Semester-wise Pattern for Students Admitted to B.E. Mathematics and Computing Programme									
Year	**First Semester**			**U**	**Second Semester**			**U**
I	BITS	F110	Engineering Graphics	2	BITS	F111	Thermodynamics	3
	BIO	F110	Biology Laboratory	1	BITS	F112	Technical Report Writing	2
	BIO	F111	General Biology	3	CS	F111	Computer Programming	4
	CHEM	F110	Chemistry Laboratory	1	EEE	F111	Electrical Sciences	3
	CHEM	F111	General Chemistry	3	MATH	F112	Mathematics II	3
	MATH	F111	Mathematics I	3	MATH	F113	Probability and Statistics	3
	PHY	F110	Physics Laboratory	1	ME	F112	Workshop Practice	2
	PHY	F111	Mechanics, Oscillations and Waves	3				
				17				**20**
II	MATH	F211	Mathematics III	3	ECON	F211	Principles of Economics	3
	MAC	F211	Linear Algebra and Applications	3			or	or
	MAC	F212	Object Oriented Programming	4	MGTS	F211	Principles of Management	3
	MAC	F213	Discrete Mathematics	3	MAC	F241	Numerical Analysis	3
	MAC	F214	Elementary Real Analysis	3	MAC	F242	Data Structures & Algorithms	4
	BITS	F225	Environmental Studies	3	MAC	F243	Numerical Optimization	3
			Humanities Electives	3(min)	MAC	F244	Stochastic Calculus and Application to Finance	3
					MAC	F245	Scientific Computing Laboratory	1
				22(min)				**17(min)**
Summer	**BITS F221 Practice School – I (for PS Option Only)**							
III	MAC	F311	Algebra I	3	MAC	F341	Design and Analysis of Algorithms	3
	MAC	F312	Foundations of Data Science	3	MAC	F342	Computational Partial Differential Equations	4
	MAC	F313	Statistical Data Analysis	4			Discipline Electives	6
	MAC	F314	Mathematical Modelling	4			Humanities Electives	2
			Discipline Electives	3			Open Elective	3
			Humanities Electives	3				
				20(min)				**18(min)**
IV			Open Electives	12	BITS	F412	Practice School-II	20
			Discipline Electives	3(min)			or	or
					BITS	F421T	Thesis	16
							or	
							Thesis (9) and Electives (6 to 9)	15 to18
				15(min)				**15/20**

DISCIPLINE ELECTIVE COURSES

Course Code	Course Title	L	P	U
BITS F311	Image Processing	3	0	3
BITS F316	Nonlinear Dynamics and Chaos	3	0	3
BITS F386	Quantum Information and Computation	3	0	3
BITS F463	Cryptography	3	0	3
BITS F464	Machine Learning	3	0	3
CS F212	Database Systems	3	1	4
CS F402	Computational Geometry	3	0	3
CS F407	Artificial Intelligence	3	0	3
CS F415	Data Mining	3	0	3
CS F422	Parallel Computing	3	0	3
CS F425	Deep Learning	3	0	3
CS F426	Graph Mining	3	1	4
CS G513	Network Security	3	1	4
ECON F354	Derivatives and Risk Management	3	0	3
IS F311	Computer Graphics	3	0	3
MAC F266	Study Project			3
MAC F366	Laboratory Project			3
MAC F367	Laboratory Project			3
MAC F376	Design Project			3
MAC F377	Design Project			3
MAC F411	Computation of Option Pricing Models	3	1	4
MAC F491	Special Project			3
MATH F243	Graphs and Networks	3	0	3
MATH F315	Introduction to Statistical Inference	3	0	3
MATH F424	Applied Stochastic Process	3	1	4
MATH F425	Numerical Linear Algebra	3	1	4
MATH F426	Mathematical Theory of Finite Element Methods	3	1	4
MATH F428	Time Series Analysis and Forecasting	3	1	4

BE (Mathematics and Computing)

