DEPARTMENT OF PHYSICAL SCIENCES
SCHOOL OF ENGINEERING AND COMPUTER SCIENCE
INDEPENDENT UNIVERSITY, BANGLADESH

A PROPOSAL FOR
BACHELOR OF SCIENCE WITH HONOURS (B. Sc. HONS)
PROGRAM IN
MATHEMATICS

Introduction

In today's highly scientific-technological society, mathematics plays a basic and essential role. Mathematical thought and modeling are valued tools in our sophisticated scientific and industrial community. Growth in the use of technology in every aspect of business and industry creates an increasing demand for a mathematically skilled work force. Keeping this in mind, the following undergraduate program in Mathematics is proposed.

1. Bachelor of Science (B. Sc.) Honours in Mathematics

The detailed format of the proposed program is described below.

Degree requirement

A student intending to pursue a Bachelor of Science (Honours) degree in Mathematics has to undertake a minimum of 132-134 credits of coursework. The structure of the coursework is distributed as follows.

Foundation courses	40-42 credits
Major course work	
Core courses	50 credits
Concentration and optional courses	27 credits
Minor coursework	15 credits

Description of degree requirements

Foundation courses (University requirement)				**40-42 credits**
	Communication Skills		9	
	Computer Skills (CSC 101, CSC 101L)		4	
	Numeracy		6	
	Natural Sciences		6-8	

	Social Sciences			6	
	Humanities			6	
	LFE201	Live-in Field Experience		3	
Major requirements					**77 credits**
	Core courses (Compulsory)			50 credits	
	MAT 120	Fundamentals of Mathematics	3		
	MAT 125	Calculus with Analytic Geometry-I	3		
	MAT 199L	Software Tools for Mathematics	1		
	MAT 215	Algebraic Structures	3		
	MAT 220	Real Analysis I	3		
	MAT 222	Linear Algebra-I	3		
	MAT 225	Calculus with Analytic Geometry-II	3		
	MAT 230	Ordinary Differential Equations with applications-I	3		
	MAT 299L	Computer Assisted Mathematical Problem Solving I	1		
	MAT 306	Analysis of Algorithms	3		
	MAT 306L	Labwork based on MAT306	1		
	MAT 325	Multivariable and Vector Calculus	3		
	MAT 330	Ordinary Differential Equations with applications -II	3		
	MAT 340	Partial Differential Equations	3		
	MAT 345	Complex Analysis	3		
	MAT 350	Computational Methods-I	3		
	MAT 350L	Labwork based on MAT350	1		

		MAT 399L	Computer Assisted Mathematical Problem Solving II	1		
		MAT 499	Senior Project	6		
	Concentration (Any four from the following)				12 credits	
		MAT 320	Real Analysis II	3		
		MAT 321	Abstract Algebra	3		
		MAT 421	Linear Algebra II	3		
		MAT 424	Rings and Modules	3		
		MAT 450	Computational Methods II	3		
		MAT 451	Mathematical Modeling	3		
		MAT 453	Special Functions and Transforms	3		
		MAT 454	Perturbation Methods	3		
	Optional Courses (Any five from the following)				15 credits	
		MAT 422	Analytic Number Theory	3		
		MAT 423	Algebraic Number Theory	3		
		MAT 425	Topology	3		
		MAT 426	Functional Analysis	3		
		MAT 427	Fuzzy Mathematics	3		
		MAT 428	Mathematical Logic	3		
		MAT 431	Tensor Analysis	3		
		MAT 432	Differential Geometry	3		
		MAT 433	Foundations of Geometry and non-Euclidean Planes	3		
		MAT 434	Graph Theory	3		
		MAT 435	Probability Theory	3		
		MAT 436	Mathematical Statistics	3		

		MAT 437	Stochastic Process	3		
		MAT 438	Econometrics	3		
		MAT 439	Mathematical Cryptography	3		
		MAT 440	Mathematical Coding Theory	3		
		MAT 456	Discrete Dynamical Systems	3		
		MAT 459	Astronomy	3		
		MAT 460	Astrophysics	3		
		MAT 461	Classical Mechanics	3		
		MAT 462	Quantum Mechanics	3		
		MAT 463	Theory of Relativity	3		
		MAT 464	Statistical Mechanics	3		
		MAT 465	Orbital Mechanics	3		
		MAT 469	Atmospheric Physics and Meteorology	3		
		MAT 470	Fluid Dynamics	3		
		MAT 472	Mathematical Biology	3		
		MAT 473	Optimization	3		
		MAT 474	Computer Graphics	3		
		MAT 475	Financial Mathematics	3		
		MAT 476	Actuarial Mathematics	3		
		MAT 489	Special Topics	3		
Minor requirement						**15 credits**
Total degree requirement						**132-134 credits**

