simple Random Sampling
- Regression method of estimation
- Non sampling errors
- Basic Concepts of Testing of Hypothesis
- Tests for Normal Populations

Basic Mathematics – Statistics II

- Sampling Theory, Advanced
- Sampling for proportions and percentages
- Stratified sampling
- Ration and product Methods of estimation
- Varying probability sampling
- Double sampling double sampling (Two phase sampling)
- Cluster sampling
- Two stage sampling two stage sampling (Sub sampling)
- Systematic sampling
- Sampling on successive occasions

Basic Mathematics – Probability I

- Probability Theory, Classical Method, Relative Frequency Method
- Random Variables, Induced Probability Measure, Distribution Function And Its Properties, Types Of Random Variables: Discrete,continuous And Absolutely Continuous
- Conditional Probability And Independence
- Descriptive Measures Of Probability Distributions, Measures Of Central Tendency, Mean, Median, Mode, Measures Of Dispersion, Standard Deviation, Mean Deviation, Quartile Deviation, Coefficient Of Variation
- Distributions - Bernoulli Experiment And Related Distributions , Bernoulli Distribution, Binomial Distribution, Poisson Distribution, Discrete Uniform Distribution, Uniform Or Rectangular Distribution, Quantile Function And Uniform Distribution, Normal Distribution
- Random Vectors , Joined Distributions
- Expectation And Conditional Expectation
- Point Estimation
- Interval Estimation

Basic Mathematics – Probability II

- Axiomatic Approach To Probability And Properties Of Probability Measure, Inclusion-exclusion Formula, Boole's Inequality, Bonferroni's Inequality, Equally Likely Probability Models
- Conditional Probability And Independence Of Events, Theorem Of Total Probability, Bayes' Theorem
- Continuity Of Probability Measures
- Function Of A Random Variable
- Probability Distribution Of A Function Of A Random Variable
- Expectation And Moments Of A Random Variable
- Properties Of Random Variables Having The Same Distribution
- Probability And Moment Inequalities, Markov Inequality, Chebyshev Inequality, Jensen Inequality, $\boldsymbol{AM\text{-}GM\text{-}HM}$Inequality
- Descriptive Measures Of Probability Distributions -Measures Of Skewness, Measures Of Kurtosis
- Distributions - Negative Binomial Distribution, The Hypergeometric Distribution, Gamma And Related Distributions, Beta Distribution,
- Multivariate Distributions
- Types Of Random Vectors
- Conditional Distributions
- Independent Random Variables
- Expectations And Moments, Cauchy-schwarz Inequality
- Joint Moment Generating Function
- Properties Of Random Vectors Having The Same Distribution, Uniqueness Theorem
- Multinomial Distribution
- Bivariate Normal Distribution
- Distribution Of Function Of Random Vectors, Distribution Function Technique, Transformation Of Variables Technique, Moment Generating Function Technique
- Distributions Based On Sampling From A Normal Distribution
- Convergence In Distribution And Probability, Poisson Approximation To Binomial Distribution
- The Weak Law Of Large Numbers (Wlln) And The Central Limit Theorem (Clt), Random Walk, Justification Of Relative Frequency Method Of Assigning Probabilities
- Normal Approximation To The Student-t Distribution
- Limiting Distributions - The Delta-method
- Tensor Products in Probability Theory

Quantum Computing I

- Classical Vs Quantum Information
- Quantum Building Blocks
- Single-qubit Quantum Systems, Single Quantum Bits, Single-qubit Measurement
- The State Space Of A Single-qubit System
- Multiple-qubit Systems, Quantum State Spaces, Entangled States Basics Of Multi-qubit Measurement
- Dirac's Bra/Ket Notation
- Operators, Observables
- Projection Operators For Measurement
- Hermitian Operator Formalism For Measurement
- The Pauli Operators, Pauli Matrices
- Unitary, And Normal Operators
- Matrix Representation Of Operators In 2d Spaces
- Eigenvalues And Eigenvectors
- The Characteristic Equation
- Spectral Decomposition
- Operators – Trace, Expectation Value, Functions
- Heisenberg Uncertainty Principle
- Postulates Of Quantum Mechanics
- Representing Composite States In Quantum Mechanics
- Computing Inner Products
- Tensor Products Of Column Vectors
- Operators And Tensor Products
- Tensor Products Of Matrices
- Density Operator
- Density Operator For A Pure State
- Probability Of Obtaining A Given Measurement Result
- Quantum Measurement Theory
- Distinguishing Quantum States And Measurement
- Projective Measurements
- Quantum Gates And Circuits
- Single-qubit Gates
- Hadamard Gates
- Z–y Decomposition
- Basic Quantum Circuit Diagrams
- Controlled Gates
- The Phase Gate
- Gate Decomposition