MAC F211 Linear Algebra and Its Applications **3 0 3**

Quick Review of Vector Spaces and Linear Transformations: Basis and dimension, rank-nullity theorem, change of basis; Inner product spaces: Cauchy Schwarz's inequality, Orthonormal basis, Gram-Schmidt orthonormalization, QR decomposition, orthogonal projection with projection theorem, General Least-squares problem, Discrete Fourier Transform; Norms of vectors, functions, and matrices, matrix decompositions; Eigenvalues and eigenvectors, Diagonalization, Spectral Theorem, Cayley-Hamilton Theorem, Primary Decomposition theorem, Jordan canonical forms (without proof); Singular value decomposition and applications: Reduced SVD, norms, condition number, and Rank via SVD, Moore-Penrose inverse, Principal Component Analysis, and Lowrank approximations, least-squares solutions to linear systems.

Pre-requisites: MATH F112: Mathematics II

MAC F212 Object Oriented Programming **3 1 4**

Object orientation concepts, theories, and principles; fundamental concepts of the object model: classes, objects, methods and messages, encapsulation and inheritance, interface and implementation, reuse and extension of classes, inheritance, and polymorphism; overloading and overriding; static and dynamic binding; multithreaded programming; event handling and exception handling; the process of object-oriented requirements specification, analysis, and design; notations for objectoriented analysis and design; case studies and applications using some object-oriented programming languages. Object Oriented Design Patterns: Behavioral, Structural, and Creational.

Equivalent: CS F213/IS F213: Object Oriented Programming

MAC F213 Discrete Mathematics **3 0 3**

Set theory: Sets, relations and functions, equivalence relations, partially ordered sets, countability of sets, lattices and Boolean algebras; Logic and Methods of Proof: Propositional logic, language of propositional logic, predicate logic and logical inference with quantifiers, introduction to different standard proof techniques; Combinatorics: Counting techniques: pigeon hole principle, inclusion-exclusion principle, recurrence relation, and generating function, partitions, special numbers like Fibonacci, Stirling, and Catalan numbers (Just an introduction). Graph Theory: Graphs and digraphs, special types of graphs, trees, isomorphism, connectedness, Euler and Hamilton graphs, planar graphs, Graph Laplacian; graph colouring.

Equivalent: MATH F213: Discrete Mathematics

MAC F214 Elementary Real Analysis **3 0 3**

Countability and uncountability of sets; real numbers; limits and continuity; compactness and connectedness in a metric space; Riemann integration; uniform convergence.

Equivalent: MATH F214: Elementary Real Analysis

MAC F241 Numerical Analysis **3 0 3**

Principles of floating point computations and rounding errors; Systems of Linear Equations: factorization methods, pivoting and scaling, residual error correction method; Iterative methods: Jacobi, Gauss-Seidel methods with convergence analysis; Eigenvalue problems: algorithms with implementation issues; Nonlinear algebraic equation: root finding (bisection, secant, fixed point iteration and Newton-Raphson methods), nonlinear algebraic system (Fixed point iteration, Newton and Newton like methods); Interpolation: Lagrange interpolation techniques, piecewise linear and cubic splines, error estimates; Approximation: uniform approximation by polynomials, data fitting and least squares approximation; Numerical Integration: integration by interpolation, adaptive quadratures and Gauss methods; Initial Value Problems for Ordinary Differential Equations: Euler's method, single step Runge-Kutta methods, multi-step methods, predictor and corrector scheme, stability and convergence analysis. FDM for Two point BVP.