Course descriptions

MAT 120 Fundamentals of Mathematics (3 credits)

Elements of logic: Mathematical statements. Logical connectives. Conditional and biconditional statements. Truth tables and tautologies. Quantifications. Logical implication and equivalence. Deductive reasoning. Methods of proof (direct, indirect); method of induction. Sets and subsets. Set operations. Family of Sets. De Morgan's laws. Relations and functions: Cartesian product of sets. Relations. Order relation. Equivalence relations. Functions. Images and inverse images of sets. Injective, surjective, and bijective functions. Inverse functions. The Real number system: Field and order properties. Natural numbers, integers and rational numbers. Absolute value. Basic inequalities. (Including inequalities involving means, powers; inequalities of Cauchy, Chebyshev, Weierstrass). The Complex number system: Geometrical representation Polar form. De Moivre's theorem and its applications. Elementary number theory: Divisibility. Fundamental theorem of arithmetic. Congruence's (basic properties only). Summation of finite series: Arithmetic-geometric series. Method of difference. Successive differences. Theory of equations: Synthetic division. Number of roots of polynomial equations. Relations between roots and coefficients. Multiplicity of roots. Symmetric functions of roots. Transformation of equations.

Prerequisite: Enrollment in Math program

Books:

1. Shwu-Yeng T. Lin and You-Feng Lin, *Set Theory with Applications*, 2nd edition, Book Publishers, 1985.
2. J. W. Archbold, *Algebra*, 4th edition, Pitman, 1973.
3. W. L. Ferrar, *Higher Algebra*, Oxford University Press, 1967.

MAT 125 Calculus with Analytic Geometry I (3 credits)

Review of Analytic geometry in two dimensions: Transformation of coordinates, parametric and polar curves. Functions and their graphs; limits of functions: definition, limit theorems with proofs, limit at infinity and infinite limits; continuity of functions, algebra and properties of continuous functions; differentiation: tangent lines and rates of change, definition of derivative, rules of differentiation; Leibnitz theorem. Related rates. Linear approximations and differentials; Rolle's theorem; mean value theorems; extrema of functions, problems involving maxima and minima; concavity and points of inflection; Taylor's theorem, Taylor's series, differentiation and integration of series; indeterminate forms, l'Hospital's rules.

Prerequisite: Enrollment in Math program

Books:

1. Ron Larson, Bruce Edwards, *Calculus*, 9th edition, Cengage Learning, 2009.
2. James Stewart, *Calculus*, 6th edition, Cengage Learning, 2007.
3. Michael Spivak, *Calculus*, 4th edition, Wiley, 2008.
4. Morris Kline, *Calculus, An Intuitive Approach*, 2nd edition, 1998.
5. Tom M. Apostol, *Calculus, Vol 1: One variable calculus with introduction to linear algebra*, Wiley, 1991.

MAT 199 L Software Tools for Mathematics (1 credit)

This course will cover current software tools used for learning mathematics. At present, the course will cover MATLAB and Mathematica.

Prerequisite: Enrollment in Math program

MAT 215 Algebraic Structures (3 credits)
Review of sets, functions and relations; Ordered Sets, bounds of elements, Zorn's Lemma, dimension; Lattices: independence and rank, distributivity and modularity, dimension and independence in modular lattices, inclusion-ordered lattices; Quotient Sets, Product Sets, and Cardinal Numbers; Groupoids: compositions, subgroupoids, homomorphisms, congruences and quotient groupoids, canonical homomorphisms, normal subsets, normal subgroupoids and normal series; Semigroups and Groups: idempotent elements, identities and absorbent elements, cancellable and invertible elements, associativity and commutativity, semigroups and groups, division in semigroups, groups of quotients, integers and rational numbers, subgroups, factor groups, product of groups, congruences on groups, direct products of groups, Abelian groups, rank, divisible groups.
Prerequisite: MAT 120

Books:
1. Joseph Landin, *An introduction to algebraic structures*, Dover Publications, 2010.
2. Donald Passman, *An algebraic structures of group rings*, Dover publications, 2011.
3. Jingjing Ma, *Lectures notes on algebraic structures of lattice-oriented rings*, World Scientific Publishing Company, 2014.
4. George R. Kempf, *Algebraic Structures*, Vieweg Tauber Verlag Publishing, 1995.