Quantum Computing II

- The Measurement Postulate
- Quantum State Transformations
- Unitary Transformations, No-Cloning Principle
- Pauli Transformations, Hadamard Transformation
- Multiple-Qubit Transformations from Single-Qubit Transformations
- The Controlled-NOT and Other Singly Controlled Gates
- A Universally Approximating Set of Gates
- Standard Circuit Model
- Time Evolution of the Density Operator
- Density Operator for a Mixed State
- Characterizing Mixed States
- Probability of Finding an Element of the Ensemble in a Given State
- Completely Mixed States
- The Partial Trace and the Reduced Density Operator
- The Density Operator and the Bloch Vector
- Measurements on Composite Systems
- Generalized Measurements
- Positive Operator-Valued Measures
- ENTANGLEMENT, EPR Paradox and Bell's Theorem, Bell's Inequality
- Pauli Representation
- Entanglement Fidelity
- Schmidt Decomposition
- Applications of Simple Gates, Dense Coding, Quantum Teleportation, Realizing Unitary Transformations as Quantum Circuits
- Matrix Representation of Serial and Parallel Operations
- Basic Quantum Cryptography, Controlled NOT Attack
- Quantum Operations and Krauss Operators

Quantum Computing III

- Quantum Interference
- Quantum Parallelism and Function Evaluation
- Entanglement Swapping
- Superdense Coding
- Quantum Cryptography - B92 Protocol, E91 Protocol
- Quantum Fourier Transform
- Phase Estimation
- The Depolarization Channel
- The Bit Flip and Phase Flip Channels
- Amplitude Damping
- Phase Damping
- Quantum Error Correction
- Information Content and Entropy, Shannon Entropy, Von Neumann Entropy
- Quantum Versions of Classical Computations
- Reversible and Quantum Versions of Simple Classical Gates
- Reversible Implementations of Classical Circuits
- Language for Quantum Implementations, In-Place Addition, Modular Addition, Modular Multiplication, Modular Exponentiation
- QUANTUM ALGORITHMS, Computing with Superpositions, Notions of Complexity
- Simple Quantum Algorithms, Quantum Subroutines, Deutsch-Jozsa Problem, Bernstein-Vazirani Problem, Simon's Problem, Distributed Computation
- Quantum Parallelism
- Machine Models and Complexity Classes
- Quantum Fourier Transformations
- Shor's Algorithm
- Grover's Algorithm and Generalizations
- Some Relations Between Quantum Mechanics and Probability Theory
- Quantum Mechanics as a Generalization of Probability Theory

Quantum Computing IV

- Classifying Entangled States, Bipartite Quantum Systems
- Multipartite Entanglement
- Transformations of Quantum Subsystems and Decoherence, Superoperators
- Quantum Error Correction
- CSS Codes, Stabilizer Codes, CSS Codes as Stabilizer Codes
- Fault Tolerance and Robust Quantum Computing
- Limitations of Quantum Computing
- Alternatives to the Circuit Model of Quantum Computation
- ADIABATIC QUANTUM COMPUTATION
- Adiabatic Processes
- Adiabatic Quantum Computing
- CLUSTER STATE QUANTUM COMPUTING
- Cluster States
- Cluster State Preparation
- Adjacency Matrices
- Stabilizer States
- Cluster State Processing
- Holonomic Quantum Computation
- Topological Quantum Computation
- Quantum Protocols
- Building Quantum Computers
- Simulating Quantum Systems

Computer Science I

- Deterministic vs Non-deterministic computations,
- Turing Machine, Non deterministic Turing
- Probabilistic and Quantum computations, Reversible computing,
- Decidability properties of Regular and Context Free Languages, Undecidability, Reduction, Applications of Reduction
- Rice's theorem
- Introduction to Computational Complexity Theory, Classes P, NP, NP-Completeness
- Quantum and classical complexity classes, , Big-O, Little-O, Easy vs Hard