Equivalent: MATH F313: Numerical Analysis

MAC F242 Data Structures & Algorithms **3 1 4**

Introduction to Abstract Data Types, Data Structures and Algorithms; Analysis of Algorithms, Time and Space Complexity, Complexity Notation, Solving Recurrence Relations.; Divide-and Conquer as a Design Technique; Recursion – Recursive Data Types, Design of Recursive Functions / Procedures, Tail Recursion, Conversion of Recursive Functions to Iterative Form. Linear data structures – Lists, Access Restricted Lists (Stacks and Queues); Searching and Order Queries. Sorting – Sorting Algorithms (Online vs. Offline, Inmemory vs. External, In-space vs. Out-of-space, Quick Sort and Randomization), Lower Bound on Complexity of Sorting Algorithms. Unordered Collections: Hash tables (Separate Chaining vs. Open Addressing, Probing, Rehashing). Binary Trees – Tree Traversals. Partially Ordered Collections: Search Trees and Height Balanced Search Trees, Heaps, and Priority Queues. Probabilistic/Randomized Data Structures (such as Bloom Filters and Splay Trees). Generalized Trees – Traversals and Applications. Text Processing – Basic Algorithms and Data Structures (e.g. Tries, Huffman Coding, String search/pattern matching). External Memory Data Structures (B-Trees and variants). Graphs and Graph Algorithms: Representation schemes, Problems on Directed Graphs (Reachability and Strong Connectivity, Traversals, Transitive Closure. Directed Acyclic Graphs - Topological Sorting), Problems on Weighted Graphs (Shortest Paths. Spanning Trees).

Equivalent: CS F211: Data Structures & Algorithms

MAC F243 Numerical Optimization **3 0 3**

Review of Several Variable Calculus: Directional Derivatives, Gradient and Hessian, Taylor‘s theorem; Unconstrained optimization using calculus: minima and maxima, feasible directions, Convex functions, Coercive functions; Unconstrained optimization via iterative methods: Line search method, Newton‘s method, Gradient/conjugate gradientbased methods, Quasi-Newton methods; Constrained optimization: Penalty methods, Lagrange multipliers, Karush-Kuhn-Tucker conditions, Quadratic programming; Linear programming (LP): Formulation of LP, Theorems dealing with vertices of feasible regions and optimality, Graphical solution; Simplex and revised simplex method, Duality theory.

Pre-requisites: MATH F112: Mathematics II

Note: Those who have done MATH F471 are not allowed to take this course.

MAC F244 Stochastic Calculus & Application to Finance **3 0 3**

Overview of financial markets, derivative securities, discrete-time binomial model, arbitrage, hedging and replicating portfolios, riskneutral probabilities and pricing formula, market completeness, concept of probability as measure, filtering, etc., stochastic processes, conditional expectation, martingales, Markov processes, Brownian motion and quadratic variation, Ito’s integral and calculus, replicating portfolios and hedging in continuous time, Black-Scholes-Merton formulae, change of measure, Girsanov's theorem, risk-neutral pricing pricing and existence of risk-neutral measure, market completeness and uniqueness of riskneutral measure, Markov property, Feyman-Kac theorem, local volatility and stochastic volatility models.

Pre-requisites: MATH F113: Probability and Statistics *OR* MATH F211: MATHEMATICS-III *OR* MATH F214: Elementary Real Analysis

MAC F245 Scientific Computing Laboratory **0 1 1**

Introduction to MATLAB

<u>Related to Numerical Analysis</u>

Computational implementations of linear algebraic system: Gauss elimination, LU, Cholesky, QR decompositions; Iterative algorithms and their implementation; Least Square Method and SVD. Root finding algorithm; System of Nonlinear algebraic equations: one point iterative method and Newton’s method; Piecewise Interpolations; Implementation of numerical quadrature’s; Numerical implementations of ODEs.

<u>Related to Numerical Optimization</u>

Computational tools for optimization: Simplex algorithms, Newton’s methods, Nonlinear optimization: Line search method, Newton‘s method, Gradient/conjugate gradient algorithms, Quasi-Newton methods, Penalty methods; Quadratic programming; Simplex and revised simplex methods.

MAC F311 Algebra I **3 0 3**

Groups, subgroups, a counting principle, normal subgroups, and quotient groups, Cayley’s theorem, automorphisms, permutation groups, Sylow’s theorems, Rings, ring of real quaternions, ideals and quotient rings, homomorphisms, Euclidean rings, polynomial rings, and polynomials over the rational field.