MAT 220 Real Analysis I (3 credits)
Bounded sets of real numbers, supremum and infimum, completeness axiom, Dedekind's theorems, cluster (limit) points, Bolzano-Weierstrass theorem; Infinite sequences, convergence, theorems on limits, monotone sequences, subsequences; Infinite series of real numbers: convergence and absolute convergence, tests for convergence, Gauss's tests, Leibnitz's test; Properties of continuous functions, intermediate value theorem; The derivative: standard theorems; Darboux's theorem; Riemann integral: definitions via Riemann's sums and Darboux's sums, necessary and sufficient conditions for integrability, classes of integrable functions, fundamental theorem of calculus; uniform convergence: interchangeability of limiting processes; power series, differentiation and integration of power series, Abel's continuity theorem; Improper integrals: Tests for convergence; Integrals depending upon a parameter, differentiation and integration under the integral sign.
Prerequisite: MAT 120, MAT 125
Books:
1. Robert G. Bartle, Donald R. Sherbet, Introduction to Real Analysis, 4th edition, Wiley, 2011.
2. Brian S. Thomson, Judith B. Bruckner, Andrew M. Bruckner, *Elementary Real Analysis*, 2nd edition, CreateSpace Independent Publishing Platform, 2008.

A. N. Kolmogorov, S. V. Fomin, Richard A. Silverman, *Introductory Real Analysis*, Dover Publications, 1975.

3. Hasley Royden, Patrick Fitzpatrick, *Real Analysis*, 4th edition, Pearson, 2010.
4. Charles C. Pugh, *Real Mathematical Analysis*, Springer, 2003.
5. Michael J. Schramm, *Introduction to Real Analysis*, Dover Publications, 2008.

MAT 222 Linear Algebra I (3 credits)

Vectors in R^n and C^n: Review of geometric vectors in R^2 and R^3 space, vectors in R^n and C^n, inner product, norm and distance in R^n and C^n, Matrices and Determinants: definition, matrix algebra, determinant: properties, minors, cofactors, expansion and evaluation of determinants, elementary row and column operations and row-reduced echelon matrices, invertible matrices, block matrices; System of Linear Equations: matrix and determinant methods for finding the solution, overdetermined and underdetermined solutions; Vector Spaces: notions of groups and fields, abstract vector space, subspace, sum of subspaces; Linear independence of vectors; basis and dimension of vector spaces, row and column space of a matrix; rank of matrices; solution spaces of systems of linear equations; Linear transformations: Kernel and image of a linear transformation and their properties, matrix representation of linear transformations, change of bases; Eigenvalues and Eigenvectors, Diagonalization. Cayley-Hamiton theorem, applications.

Prerequisite: MAT 120

Books:

1. David Poole, *Linear Algebra: A Modern Introduction*, 4th edition, Cengage Learning, 2014.
2. David Lay, *Linear Algebra with Applications*, 4th edition, Pearson, 2011.
3. Gilbert Strang, *Introduction to Linear Algebra*, 4th edition, Welesley Cambdirge Press, 2009.
4. Charles G. Cullen, *Matrices with Linear Transformations*, 2nd edition, Dover Publications, 1990.
5. Gareth Williams, *Linear Algebra with Applications*, 7th edition, Jones and Bartlett Learning, 2009.

MAT 225 Calculus with Analytic Geometry II (3 credits)

Integral: Antiderivatives and indefinite integrals, techniques of integration, definite integration, Riemann sums; properties of integration, integration by reduction; applications of integration: plane areas, volume of solids, arc length and surface of revolution; Improper integrals: Gamma and beta functions; Area and arc length in polar coordinates; Vectors in plane and space: algebra of vectors, applications in plane and space geometry, Conic Sections: Review of standard forms, reduction of second degree equations to standard forms, pairs of straight lines, identification of conics, equations of conics in polar coordinates, Infinite Series, Convergence of series.

Prerequisite: MAT 125

Books:

1. James Stewart, *Calculus*, 6th edition, Cengage Learning, 2007.
2. Michael Spivak, *Calculus*, 4th edition, Wiley, 2008.
3. Morris Kline, *Calculus, An Intuitive Approach*, 2nd edition, 1998.
4. Tom M. Apostol, *Calculus, Vol 2: Multivariate Calculus*, Wiley, 1991.
5. Ron Larson, Bruce Edwards, *Calculus*, 9th edition, Cengage Learning, 2009.

MAT 230 Ordinary Differential Equations with applications I (3 credits)

Classification of differential equations, solutions of ODE, supplementary conditions, direction fields, existence and uniqueness theorems; first order differential equations, linear equations, exact equations, integrating factors, substitutions and transformations; applications of first order differential equations, orthogonal and oblique trajectories; Higher order linear differential equations: Linear differential operators, basic theory of linear differential equations, homogeneous systems, reduction of order, non-homogeneous equation, method of undetermined coefficients, variation of parameters, Euler-Cauchy differential equations; Modeling with second-order equations: one-dimensional free and forced vibration, electric circuit problems, motion of a rocket.

