TECHNO INDIA UNIVERSITY
WESTBENGAL

Detailed Syllabus for 2-Years M.Tech
in
Computational Mathematics

Department of Mathematics

TECHNO INDIA UNIVERSITY
WESTBENGAL

Techno India University, West Bengal

EM-4, EM Block, Sector V, Bidhannagar, Kolkata, West Bengal 700091

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M.Tech in Computational Mathematics

Course Curriculum

Semester I

Sl. No.	Course Code	Course Title	Contact Hrs./ Week			Credit	Page No.
			L	T	P		
Theory							
1	MCM101_TIU	Advanced Graph Theory	02	00	00	2	
2	MCM102_TIU	Advanced Algorithm	03	00	00	3	
3	MCM103_TIU	Multivariate Statistical Technique	02	00	00	2	
4	MCM104_TIU	Deep Learning & Artificial Neural Network	02	00	00	2	
5	MCM105_TIU	Computational Linear Algebra	02	00	00	2	
6	MCM106_TIU	Object Oriented Programming	02	00	00	2	
Practical							
1	MCM101L_TIU	Object Oriented Programming: LAB	00	00	02	2	
2	MCM102L_TIU	Deep Learning & Artificial Neural Network: LAB using Python	00	00	02	2	
Sessional							
1	MCM101S_TIU	Entrepreneurship Skill Development (ESD)	00	02	00	2	
2	MCM102S_TIU	Career Advancement & Skill Development (CASD)	02	00	00	2	
					Total Credit	**21**	

Semester II

Sl. No.	Course Code	Course Title	Contact Hrs./ Week			Credit	Page No.
			L	T	P		
Theory							
1	MCM201_TIU	Computational Geometry	03	00	00	3	
2	MCM202_TIU	Quantum Computing	03	00	00	3	
3	MCM203_TIU	Data Mining & Visualization	03	00	00	3	
4	MCM204_TIU	Analytical Number Theory	02	00	00	2	
5	MCM205_TIU	Concrete Mathematics	03	00	00	3	
Practical							
1	MCM201L_TIU	Data Mining & Visualization: LAB	00	00	02	2	
Sessional							
1	MCM201S_TIU	Entrepreneurship Skill Development (ESD)	00	02	00	2	
2	MCM202S_TIU	Career Advancement & Skill Development (CASD)	02	00	00	2	
					Total Credit	**20**	

Semester III

Sl. No.	Course Code	Course Title	Contact Hrs./ Week			Credit	Page No.
			L	T	P		
Theory							
1	MCM301_TIU	Industrial Project/ Entrepreneurial Project Phase 1	10	00	00	10	
Practical							
1	MCM301P_TIU	Internship	00	00	04	04	
					Total Credit	**14**	

Semester IV

Sl. No.	Course Code	Course Title	Contact Hrs./ Week			Credit	Page No.
			L	T	P		
Theory							
1	MCM401_TIU	Dissertation /Industrial Project/ Entrepreneurial Project Phase 2	12	00	00	12	
					Total Credit	**12**	

SEMESTER 1

ADVANCED GRAPH THEORY

SL. NO.	CONTENTS
1	Review of basic definitions and concepts of graph theory
2	Matchings and Factors: Maximum matchings, Hall's matching condition, min-max theorems, independent sets and covers, dominating sets, algorithms for maximum bipartite, weighted bipartite and stable matchings and their applications, matchings in general graphs, Tutte's 1- factor theorem, BergeTutte formula, Petersen's results regarding regular graphs and factors
3	Stable Sets and Cliques: Stable sets, stability and clique numbers, Shannon capacity, stable sets in digraphs, kernels Turan's theorem and its application to combinatorial geometry, Ramsey's theorem, Ramsey numbers and Ramsey graphs, bounds on Ramsey numbers, application of Ramsey's theorem to number theory, the regularity lemma, regular pairs and regular partitions, the Erdos- Stone theorem, linear Ramsey numbers.
4	Perfect Graphs:The perfect graph theorem, chordal graphs and other classes of perfect graphs, imperfect graphs, the strong perfect graph conjecture.
5	Matroids: Hereditary systems, properties of matroids, the span function, dual of a matroid, matroid minors and planar graphs, matroid intersection, union.
6	Eigen values of Graphs: Characteristic polynomial, eigen values and graph parameters, eigen values of regular graphs, eigen values and expanders, strongly regular graphs.