Equivalent: MATH F215: Algebra I

MAC F312 Foundations of Data Science **3 0 3**

Introduction to Data Science, Review of Probability, Random Variables and Probability Distributions, Bayesian probabilities, Conditional Gaussian distributions, Marginal Gaussian distributions, Bayes' theorem for Gaussian variables, Maximum likelihood and Bayesian Inference for the Gaussian, Mixtures of Gaussians, Probability Bounds, Nonparametric Methods – Kernel density estimators, Nearest-neighbour methods, Bayesian Curve Fitting, Introduction to constrained and unconstrained optimization, High Dimensional Data & Curse of Dimensionality, Dimensionality Reduction, PCA & SVD, Data Visualization Techniques, OLAP and Multidimensional Data Analysis, Data Pre-processing, Big Data and Big Data Analytics, and Social Media data.

Equivalent: CS F320: Foundations of Data Science

3 1 4

MAC F313 Statistical Data Analysis

Graphical Representation of one- and two-dimensional data; simulation from common distributions including binomial, Poisson, normal, gamma exponential; inverse transform and acceptance-rejection method; goodness of fit tests; tests for independence; simple linear regression and least squares, MLE for regression, residual analysis; multiple linear regression, and variable selection; Generalized linear models, classification, logistic regression, LDA, QDA; Monte-Carlo simulation and integration; Bayes' theorem and Bayesian learning, Frequentist versus Bayesian and simple implementation.

<u>Lab Component</u>: Introduction to R programming and Implementations of algorithms discussed in this course.

Pre-requisites: MATH F113: Probability and Statistics

MAC F314 Mathematical Modelling **3 1 4**

Review of ODEs: local existence, uniqueness results (without proof), Gronwall's inequality, continuation of solution (without proof),equilibrium points, linearised stability, phase-plane analysis and Liapunov stability (without proof); Mathematical Modelling: Principle of modelling, Dimensional analysis and scaling; Discrete Models: basic theory of difference equations (steady state, stability and critical parameters), Difference Equations applied to Biological models (Cell division and insect population, single population), two species interactions, Nicholson Baily model; Modeling through ODEs of firstorder: growth and decay models, compartment models; Modeling through systems of ODEs: bacterial growth in Chemostat, Glucose-Insulin Kinetics, Pray-Predator systems, SIR model, Hodgkin-Huxley nerve conduction model, Fitzhugh-Nagumo model of for Neural Impulses with analysis (limit cycle, oscillations); Modelling through PDEs: basics of modelling (conservation principles), diffusion based population dispersal model, Chemostatic motion of micro-organisms.*Lab*

<u>Component</u>: Group projects on Case Studies.

Equivalent: MATH F420: Mathematical Modeling

Pre-requisites: MATH F211: MATHEMATICS-III

MAC F341 Design and Analysis of Algorithms **3 0 3**

Basic Design Techniques – Divide-and-Conquer, Greedy, Dynamic Programming (Examples, Analysis, General Structure of Solutions, Limitations and Applicability). Specialized Design Techniques: Network Flow, Randomization (Examples, Analysis, Limitations). Complexity Classes and Hardness of Problems – P, NP, Reductions, NP-hardness and NP-Completeness, Reduction Techniques, Basic NP-complete problems. Design Techniques for Hard Problems – Backtracking, Branch-and-Bound, and Approximation (General approaches and structure of solution, Analysis, and Limitations). Linear Programming – LP Problem and Simplex Algorithm, Approach for using LP for modeling and solving problems. Introduction to Design and Analysis of Parallel and Multi-threaded Algorithms.

Equivalent: CS F364: Design and Analysis of Algorithms

MAC F342 Computational Partial Differential Equations **3 1 4**

Review of linear PDEs: First order linear scalar equation and explicit solution by characteristic method; Classification of 2nd order linear PDEs and maximum principle for Laplace and heat equations.