Prerequisite: MAT 225

Books:

1. William Adkins, Mark G. Davidson*, Ordinary Differential Equations*, Springer, 2012.
2. Morris Tenenbaum, Harry Pollard, *Ordinary Differential Equations*, Dover Publications, 1985.
3. Shepley Ross, Introduction *to Ordinary Differential Equations*, 4^{th} edition, Wiley, 1989.
4. William E. Boyce, Richard E. DiPrima, *Elementary Differential Equations and Boundary Value Problems*, 10^{th} edition, Wiley, 2012.
5. Earl A. Coddington, Norman Levinson, *Theory of Ordinary Differential Equations*, Krieger Publishing Company, 1984.
6. Steven G. Krantz, George F. Simmons, *Differential Equations: Theory, Techniques and Practice*, 2^{nd} edition, Chapman and Hall/CRC, 2014.

MAT 299L Computer Assisted Mathematical Problem Solving I(1 credit)

This course is designed to improve the creativity and expertise of students in formulating and solving problems from various areas of mathematics and their applications.

Possible topics: Calculus, Linear Algebra, Differential Equations, and others.

Prerequisite: MAT 222, MAT 230

MAT 306 Analysis of Algorithms (3 credits)

Fundamentals of algorithms, Complexity analysis, Asymptotic notations (Theta, Big O, Omega). Different sorting algorithms: Bubble/Insertion(N^2); Recursive sorting algorithms: Merge, Quick, Heap (NlgN); Decision tree analysis: nlgn bound on comparison based sorting. Sorting in linear time: Counting/ Radix sort. Spanning trees. Greedy algorithms: Shortest path (Dijkstra), MST (Minimum spanning tree algorithms: Kruskal, Prim). Hashing. NP problems (TSP).

Prerequisite: CSC 101, MAT 120, MAT 125

Books:

1. Robert Sedgewick, Phillipe Flajolet, An *Introduction to the Analysis of Algorithms*, 2^{nd} edition, Addison Wesley, 2013.
2. Jeffrey McConnel, *Analysis of Algorithms*, 2^{nd} edition, Jones and Bartlett, 2007.
3. Thomas H. Cormen, Charles E. Lieserson, Ronald R. Livest, Clifford Stein, *Introduction to Algorithms*, 3^{rd} edition, MIT Press, 2009.
4. Anany Levitin, *Introduction to the Design and Analysis of Algorithms*, 3^{rd} edition, Addison-Wesley, 2011.
5. Alfred V. Aho, John E. Hopcroft, Jeffrey D. Ullman, *The Design and Analysis of Computer Algorithms*, Addison Wesley, 1974.

MAT 306L Labwork based on MAT 306 (1 credit)

MAT 320 Real Analysis II (3 credits)

Metric Spaces. Metric, definition and examples, ε -neighbourhood, open and closed sets in metric spaces, interior, exterior and boundary of a set, bounded sets, equivalent metrics; Cluster points of sets in metric spaces, derived set, closure of a set; Infinite sequences in metric spaces and their convergence, Cauchy sequences, complete metric spaces; Continuity and uniform continuity of functions on metric spaces; Compactness in metric spaces, necessary and sufficient condition of compactness, Heine-Borel theorem; Differentiation in R^n, Jacobian, implicit and inverse function theorems, Integration in R^n, Fubini's theorem, change of variables.

Prerequisite: MAT 220, MAT 225

Books:

1. Robert G. Bartle, Donald R. Sherbet, Introduction to Real Analysis, 4th edition, Wiley, 2011.
2. Brian S. Thomson, Judith B. Bruckner, Andrew M. Bruckner, *Elementary Real Analysis*, 2nd edition, CreateSpace Independent Publishing Platform, 2008.

a. N. Kolmogorov, S. V. Fomin, Richard A. Silverman, *Introductory Real Analysis*, Dover Publications, 1975.

3. Hasley Royden, Patrick Fitzpatrick, *Real Analysis*, 4th edition, Pearson, 2010.
4. Charles C. Pugh, *Real Mathematical Analysis*, Springer, 2003.
5. Michael J. Schramm, *Introduction to Real Analysis*, Dover Publications, 2008.

MAT 321 Abstract Algebra (3 credits)

Groups and subgroups, groups of symmetry, permutation groups, symmetric group on *n* letters, cyclic groups; Left and right congruence modulo a sub-group, cosets, Lagrange's theorem, product of cosets, Frobenius' counting formula; normal subgroups, quotient groups, homomorphisms and automorphisms, isomorphism theorems, conjugacy, class equation, direct product, groups of small orders, Rings, ideals and quotient rings, prime and maximal ideals; Integral domain, field of fractions, Principal ideal domains, Euclidean domains, unique factorization domains, Polynomial rings, primitive polynomials, Gauss theorem, Eisenstein's irreducibility criterion; Characteristic of a ring or integral domain, prime fields, structure of prime fields.