SUGGESTED READING:

- West, D. B."Introduction to Graph Theory", 2nd Ed. Pearson Education
- N. Deo , "Graph theory with applications to engineering and computer science"
- Bondy, J.A.and Murty, U. S. R.,"Graph theory", Springer
- Diestel, R.,"Graph Theory" 4th Ed., Springer
- Chartrand, G. and Zhang, P.,"Introduction to Graph Theory", Tata McGraw Hill
- Bela, B., "Modern Graph Theory", Springer

ADVANCED ALGORITHM

SL. NO.	CONTENTS
1	Data Structures: More Advanced Solutions to Basic Data Structuring Problems: Fibonacci Heaps. Van Emde Boas Priority Queues. Dynamic Data Structures for Graph Connectivity/Reachability. Bit Tricks: Word-level Parallelism. Transdichotomous Model. o(n \log n) Integer Sorting. String Algorithms: Rabin-Karp Fingerprinting Algorithm. Suffix Trees. Maximum Flows: Augmenting Paths and Push-Relabel Methods. Minimum Cost Flows. Bipartite Matching. Linear Programming: Formulation of Problems as Linear Programs. Duality. Simplex, Interior Point, and Ellipsoid Algorithms. Online Algorithms: Ski Rental. River Search Problem. Paging. The k-Server Problem. List Ordering and Move-to-Front. Approximation Algorithms: One Way of Coping with NP-Hardness. Greedy Approximation Algorithms. Dynamic Programming and Weakly Polynomial-Time Algorithms. Linear Programming Relaxations. Randomized Rounding. Vertex Cover, Wiring, and TSP. Fixed-Parameter Algorithms: Another Way of Coping with NP-Hardness. Parameterized Complexity. Kernelization. Vertex Cover. Connections to Approximation. Parallel Algorithms: PRAM. Pointer Jumping and Parallel Prefix. Tree Contraction. Divide and Conquer. Randomized Symmetry Breaking. Maximal Independent Set. External-Memory Algorithms: Accounting for the Cost of Accessing Data from Slow Memory. Sorting. B-trees. Buffer Trees. Cache-oblivious Algorithms for Matrix Multiplication and Binary Search. Computational Geometry: Convex Hull. Line-segment Intersection. Sweep Lines. Voronoi Diagrams. Range Trees. Seidel's Low-dimensional LP Algorithm. Streaming Algorithms: Sketching. Distinct and Frequent Elements.

SUGGESTED READING:

- Thomas H. Cormen, Charles E. Leiserson, R.L. Rivest.. “Introduction to Algorithms”, Prentice Hall of India Publications.
- “Algorithm Design”, Kleinberg and Tardos, Pearson
- Merc De-Berg eta al. “Computational Geometry: Algorithms and Applications”, 3rd Edition, Springer
- Sara Baase and Allen Van Gelder. “Computer Algorithms: Introduction to Design and Analysis”, Pearson education (Singapore) Pvt. Ltd, New Delhi, 2007.
- Alfred V. Aho, John E. Hopcroft, Jeffrey D. Ullman.. “The Design and Analysis of Computer Algorithms”, Pearson Education (Singapore) 2006.
- “Algorithmics: Theory and Practice”, Brassard and Bratley, Prentice Hall

MULTIVARIATE STATISTICAL TECHNIQUE

SL. NO	CONTENTS
1	Definitions and basic concepts of multivariate modelling – variate, type of variables, measurement scale, measurement error, multivariate measurement; types of multivariate techniques, classification of multivariate techniques, guidelines for multivariate analysis, structured approach to multivariate model building, and cases for multivariate modelling.
2	Multivariate basics – multivariate descriptive statistics, statistical distance, multivariate normal distribution and its properties, examining data and outliers detection, and multivariate sampling distributions. Comparison of several multivariate means – paired comparisons.
3	Multivariate modelling of variance (MANOVA) – Univariate procedure, objectives, design issues and assumptions, estimation of MANOVA model, goodness of fit, interpretation of results, validations, and case examples.
4	Multiple linear regressions - Objectives, design and assumptions, estimating the regression model and assessing overall model fit, interpreting the regressing variate, validation of results, stepwise and hierarchical regression, and case examples.
5	Principal component analysis – Objectives, population principal components, method of estimation, interpretation of components, and case examples. Discriminant analysis – Objective, design and assumptions, estimating discriminant model and assessing overall fit, results and validations, case examples.
6	Factor analysis - Objectives, design issues and assumptions, orthogonal factor model, method of estimation, principal component analysis, maximum likelihood method, factor rotation, factor scores, interpretation of factors, and case examples.
7	Path Analysis and Structural equation modelling – Developing modelling strategy, confirmatory and competing models, stages in structural equation modelling, developing a theoretically based model, constructing path diagram, converting path diagram to structural equations, input matrix, measurement model, LISREL, goodness of fit criteria, and case examples. Hand on experience through EXCEL, MATLAB and SPSS.