Artificial Intelligence I

- Knowledge Representation and Reasoning
- Formal Logics
- Introduction to AI
- Intelligent Agents
- State Space Search
- Uninformed and Informed Search
- Constraint Satisfaction Problems
- First Order Logic
- Rule Based Systems
- Representation in FOL, Skolemization, Terminological Facts, Properties and Categories, Reification and Abstract Entities, Resource Description Framework (RDF), Event Calculus: Reasoning About Change
- Semantic Net
- Natural Language Understanding
- Resolution Refutation in FOL
- Knowledge Structures
- Description Logic, Normalisation, Structure Matching, Classification
- DL and Inheritance, Taxonomies and Inheritance, Beliefs, Inheritance Hierarchies:
- Default Reasoning, Circumscription, Minimal Models
- Reasoning with Uncertainty
- Fuzzy Reasoning
- Epistemic Logic

Machine Learning I

- Introduction to Machine Learning
- Supervised Learning
- Unsupervised Learning
- Reinforcement Learning
- Hypothesis Space and Inductive Bias
- Evaluation and Cross-Validation
- Statistical Decision Theory - Regression
- Statistical Decision Theory - Classification
- Bias-Variance
- Linear Regression
- Linear Regression - Multivariate Regression
- K-Nearest Neighbour
- Feature Selection & Extraction, Collaborative Filtering, Dimensionality Reduction, Subset Selection, Shrinkage Methods, Principal Components Regression, Partial Least Squares
- Classification - Linear Models, Linear Classification, Logistic Regression, Linear Discriminant Analysis
- Optimization
- Classification - Separating Hyperplane Approaches
- Perceptron Learning, SVM, SVM Kernels
- Parameter Estimation
- Maximum Likelihood Estimate
- Priors & MAP Estimate
- Bayesian Parameter Estimation
- Decision Trees, Overfitting
- Regression Trees
- Stopping Criteria & Pruning
- Loss Functions for Classification
- Categorical Attributes
- Multiway Splits
- Missing Values, Imputation & Surrogate Splits
- Instability, Smoothness & Repeated Subtrees
- Evaluation Measures, Bootstrapping & Cross Validation, 2 Class Evaluation Measures, ROC Curve, Minimum Description Length & Exploratory Analysis
- Hypothesis Testing, Sampling Distributions & the Z Test, Student\'s t-test, The Two Sample & Paired Sample t-tests, Confidence Intervals

Machine Learning II

- Ensemble Methods, Bagging, Committee Machines & Stacking, Boosting, Gradient Boosting, Random Forest
- Graphical Models
- Bayesian Learning, Naive Bayes
- Bayesian Networks
- Undirected Graphical Models, Potential Functions
- Hidden Markov Models
- Variable Elimination
- Belief Propagation
- Clustering
- Partitional Clustering, K-means
- Hierarchical Clustering
- Threshold Graphs
- The BIRCH Algorithm
- The CURE Algorithm
- Density Based Clustering
- Gaussian Mixture Models
- Gaussian Mixture Models
- Expectation Maximization
- Spectral Clustering
- Computational Learning Theory
- Sample Complexity – Finite Hypothesis Space
- VC Dimension
- Frequent Itemset Mining, apriori Property
- Reinforcement Learning, RL Framework and TD Learning, Solution Methods & Applications
- Multi-Class Classification

Deep Learning I

- Biological Neuron
- McCulloch Pitts Neuron, Thresholding Logic
- Perceptrons
- Error and Error Surfaces
- Perceptron Learning Algorithm
- Proof of Convergence of Perceptron Learning Algorithm
- Linearly Separable Boolean Functions
- Representation Power of a Network of Perceptrons
- Sigmoid Neuron
- A typical Supervised Machine Learning Setup
- Learning Parameters: (Infeasible) guess work
- Learning Parameters: Gradient Descent
- Representation Power of Multilayer Network of Sigmoid Neurons
- Feedforward Neural Networks (a.k.a multilayered network of neurons)
- Learning Paramters of Feedforward Neural Networks (Intuition)
- Output functions and Loss functions
- Backpropagation (Intuition)
- Backpropagation: Computing Gradients w.r.t. the Output Units
- Backpropagation: Computing Gradients w.r.t. Hidden Units
- Backpropagation: Computing Gradients w.r.t. Parameters
- Backpropagation: Pseudo code
- Derivative of the activation function
- Information content, Entropy & cross entropy
- Contours Maps
- Momentum based Gradient Descent
- Nesterov Accelerated Gradient Descent
- Stochastic And Mini-Batch Gradient Descent
- Tips for Adjusting Learning Rate and Momentum
- Line Search
- Gradient Descent with Adaptive Learning Rate
- Bias Correction in Adam
- Eigenvalue Decompositon
- Principal Component Analysis and its Interpretations
- Singular Value Decomposition