Prerequisite: MAT 215

Books:

1. Charles C. Pinter, *A Book of Abstract Algebra*, Dover Publications, 2nd edition, Dover Publications, 2009.
2. David S. Dummit, Richard S. Foote, *Abstract Algebra*, 3rd edition, Wiley, 2003.
3. Thomas W. Hungerford, *Abstract Algebra: An Introduction*, 3rd edition, Cengage Learning, 2012.
4. Dan Saracino, *Abstract Algebra: A First Course*, 2nd edition, Waveland Press, 2008.
5. John B. Fraleigh, *A First Course in Abstract Algebra*, 7th edition, Pearson, 2002.
6. Joseph Gallian, *Contemporary Abstract Algebra*, 8th edition, Cengage Learning, 2012.

MAT 325 Multivariable and Vector Calculus (3 credits)

Vector-valued functions of a single variable, derivatives and integrals of vector valued functions; tangent lines to vector-valued functions, arc length; curvature of plane and space curves; Partial Differentiation: functions of several variables, limits and continuity, partial derivatives,. directional derivatives; gradient vectors and tangent planes; Extrema of functions of several variables, Lagrange multipliers. Taylor's formula; Differentiation of Vectors, Multiple integrals: Double and triple integrals, iterated integrals, areas and volumes, integrals in cylindrical and spherical coordinates; General multiple integrals, change of variables in multiple integrals, Jacobians; Integration of Vector, gradient, divergence, curl. Green's theorem, Gauss's theorem, Stokes' theorem.

Prerequisite: MAT 225

Books:

1. James Stewart, *Multivariable Calculus*, 7th edition, Cengage Learning, 2011.
2. Clark Bray, *Multivariable Calculus*, CreateSpace Independent Publishing Platform, 2013.
3. Ron Larson, Brice H. Edwards, *Multivariable Calculus*, 10th edition, Cengage Learning, 2013.
4. C. Henry Edwards, Davdi E. Penney, *Multivariable Calculus*, 6th edition, Pearson, 2012.
5. William G. McCallum, Deborah Hughes-Hallett, Andrew M. Gleason, Selin Kalayciglu, Brigitte Lahme, Patti Frazer Lock, Guadalupe I. Lozano, Jerry Morris, David Mumford, Brad G. Osgood, Cody L. Patterson, Douglas Quinney, Adam H. Spiegler, Jeff Tecosky-Feldman, Thomas W. Tucker, *Calculus: Multivariable*, 6th edition, Wiley, 2012.

MAT 330 Ordinary Differential Equations with applications II (3 credits)

Fundamental existence and uniqueness theorem, dependence of solutions on initial conditions and equation parameters, existence and uniqueness theorems for systems of equations and higher-order equations; Series solutions of second order linear equations: Taylor series solutions about an ordinary point. Frobenius series solutions about regular singular points. Series solutions of Legendre, Bessel, Laguerre and Hermite differential equations, Hyper geometric equations; Systems of linear first order differential equations: Elimination method. Matrix method for homogeneous linear systems with constant coefficients. Variation of parameters; Eigenvalue problems and Strum-Liouvile boundary value problems: Regular Strum-Liouville boundary value problems, non-homogeneous boundary value problems and the Fredholm alternative, solution by eigenfunction expansion, Green's functions. Singular Strum Liouville boundary value problems/Oscillation and comparison theory.

Prerequisite: MAT 230, MAT 325

Books:

1. William Adkins, Mark G. Davidson*,* *Ordinary Differential Equations*, Springer, 2012.
2. Morris Tenenbaum, Harry Pollard, *Ordinary Differential Equations*, Dover Publications, 1985.
3. Shepley Ross, Introduction *to Ordinary Differential Equations*, 4th edition, Wiley, 1989.
4. William E. Boyce, Richard E. DiPrima, *Elementary Differential Equations and Boundary Value Problems*, 10th edition, Wiley, 2012.
5. Earl A. Coddington, Norman Levinson, *Theory of Ordinary Differential Equations*, Krieger Publishing Company, 1984.

6. Steven G. Krantz, George F. Simmons, *Differential Equations: Theory, Techniques and Practice*, 2nd edition, Chapman and Hall/CRC, 2014.

MAT 340 Partial Differential Equations (3 credits)

First order equations: complete integral, general solution, Cauchy problems, method of characteristics for linear and quasi-linear equations, Charpit's method for finding complete integrals, methods for finding general solutions; Second order equations: classifications, reduction to canonical forms, characteristic curves; Boundary value problems related to linear equations: applications of Fourier methods, mixed boundary conditions; Problems involving cylindrical and spherical symmetry, boundary value problems involving special functions; Transform methods for boundary value problems: Applications of the Laplace transforms; Fourier transform, non-homogeneous equations.