SUGGESTED READING:

- Johnson R.A. and Wichern D.W., “Applied Multivariate Statistical Analysis”, Pearson Education, Delhi, 2002, 767 pp.
- Hair J.F., Anderson R.E., Tatham R.L., Black W.C., “Multivariate data analysis with readings”, Prentice Hall, Englewood Cliffs, New Jersey 07632, 1995, 745 pp.
- Agresti A. “Analysis of ordinal categorical data”, John Wiley & Sons, New York, 1984, 287 pp.

DEEP LEARNING & ARTIFICIAL NEURAL NETWORK

SL. NO	CONTENTS
1	Introduction to Deep Learning: History of DL, DL vs. ML, Types of Learning (supervised, unsupervised, semi, weak, self, etc.). Linear Classifiers, Linear Machines with Hinge Loss. Optimization Techniques, Gradient Descent, Batch Optimization. Introduction to Neural Network, Multilayer Perceptron, Back Propagation Learning. Unsupervised Learning with Deep Network. Convolutional Neural Network, building blocks of CNN (activation, normalization, pooling, padding), Transfer Learning, hyper-parameter tunning, Revisiting Gradient Descent, Momentum Optimizer, RMSProp, Adam optimizer. Effective training in Deep Net- early stopping, Dropout, Batch Normalization, Instance Normalization, Group Normalization. Recent Trends in Deep Learning Architectures, Residual Network, Skip Connection Network, Fully Connected CNN, LSTM, Autoencoders, Transformers, Multi-branch CNN, Generative Networks (GAN), Recurrent Neural Nets (RNN), GRU, complex models. Classical Supervised Tasks with Deep Learning, Image Denoising, Semantic Segmentation, Object Detection, Anomaly Detection, Object tracking, optical flow estimation, etc. LSTM Networks, Generative Modeling with DL, Variational Autoencoder, Generative Adversarial Network Revisiting Gradient Descent, Momentum Optimizer. Natural language processing: word embeddings, sentiment analysis.

SUGGESTED READING:

- "Deep Learning", Ian Goodfelllow, Yoshua Benjio, Aaron Courville, The MIT Press, 2016.
- "Deep Learning", Andrew W. Trask, Manning Publications, 2019.
- "Pattern Classification", David G. Stork, Peter E. Hart, and Richard O. Duda, 2nd Edition, Wiley, 1973.
- "Pattern Recognition", Theodoridis, S. and Koutroumbas, K. Edition 4. Academic Press, 2008

COMPUTATIONAL LINEAR ALGEBRA

SL. NO	CONTENTS
1	Prerequisite: Linear Algebra Basic concepts, floating point numbers and errors in computation, stability of algorithms and conditioning of problems. Numerical solutions of linear systems, direct methods - Gaussian elimination with pivotal condensation, operational count and error bound. LU factorization, QR factorization, condition number and ill conditioned systems, matrix and vector norms, error bounds, Wilkinsons algorithm for ill-conditioned systems, iterative methods - Jacobi, Gauss-Seidel, SOR. Convergence and rate of convergence, conjugate gradient method, Arnoldi process and GMRES, large sparse systems, matrix inverse, generalized inverse. Least squares solution of linear systems, numerical eigenvalue problems, computation of eigenvalues and eigenvectors, singular value decomposition and least squares problem, SVD and the pseudo inverse, Jacobi, Givens and Householders methods for symmetric matrices, Hessenberg QR iteration.

SUGGESTED READING:

- Wendland, Holger. “Numerical linear algebra. An introduction”, Cambridge Texts in Applied Mathematics. Cambridge University Press, Cambridge, 2018. x+408 pp.
- Watkins, David S. “Fundamentals of matrix computations”, Third edition. Pure and Applied Mathematics (Hoboken). John Wiley & Sons, Inc., Hoboken, NJ, 2010.
- Datta, Biswa Nath. “Numerical linear algebra and applications”, Second edition. Society for Industrial and Applied Mathematics (SIAM), Philadelphia, PA, 2010
- Ipsen, Ilse C. F. “Numerical matrix analysis. Linear systems and least squares”, Society for Industrial and Applied Mathematics (SIAM), Philadelphia, PA, 2009.
- Saad, Yousef . “Iterative methods for sparse linear systems”, Second edition. Society for Industrial and Applied Mathematics, Philadelphia, PA, 2003