Finite differences: Grids, Finite-difference approximations to derivatives. Linear Transport Equation: Upwind, Lax-Wendroff and Lax-Friedrich schemes,von-Neumann stability analysis, CFL condition, Lax-Richtmyer equivalence theorem ; . Heat Equation: Initial and boundary value problems (Dirichlet and Neumann), Explicit and implicit methods (Backward Euler and Crank-Nicolson schemes) with consistency and stability, Discrete maximum principle, Convergence ; Poisson's Equation: Finite difference scheme for boundary value problems, Discrete maximum principle, Iterative methods for linear systems (Jacobi, GaussSeidel, SOR methods and Conjugate Gradient method), PeacemanRachford algorithm (ADI) for linear systems. Wave Equation: Explicit schemes and their stability analysis.

Lab Component: Implementation of algorithms discussed in this course

Equivalent: MATH F422: Numerical Methodology for Partial Differential Equations

MAC F411 Computation of Option Pricing Models **3 1 4**

Review of financial market and options: arbitrage, options (European option, american option), interest rate and present value, random nature of stock markets and simple asset price model, Ito Lemma (without proof) and elimination of randomness; Basic Option theory: value of option, put-call parity; Black-Scholes PDE: European option, on dividend paying assets, American options, Hedging and implied volatility; Explicit Solution of Black Scholes equation; American option as free boundary problem and formulation as variational inequality; Finite Difference methods for European options: Explicit Scheme with stability, convergence and probabilistic interpretation, implicit schemes (backward Euler, Crank-Nicolson scheme with stability and convergence; FDM for American options with projected SOR and convergence; pricing of Exotic options; Monte-Carlo for option valuation.

Lab Component: Implementation of European, American, and exotic options. Monte-Carlo Simulation.

MAC F266 Study Project **3**

These courses include projects which are oriented towards readings from published literature or books about new frontiers of development or analysis of available database. These courses are normally available to students in second or higher levels. These courses must coterminate with project reports.

MAC F366 Laboratory Project **3**

MAC F367 Laboratory Project **3**

These courses include projects involving laboratory investigation or laboratory development in the student's discipline or interdisciplinary areas. These courses are normally available to students in third or higher levels. These courses must coterminate with project reports.

MAC F376 Design Project **3**

MAC F377 Design Project **3**

These courses are intended to impart training in design of product/ process or other artifact to the students in the discipline or interdisciplinary areas. These courses are normally available to students in third or higher levels. These courses must coterminate with project reports.

MAC F491 Special Project **3**

BITS F311 Image Processing **3 0 3**

Introduction to Image Processing and Imaging systems, Image sampling, Transforms, Enhancement and Restoration, Coding and Communications, Image Compression, Image understanding, Neural network and PR Approaches.

BITS F316 Nonlinear Dynamics and Chaos **3 0 3**

Chaos – definitions, characteristics, and measures; Examples of chaotic systems; Nonlinear dynamics and chaos – state space, Poincare sections, Iterated maps, Period-doubling; Quasi-periodicity, Intermittency, fractals; computer simulations of chaotic systems; Selected topics and applications of chaos theory; Examples will be drawn from different disciplines in science, engineering, and social sciences.

BITS F386 Quantum Information and Computation **3 0 3**

History and scope, introduction to quantum information, quantum bits (qubits), quantum parallelism, teleportation etc. Basic ideas of quantum systems, two-state systems, evolution of states, superposition, entanglement, quantum measurement, decoherence. Basic ideas of computation theories and models, computational resources, complexity. Quantum Gates: single qubit, multiple qubit gates, controlled gates, universal gates, measurement. Quantum algorithms, Deutsch', Shor's and Grover's Algorithms, quantum circuits. Quantum Fourier Transform and applications, Quantum Search Algorithm. Physical Implementation of quantum computation. Compression and transmission of quantum information, quantum noise, error-correction, coding and cryptography, complexity, fault-tolerant computation.

BITS F463 Cryptography **3 0 3**

Objectives of cryptography; ciphers – block and stream; mathematical foundations – modular arithmetic, finite fields, discrete logarithm, primality algorithms; RSA; digital signatures; interactive proofs; zero–knowledge proofs; probabilistic algorithms; pseudo-randomness.