Prerequisite: MAT 330

Books:

1. Walter A. Strauss, *Partial Differential Equations: An Introduction*, 2nd edition, Wiley, 2007.
2. Richard Haberman, *Applied Partial Differential Equation with Fourier Series and Boundary Value Problems*, 5th edition, Pearson, 2012.
3. Nakhle H. Asmar, *Partial Differential Equations*, 2nd edition, Pearson, 2004.
4. Peter Olver, *Introduction to Partial Differential Equations*, Springer 2013.
5. Sandro Salsa, *Partial Differential Equations in Action: From Theory to Modelling*, Springer, 2010.
6. S. L. Sobolev, *Partial Differential Equations of Mathematical Physics*, Dover Publications, 2011.

MAT 345 Complex Analysis (3 credits)

Complex number, complex plane, algebra of complex numbers; Functions of a complex variable, differentiability of a complex function, analytic functions and their properties, harmonic functions; power series; Complex integration: Line integration over rectifiable curves, Winding number, Cauchy's theorem, Cauchy's integral formula, Liouville's theorem, fundamental theorem of Algebra; Singularities, residues, Taylor's and Laurent's expansion; Cauchy's residue theorem; Evaluation of integrals by contour integration; Rouche's theorem; Conformal mappings, bilinear transformations; Meromorphic functions; Infinite product decomposition of entire functions.

Prerequisite: MAT 220, MAT 325

Books:

1. Theodore Gamelin, *Complex Analysis*, Springer, 2003.
2. Serge Lang, *Complex Analysis*, 3rd edition, 2008.
3. Joseph Bak, Donald Newman, *Complex Analysis*, 3rd edition, 2010.
4. Francis Flanigan, *Complex Analysis*, Dover Publications, 2010.
5. Edward B. Saff, David Snider, F*undamentals of Complex Analysis with Applications to Engineering, Science and Mathematics*, 3rd edition, Pearson, 2003.
6. Lars Ahlfors, *Complex Analysis*, 3rd edition, McGraw Hill, 1979.

7. Dennis G. Zill, Patrick D. Shanahan, *A First Course in Complex Analysis with Applications*, 3rd edition, Jones and Bartlett Learning, 2013.

MAT 350 Computational Methods I (3 credits)

Representation of numbers inside a computer, truncation error, round-off error, arithmetic operations, round-off errors and algorithms, catastrophic cancellation, propagation of errors; Solution of nonlinear equations, open methods and bracketing methods, bisection method, false position method, Newton-Raphson method, convergence, error propagation, accelerating convergence; System of linear equations, Gaussian elimination, scaling and pivoting, LU decomposition, over and underdetermined systems, iterative techniques; Interpolation and polynomial approximation: Taylor's polynomials, Lagrange polynomials, Newton's divided difference, spline interpolation, cubic splines, extrapolation; Differentiation and Integration: Numerical differentiation, Richardson's extrapolation, Elements of Numerical Integration, Adaptive quadrature method, Romberg's integration, Gaussian quadrature, Newton-Cotes methods.

Prerequisite: MAT 222, MAT 230

Books:

1. Anne Greenbaum, Timothy P. Chartier, *Numerical Methods*: Design, Analysis and Computer Implementation of Algorithms, *Princeton University Press*, 2012.
2. Joe D. Hoffman, Steven Frankel, *Numerical Methods for Engineers and Scientists*, 2nd editions, CRC Press, 2001.
3. Amos Gilat, *Numerical Methods for Engineers and Scientists*, 3rd editions, Wiley, 2013.
4. J. Douglas Faires, Richard L. Burder, *Numerical Methods*, 4th edition, Cengage, 2012.
5. Steven Chapra, Raymond Canale, *Numerical Methods for Engineers*, 7th edition, McGram Hill, 2014.

MAT 350L Labwork based on MAT350 (1 Credit)

MAT 399L Computer Assisted Mathematical Problem Solving II (1 credit)

Continuation of MAT 299L.

Prerequisite: MAT 299L, MAT 330, MAT 350

MAT 421 Linear Algebra II (3 credits)

Similar Matrices: Canonical forms of matrices, Symmetric, orthogonal and Hermitian matrices; Linear Functional and dual Space: Linear functional and the dual space, dual basis, second dual space, annihilators, transpose of a linear transformation; Inner Product Space: Inner products, inner product spaces, Orthogonality and orthonormal sets, linear functions and adjoints, positive operators, unitary operators and normal operators, Spectral theorem; Bilinear, quadratic & hermitian forms: Matrix form, transformations, canonical forms, reduction form, definite and semi-definite forms, principal minors, and factorable forms; Application of linear algebra in solving problems in mathematics and applied sciences.