Deep Learning II

- Autoncoders
- Link between PCA and Autoencoders
- Regularization in autoencoders (Motivation)
- Denoising Autoencoders
- Sparse Autoencoders
- Contractive Autoencoders
- Bias and Variance
- Train error vs Test error
- Train error vs Test error (Recap)
- True error and Model complexity
- L2 regularization
- Dataset augmentation
- Parameter sharing and tying
- Adding Noise to the inputs
- Adding Noise to the outputs
- Early stopping
- Ensemble Methods
- Dropout
- A quick recap of training deep neural networks
- Unsupervised pre-training
- Better activation functions
- Better initialization strategies
- Batch Normalization
- One-hot representations of words
- Distributed Representations of words
- SVD for learning word representations
- Continuous bag of words model
- Skip-gram model
- Contrastive estimation
- Hierarchical softmax
- GloVe representations
- Evaluating word representations
- Relation between SVD and Word2Vec

Deep Learning III

- The convolution operation
- Relation between input size, output size and filter size
- Convolutional Neural Networks
- CNNs
- Image Classification GoogLeNet and ResNet)
- Visualizing patches which maximally activate a neuron
- Visualizing filters of a CNN
- Occlusion experiments
- Finding influence of input pixels using backpropagation
- Guided Backpropagation
- Optimization over images
- Create images from embeddings
- Deep Dream
- Deep Art
- Sequence Learning Problems
- Recurrent Neural Networks
- Backpropagation through time
- The problem of Exploding and Vanishing Gradients
- Selective Read, Selective Write, Selective Forget - The Whiteboard Analogy
- Long Short Term Memory(LSTM) and Gated Recurrent Units(GRUs)
- How LSTMs avoid the problem of vanishing gradients
- Introduction to Encoder Decoder Models
- Applications of Encoder Decoder models
- Attention Mechanism
- Attention over images
- Hierarchical Attention

Quantum Algorithms I

- **Algebraic and Number Theoretic Algorithms**
- Solving Exponential Congruences, Running Time:Polynomial
- Verifying Matrix Products, Running Time: Polynomial
- Subset-sum, Running Time: Polynomial
- Constraint Satisfaction, Running Time: Polynomial

- **Oracular Algorithms**
- Searching, Running Time: Polynomial
- Bernstein-Vazirani, Running Time: Polynomial Directly, Superpolynomial Recursively
- Formula Evaluation, Running Time: Polynomial
- Gradients, Structured Search, and Learning Polynomials, Running Time: Polynomial
- Ordered Search, Running Time: Constant factor
- Graph Properties in the Adjacency Matrix Model, Running Time: Polynomial
- Graph Properties in the Adjacency List Model, Running Time: Polynomial
- Collision Finding and Element Distinctness, Running Time: Polynomial
- Graph Collision, Running Time: Polynomial
- Matrix Commutativity, Running Time: Polynomial
- Group Commutativity, Running Time: Polynomial
- Center of Radial Function, Running Time: Polynomial
- Statistical Difference, Running Time: Polynomial
- Counterfeit Coins, Running Time: Polynomial
- Matrix Rank, Running Time: Polynomial
- Matrix Multiplication over Semirings, Running Time: Polynomial
- Subset finding, Running Time: Polynomial
- Search with Wildcards, Running Time: Polynomial
- Network flows, Running Time: Polynomial
- Junta Testing and Group Testing, Running Time: Polynomial

- **Approximation and Simulation Algorithms**
- Simulated Annealing, Running Time: Polynomial

Quantum Algorithms II

- **Algebraic and Number Theoretic Algorithms**
- Factoring, Running Time: Superpolynomial
- Discrete-log, Running Time: Superpolynomial
- Pell's Equation, Running Time: Superpolynomial
- Principal Ideal, Running Time: Superpolynomial
- Unit Group, Running Time: Superpolynomial