OBJECT ORIENTED PROGRAMMING

SL. NO	CONTENTS
1	Object Oriented Programming and languages: fundamentals, necessity and advantages, Objects and Classes, Encapsulation. Data and method binding, access specification: private, protected and public.
2	Inheritance: passing knowledge down. single versus multiple inheritance, sub and super classes. Code reuse, inheritance and subtyping
3	Polymorphism: Simple (or static) polymorphism (in C++), method overloading, subtype polymorphism (extending a class) through method overriding, 'virtual' methods (in C++) and distinction with nonvirtual ones, abstraction through polymorphism, 'abstract' classes and methods, 'pure' virtual functions in C++.
4	Interfaces: OOPLs allowing interfaces (like Java), interfaces versus multiple inheritance. Exception Handling: the 'try-catch-throw-finally' paradigm, catching and throwing errors, ensuring cleaning up using 'finally', exception classes and their hierarchy, error handling as a built-in feature (as in Java), exception specification, the 'throws' keyword and compiler behavior.
5	Templates: Introduction, simple generic classes & generic function, simple example programs. STLList, Vector, Array.

SUGGESTED READING:

- Herbert Schildt, “The complete Reference C++”
- E.Balagurusamy, “OBJECT ORIENTED PROGRAMMING WITH C+”

SEMESTER 2

COMPUTATIONAL GEOMETRY

SL. NO.	CONTENTS
1	Introduction to computational geometry, Applications of computational geometry, Convex hulls in 2D and 3D, Lower bounds, Triangulations: introduction, Polygon triangulations, Triangulation representations, Point-set triangulations, Planar graphs
2	Voronoi diagrams: construction, Voronoi diagrams: applications and variants, Delaunay triangulations: divide-and-conquer, flip and incremental algorithms, Case studies on flip and incremental methods, Duality of Voronoi diagrams: introduction and case studies, Min–max angle properties
3	Geometric searching: point location, Fractional cascading, Linear programming with prune-and-search, Finger trees and concatenable queues, Segment trees and interval trees, Visibility: weak and strong visibility algorithms, Visibility with reflections, Art-gallery problems
4	Arrangements of lines and hyperplanes, Zone theorems, Many-faces complexity and algorithms, Zone theorem case studies, Combinatorial geometry: Ham-sandwich cuts
5	Sweep techniques: plane sweep for segment intersections, Fortune's sweep for Voronoi diagrams, Topological sweep for line arrangements, Randomization in computational geometry: algorithms and counting techniques, Randomization examples, Robust geometric computing and examples, Applications and case studies in computational geometry

SUGGESTED READING:

- Mark de Berg, Otfried Cheong, Marc van Kreveld, Mark Overmars, "Computational Geometry: Algorithms and Applications (Springer)"
- Franco P. Preparata, Michael Ian Shamos, "Computational Geometry: An Introduction (Springer)"
- Kurt Mehlhorn, "Data Structures and Algorithms 3: Multi-dimensional Searching and Computational Geometry (Springer)"

QUANTUM COMPUTING

SL. NO.	CONTENTS
1	Brief review of linear algebra and probability preliminaries. Basic notions: Qubits, Dirac's notation, operations on qubits, unitary operators and matrix representations. Single qubit gates - Hadamard, Rotation, NOT and Phase gates. Multi-qubit gates – CNOT, Toffoli. SWAP test. Quantum circuits, Church-Turing hypothesis and extensions, Universality of quantum circuits No cloning theorem, Relation to probabilistic computation, Bell pair, EPR paradox Quantum Oracles, Quantum algorithms for promise problems: Deutsch-Jozsa, Bernstein-Vazirani and Simon Phase estimation, Eigenvalue estimation and Quantum Fourier Transforms. Searching in an unstructured database: Grover search – geometric and diffusion views. Quantum walks. Optimality of Grover search. Shor's algorithm for factoring. Order finding, Period finding, Reductions. Quantum algorithms for hidden subgroup, element distinctness, collision detection and triangle counting problems. Lower bounds. Adversary method, polynomial method, quantum query complexity Quantum Complexity Theory. Complexity class BQP and its connections to classical computation.