Prerequisite: MAT 222

Books:

1. Nicholas Loehr, *Advanced Linear Algebra*, Chapman and Hall/CRC, 2014
2. Bruce Cooperstein, *Advanced Linear Algebra*, CRC Press, 2010.
3. Sohel A. Daniat, Eli Saber, *Advanced Linear Algebra with MATLAB*, CRC Press, 2009.

4. Stephen H. Friedberg, Arnold J. Insel, Lawrence E. Spence, *Linear Algebra*, 4th edition, Pearsons, 2002.
5. Otto Bretscher, *Linear Algebra with Applications*, 4th editions, Pearson, 2008.
6. Steve Leon, *Linear Algebra with Applications*, 8th edition, Pearson, 2009.
7. Peter Olver, Cheri Shakiban, *Applied Linear Algebra*, Pearson. 2005.

MAT 422 Analytic Number Theory (3 credits)
Euler-Maclaurin summation formula, average orders of the divisor function, the sum of divisors function and Euler's phi function, the set of lattice points visible from the origin, distribution of square free integers. Abel summation formula, Tchebychev's theorem, Bertrand's postulate, series of reciprocals of primes and related series, Tchebychev's functions, results equivalent to the prime number theorem. Dirichlet characters, orthogonality relation, sums involving Dirichlet characters, Dirichlet's theorem on primes in arithmetic progressions. Dirichlet series and Euler products, Riemann zeta function, analytic continuation, functional equation, special values, Bernoulli numbers and Bernoulli polynomials. Analytic proof of the prime number theorem, zeros of the Riemann zeta function, Riemann hypothesis.
Prerequisite: MAT 345
Books
1. Tom M. Apostol, *Introduction to Analytic Number Theory* , Springer, 1976
2. K. Chandrasekharan, *Introduction to Analytic Number Theory*, Springer 1968
3. Harold Davenport, *Multiplicative Number Theory*, 3rd edition, Springer 2000
4. Henryk Iwaniec and Emmanuel Kowalski, *Analytic Number Theory,*American Mathematical Society, 2004.

MAT 423 Algebraic Number Theory (3 credits)
Algebraic numbers and algebraic integers, the ring of algebraic integers of a number field, conjugates and discriminants, integral bases, norms and traces, quadratic and cyclotomic fields; Factorization into irreducibles, examples of non-unique factorizations, Euclidean domains, Euclidean quadratic fields, applications to Diophantine equations; Prime ideals, fractional ideals, unique factorization into a product of prime ideals, norm of an ideal; Lattices, Minkowski's theorem, application to sums of two or four squares, geometric representation of algebraic numbers; Class group and class number, finiteness of class number, Dedekind's theorem on factorization of a rational prime, class number calculations; Proof of the first case of Fermat's last theorem for regular primes.
Prerequisite: MAT 321
Books:
1. John William Scot Cassel, Albrecht Frhlich, *Algebraic Number Theory*, 2nd edition, London Mathematical Society, 2010.
2. Robert B. Ash, *A Course on Algebraic Number Theory*, Dover Publications, 2010.
3. Kenneth Ireland, Michael Rosen, *A Classical Theory of Modern Number Theory*, 2nd edition, Springer, 1998.
4. Richard A Molin, *Algebraic Number Theory*, 2nd edition, Chapman and Hall, 2011.
5. Jurgen Neukirch, Norbert Schappacher, *Algebraic Number Theory*, Springer, 2010.

6. Saban Alaca, Kenneth S. Williams, *Algebraic Number Theory*, Cambridge University Press, 2010.
7. Harry Pollard, Harold G. Diamond, *A Theory of Algebraic Number Theory*, Dover Publications, 2010.
8. Fraser Jarvis, *Algebraic Number Theory*, Springer, 2014.

MAT 424 Rings and Modules (3 credits)

Basic module theory, the language of categories, chain conditions, composition series, Wedderburn's theorem, the Kull-Schmidt theorem, Noetherian rings, polynomial rings, the Euclidean algorithm, factorization, principal ideal domains, modules over PIDs, the primary decomposition theorem, algebraic integers, direct products of rings, Zorn's lemma, tensor products of modules and algebras, the invariant basis number.

Prerequisite: MAT 321

Books:

1. Paul M. Cohn, *Introduction to Ring Theory*, Springer, 2001.
2. H. Matsumura, Miles Reid, *Commutative Ring Theory*, Cambridge University Press, 1989.
3. Louis H. Rowen, *Ring Theory*, Academic Press, 1998.
4. Donald S. Passman, *A Course in Ring Theory*, Chelsea Publishing Company, 2004.
5. John J. Watkins, *Topics in Commutative Ring Theory*, Princeton University Press, 2007.