- **Oracular Algorithms**
- Abelian Hidden Subgroup, Running Time: Superpolynomial
- Non-Abelian Hidden Subgroup, Running Time: Superpolynomial
- Bernstein-Vazirani, Running Time: Polynomial Directly, Superpolynomial Recursively
- Hidden Shift, Running Time: Superpolynomial
- Pattern matching, Running Time: Superpolynomial
- Linear Systems, Running Time: Superpolynomial

- **Approximation and Simulation Algorithms**
- Quantum Simulation, Running Time: Superpolynomial
- Knot Invariants, Running Time: Superpolynomial
- Partition Functions, Running Time: Superpolynomial
- Weight Enumerators, Running Time: Superpolynomial
- String Rewriting, Running Time: Superpolynomial
- Matrix Powers, Running Time: Superpolynomial

Quantum Algorithms III

- **Algebraic and Number Theoretic Algorithms**
- Class Group, Running Time: Superpolynomial
- Gauss Sums, Running Time: Superpolynomial
- Matrix Elements of Group Representations, Running Time: Superpolynomial
- Decoding, Running Time: Varies
- Quantum Cryptanalysis, Running Time: Various

- **Oracular Algorithms**
- Deutsch-Jozsa, Running Time: Exponential over P, none over BPP
- Polynomial interpolation, Running Time: Varies
- Welded Tree, Running Time: Superpolynomial
- Hidden Nonlinear Structures, Running Time: Superpolynomial
- Group Order and Membership, Running Time: Superpolynomial
- Group Isomorphism, Running Time: Superpolynomial
- Finite Rings and Ideals, Running Time: Superpolynomial
- Electrical Resistance, Running Time: Exponential
- Machine Learning, Running Time: Varies

- **Approximation and Simulation Algorithms**
- Three-manifold Invariants, Running Time: Superpolynomial
- Adiabatic Algorithms, Running Time: Unknown
- Quantum Approximate Optimization, Running Time: Superpolynomial
- Semidefinite Programming, Running Time: Superpolynomial
- Zeta Functions, Running Time: Superpolynomial

Programming I

- Python Fundamentals
- Python data structures
- Basic Python packages, numpy, pandas, scipy, matplotlib, seaborn
- IDEs - Jupyter notebook, Spyder, PyCharm
- Qiskit programming (Qiskit Terra), Aer, Ignis, Aqua, AI)

Programming II

- Python packages, scikit-learn, PyTorch

Programming III

- Python packages, Theano, Keras, TensorFlow

Qiskit I

- Qiskit Elements, Terra, Aer, Ignis etc.
- Installation, Workflow
- **Qiskit Terra**, Overview & Organization
- Circuits and Registers
- Elementary Operations, Single Qubit Quantum states, Single-Qubit Gates, Two-qubit gates
- Custom Gates, Opaque, Composite
- Visualizing a Quantum Circuit
- Executing Quantum Programs
- Plotting Data in Qiskit
- Tools for Monitoring Backends
- **Qiskit Aer**
- QasmSimulator
- Statevector Simulator
- **Qiskit Aqua**, Organisation and components
- Algorithms, Quantum Algorithms, Classical Reference Algorrithms
- Optimizers, Local and Global
- Initial States
- Feature Maps, 1st Order, 2nd Order
- Random Distributions, Univariate
- Eigenvalues
- Reciprocals
- Circuit Collection, C-Hadamard

Qiskit II

- **Qiskit Terra**
- Three-qubit gates
- Non unitary operations
- Custom Gates, Parameterized Gates
- Rewiring Circuits
- Terra Parallel Tools
- Using User Config FilesQiskit Aer
- **Qiskit Aer**
- Unitary Simulator
- Noise model
- **Qiskit Ignis**
- Organization, circuits, fitters, filters
- Characterization
- Measurement Calibration
- **Qiskit Aqua**
- Variational Forms
- Oracles
- Feature Maps, Pauli Expansions
- Multiclass Extensions
- Random Distributions, Multivariate
- Uncertainty Problems
- Circuit Collection
- **Qiskit AI**
- **Qiskit Optimization**

Qiskit III

- **Qiskit Ignis**
- Tomography
- Randomized Benchmarking
- Quantum Volume
- **Qiskit Aqua**
- Inverse Quantum Fourier Transforms
- Neural Networks
- Circuit Collection
- **Qiskit Chemistry**
- **Qiskit Finance**