BITS F464 Machine Learning **3 0 3**

Neural networks; neuro-computing theory and applications, knowledge representation; computational learning theory; statistical/probabilistic methods, genetic algorithms; in ductive/analytic/reinforcement learning and bayesian networks; selected topics such as alpha-beta pruning in game trees, computer models of mathematical reasoning, natural language understanding and philosophical implications.

CS F212 Database Systems **3 1 4**

Data modeling, database design theory, data definition and manipulation languages, relational data model, relational algebra and relational calculus, SQL, functional dependencies and normalization, storage and indexing techniques, query processing and optimization, transaction management - concurrency control and crash recovery; distributed databases.

CS F402 Computational Geometry **3 0 3**

Introduction to Computational Geometry, degeneracies and robustness, convex hull in 2D, line-segment intersection, doubly-connected edge list, computing the overlay of two subdivisions, art gallery theorem, guarding and triangulation, monotone polygons, partitioning arbitrary polygon into monotone polygons, triangulating a monotone polygon, range search problem, Kd- trees, range trees, fractional cascading, point location problem, trapezoidal maps, randomized incremental algorithm to compute trapezoidal map, post-office problem, Voronoi diagram and its properties, Algorithm to compute Voronoi diagram, Delaunay triangulation and relation with Voronoi diagram, Computing Delaunay triangulation, line and point duality, arrangement of lines, application of computational geometry.

CS F407 Artificial Intelligence **3 0 3**

The object of this course is to give an introduction to the problems and techniques of A.I. along with the applications of A.I. techniques to the fields like natural language understanding, image processing, game theory and problem solving.

CS F415 Data Mining **3 0 3**

Data Mining – introduction, fundamental concepts; motivation and applications; role of data warehousing in data mining; challenges and issues in data mining; Knowledge Discovery in Databases (KDD); role of data mining in KDD; algorithms for data mining; tasks like decision-tree construction, finding association rules, sequencing, classification, and clustering; applications of neural networks and machine learning for tasks of classification and clustering.

CS F422 Parallel Computing **3 0 3**

Introduction to parallel computing; Models of parallel computers; Interconnection networks, basic communication operations; Introduction to parallel algorithms; Parallel programming paradigms; issues in implementing algorithms on parallel computers; Parallel programming with message passing interface; Performance analysis; Scalability analysis; Basic design techniques for parallel algorithms; Parallel algorithms for selected topics like sorting, searching and merging, matrix algebra, graphs, discrete optimization problems and computational geometry.

CS F425 Deep Learning **3 0 3**

Basic neural networks, derivative-based optimisation, gradient descent and its variants, various learning algorithms: SGD, RMSProp, Adam, Shallow Networks, Stacking, multilayer perceptron, activation functions, parameter initialisation strategy, cost function, backpropagation using gradient descent, visual data, convolution operation, pooling, variants of convolution function, CNN architectures: Dense convolutional neural networks (DenseNets), AlexNet, VGG, etc., sequence models, GRU, LSTM, encoders-decoders, vanishing gradient, autoencoders, generative modelling, VAE, real world applications.

CS F426 Graph Mining **3 1 4**

Managing and mining graphs which are massive and cannot held in main memory, applications of graphs are web, social networks, computational biology, communication networking etc., static graphs, dynamic graphs, indexing and querying graphs, graph representation, random walks, page rank, triangular computation, Node classification, Graph clustering, graph similarity and alignment, Graph summarization, subgraph mining, streaming graphs, Deep learning for graphs

Pre-requisite: CS F211 **:** Data Structure and Algorithms

CS G513 Network Security **3 1 4**

This course examines issues related to network and information security. Topics include security concepts, security attacks and risks, security architectures, security policy management, security mechanisms, cryptography algorithms, securitystandards, security system interoperation and case studies of the current major security systems.