SUGGESTED READING:

- "Quantum Computation and Quantum Information" , Michael A. Nielsen and Isaac L. Chuang
- "An Introduction to Quantum Computing", Phillip Kaye, Raymond Laflamme and Michele Mosca
- "Quantum Algorithms via Linear Algebra: *A Primer*", Richard J. Lipton and Kenneth W. Regan

DATA MINING & VISUALIZATION

SL. NO.	CONTENTS
1	Transaction Processing: Consistency, Atomicity, Isolation and Durability, Serializable Schedule, Recoverable Schedule, Concurrency Control, Time-stamp based protocols, Isolation Levels, Online Analytical Processing . Database performance Tuning and Query optimization: Query Tree, Cost of Query, Join, Selection and Projection Implementation Algorithms and Optimization. Database Security: Access Control, MAC, RBAC, Authorization, SQL Injection Attacks. Data Mining: stages and techniques, knowledge representation methods, data mining approaches (OLAP, DBMS, Statistics and ML) . Data warehousing: data warehouse and DBMS, multidimensional data model, OLAP operations. Data processing: cleaning, transformation, reduction, filters and discretization with weka. Knowledge representation: background knowledge, representing input data and output knowledge, visualization techniques and experiments with weka, Ontologies and knowledge graph. Mining real data: preprocessing data from a real medical domain, data mining techniques to create a comprehensive and accurate model of data. Parallel Databases: Avenues for parallelism: I/O parallelism, interquery, interquery and intra operation parallelism, databases for multi-core machines. Distributed Databases: Distributed data storage, distributed transactions, commit protocols, concurrency control in distributed databases, heterogeneous and cloud-based databases. Information Retrieval: relevance ranking using terms and hyperlinks,page rank, indexing of documents, measuring retrieval effectiveness.XML and semi-structured data: necessity, XML document schema, querying: XPath and XQuery languages, applications.Advanced topics: text mining, text classification, web mining, data mining software.

SUGGESTED READING:

- Michael Steinbach, Pang-Ning Tan, and Vipin Kumar. “Introduction to Data Mining”, Pearson Education
- P. Valduriez, M. TamerOzsu. “Principles of Distributed Database Systems”, Prentice Hall
- Bing Liu. “Web Data Mining: Exploring” Hyperlinks, Contents, and Usage Data, Springer-Verlag Berlin and Heidelberg GmbH & Co. K

ANALYTICAL NUMBER THEORY

SL. NO.	CONTENTS
1	Review of complex analysis: Basic results, Fourier transform, Mellin transform. Review of Abel partial summation and the Euler-Maclaurin summation formula.
2	Arithmetic functions, Averages of arithmetical functions, Distribution of primes, finite abelian groups and characters, Gauss sums, Dirichlet series and Euler products, Riemann Zeta function, Dirichlet L-functions, Analytic proof of the prime number theorem, Dirichlet Theorem on primes in arithmetic progression.
3	Modular forms for the full modular group, Eisenstein series, cusp forms, structure of the ring of modular forms, Hecke operators and Euler product for modular forms.
4	The L-function of a modular form, functional equations, Modular forms and the sums of four squares

SUGGESTED READING:

- T. Apostol, “Introduction to analytic number theory”, SpringerVerlag. 1991
- T Lang, “Algebric Number Theory”
- J.P. Serre, “A course in arithmetic”, SpringerVerlag. 2012
- I., Henryk and E. Kowalski, “Analytic number theory”, Providence, RI: American mathematical society. 2004
- N. Koblitz, “Introduction to elliptic curves and modular forms”, Springer. 1993
- W. Stein, “Modular Forms, a computational approach”, American mathematical society.

CONCRETE MATHEMATICS

SL. NO	CONTENTS
1	Foundations: Review of mathematical induction, sums and recurrences, asymptotic notation, Basic summation formulas, binomial coefficients, binomial theorem, harmonic numbers, generating functions.
2	Integer Functions: Floor and ceiling functions, modular arithmetic, greatest common divisor, number-theoretic functions, Möbius inversion.
3	Recurrences: Linear recurrences, divide-and-conquer recurrences, methods of solution, applications in algorithms.
4	Generating Functions: Ordinary and exponential generating functions, applications to combinatorial enumeration, convolution. Discrete Probability: Discrete distributions, expected value, variance, probabilistic methods in combinatorics.
5	Advanced Topics: Asymptotics, Euler–Maclaurin summation formula, applications to computational mathematics,

SUGGESTED READING:

- Graham, R. L., Knuth, D. E., Patashnik, O., “Concrete Mathematics: A Foundation for Computer Science”, Addison-Wesley.
- Stanley, R. P., “Enumerative Combinatorics”, Vol. 1, Cambridge University Press.
- Rosen, K. H., “Discrete Mathematics and Its Applications”, McGraw Hill.
- Mitzenmacher, M., Upfal, E., “Probability and Computing: Randomized Algorithms and Probabilistic Analysis”, Cambridge University Press.