ECON F354 Derivatives and Risk Management **3 0 3**

Overview of Financial Markets. Introduction to derivatives. Definition of future, forward, option and swap. Difference between various players of derivative market, their motives and types of position they can hold. Mechanics of future, option & swap markets. Hedging strategies. Option Pricing and understanding of various factors affecting option price. Calculations of Greeks. Introduction to interest rates, yield, term structure and forward rates. Mechanics of Bond Market. Review of concept of compounding and time value of money. Difference between floating rate and fixed income bonds. Price quotes and accrued interest. Pricing of Bonds. Computation of yield. Bond Price volatility. Duration, Modified Duration and convexity. Factors affecting Bond Yields and the Term Structure. Concept of Risk. Perspective of Risk from view point of individuals, companies & financial institutions. Commercial Banks and risks faced by them. Different types of Insurance and risk faced insurance companies. Introduction to various risks: Market Risk, Credit Risk, Operational Risk, Liquidity risk & Model Risk. Concept of Value at Risk.

IS F311 Computer Graphics **3 0 3**

Graphics I/O hardware; Generation of dot, lines, conics, curves, surfaces & polygons; Filling closed regions, 2D & 3D Graphics & Transformations, Windowing, Viewing & Clipping, Efficient algorithms, Solid Modeling, Color Models & Dithering, Visible surface detection, Rendering, Animation Techniques, Advanced modeling and Future directions.

MATH F243 Graphs and Networks **3 0 3**

Basic concepts of graphs and digraphs behind electrical communication and other networks behind social, economic and empirical structures; connectivity, reachability and vulnerability; trees, tournaments and matroids; planarity; routing and matching problems; representations; various algorithms; applications.

MATH F315 Introduction to Statistical Inference **3 0 3**

Parametric point estimation; Unbiasedness; Consistency; Uniform minimum variance unbiased estimator; Method of moments; Maximum likelihood estimation and its properties; Lower bounds for the variance of an estimator; Sufficiency; Factorization theorem; Best equivariant estimators; Tests of hypotheses; Neyman-Pearson lemma; uniformly most powerful (UMP) tests; Likelihood ratio tests; Chi-square tests; Methods for finding confidence intervals.

MATH F424 Applied Stochastic Process **3 1 4**

Definition and examples of Stochastic Processes (SPs), classification of random processes according to state space and parameter space, types of SPs, elementary problems; Stationary Process: Weakly stationary and strongly stationary processes, moving average and autoregressive processes; Martingales: definition and examples of martingales; Markov Chains: Transition probability, classification of states and chains, stability of Markov chains, irreducibility, stationary distribution ergodic theorem; Continuous-time Markov Chains (CTMCs): Poisson process, birth-death process and their applications; Continuous time and continuous state space: Brownian motion, Wiener process and applications; Renewal processes in discrete and continuous time; Renewal reward process; Branching Processes; Galton-Watson branching process and its properties.

MATH F425 Numerical Linear Algebra **3 1 4**

Matrix algebra, conditioning, condition number, vector and matrix norms, perturbation theory of linear systems, stability of numerical algorithms, Cholesky decomposition, floating point arithmetic and its error analysis, singular value decomposition (SVD), algebraic and geometric properties of SVD, least square solutions, Moore Penrose inverse, Rank deficient least squares problems, Sensitivity analysis of SVD and least-squares problems, Householder matrices and transformation, QR method, Iterative methods with iterative refinement, Krylov subspace method, Arnoldi iteration, Low rank approximations.

Pre-requisite: MATH F112 Mathematics II

MATH F426 Mathematical Theory of Finite Element Methods **3 1 4**

Hilbert spaces, Sobolev Spaces, Variational formulation of elliptic boundary value problems, Lax-Milgram theorem, Error estimates, Construction of FE spaces, Polynomial approximations, interpolation errors, Aubin-Nitsche duality argument, Parabolic initial and boundary value problems: Semi-discrete and fully discrete schemes, error estimates.

MATH F428 Time Series Analysis and Forecasting **3 1 4**

The course reviews Extrapolative and Decomposition Models, Introduction to Box–Jenkins Time Series Analysis, ARIMA Models, which remains the most commonly used statistical technique in Time Series Analysis. The remainder of the course considers various practical aspects of the principles behind modern forecasting techniques. A one-hour lab will be conducted every week. Students will learn how to explore and analyze different types of Time Series data using R programming.