MAT 425 Topology (3 credits)

Topological Spaces: Definition, discrete, indiscrete, co-finite, co-countable topologies, Metric topology, cluster point of a set, neighborhood system: base and sub-base; Convergence of sequences in topological spaces, continuity of functions on topological spaces, sequential continuity, uniform continuity; separation axioms, properties of Hausdorff spaces, product spaces; Countability of topological spaces: First and second countable spaces. Countability and separability properties, Lindelof theorem; Compactness properties: Tychonoff's theorem, Equivalence of sequential compactness, Bolzano-Weierstrass property, Totally boundeness, Lebesgue number and compactness in a metic spaces.

Connectedness: Connected spaces, totally disconnected spaces, components of space, locally and pathwise connected spaces.

Prerequisite: MAT 320

Books:

1. Bert Mendelson, *Introduction to Topology*, 3rd edition, Dover Publications, 1990.
2. Colin Adams, Robert Franzosa, *Introduction to Topology*, Pure and Applied, Pearson, 2007.
3. Robert A. Conover, *A First Course in Topology: An Introduction to Mathematical Thinking*, Dover Publications, 2014.
4. Theodore W. Gamelin, Robert Everist Greene, *Introduction to Topology*, 2nd edition, Dover Publications, 1999.
5. George F. Simmons, *Introduction to Topology and Modern Analysis*, Krieger Publications Company, 2003.
6. George McCarty, Topology: *An Introduction with Applications to Topological Groups*, Dover Publications, 2010.

MAT 426 Functional Analysis (3 credits)
General linear space: Linear functional, basis and its dual on finite dimensional space, Zorn's lemma, Extension of linear functions, sublinear functional; Inner product and norm: Definitions and examples, Cauchy-Schwarz inequality, norm derived from inner product, parallelogram law, metric derived from a norm, inner product space, othogonality, Bessel's inequality; Normed linear space: Sequence space, separability, Riez's lemma, Linear mappings, boundedness and continuity, quotient space; Linear operators: Elementary properties of linear operators, linear operators in finite dimensional spaces, spaces of bounded linear operators; Banach spaces, open mapping theorem, closed graph theorem and their applications, Baire's category theorem, uniform boundedness principle, normed conjugtae of a NLS (Hahn-Banach theorem); Fixed point theorems: Contraction mapping, Banach fixed point theorem, applications of fixed point theorems; Hilbert Spaces: Basic properties, Riesz representation theorems, adjoint of a linear operator.
Prerequisite: MAT 222, MAT 320
Books:
1. George Bachman, *Functional Analysis*, Dover Publications, 1998.
2. Walter Rudin, *Functional Analysis*, 2nd edition, McGraw Hill, 1991.
3. Erwin Kreyszig, *Introductory Functional Analysis*, Wiley, 1989.
4. Frigyes Riesz, Bela Sz.-Nagy, *Functional Analysis*, Dover Publications, 1990.
5. Peter D. Lax, *Functional Analysis*, Wiley Interscience, 2002.
6. Elias M. Stein, Rami Shakarchi, *Functional Analysis: Introduction to Further Topics in Analysis*, Princeton University Press, 2011.
7. Martin Davis, *A First Course in Functional Analysis*, Dover Publications, 2013.

MAT 427 Fuzzy Mathematics (3 credits)
Crisp sets and fuzzy sets; An overview of crisps sets; the notion of fuzzy sets; basic concepts of fuzzy sets, an overview of classical logic, fuzzy logic, operations of fuzzy sets, general discussion, fuzzy complement, fuzzy union, fuzzy intersection combinations of operations, general aggregation operations; Fuzzy arithmetic: fuzzy numbers, linguistic variables, arithmetic operations on intervals and fuzzy numbers, lattice of fuzzy numbers, fuzzy equations; Fuzzy relations: Crisp and fuzzy relations, binary relations on a set, equivalence and similarity relations, compatibility or tolerance relations, orderings, morphisms, fuzzy relational equations.
Prerequisite: Senior Standing
Books:
1. Barnabas Bede, *Mathematics and Fuzzy Set and Fuzzy Logic*, Springer, 2012.
2. John N. Mordeson, Premchand S. Nair, F*uzzy Mathematics: An Introduction to Engineers and Scientists*, 2nd edition, Physica, 2001.
3. Timothy J. Ross, *Fuzzy Logic with Engineering Applications*, 3rd edition, Wiley, 2010.
4. John N. Mordeson, D. S. Malik, *Fuzzy Commtative Algebra*, World Scientific Publishing Company, 1998.
5. George J. Klir, Bo Yuan, *Fuzzy Sets and Fuzzy Logic: Theory and Applications*, Prentice Hall, 1995.

MAT 428 Mathematical Logic (3 credits)

Basic arithmetic and set theory (including cardinality, diagonalization, inductive definitions). Review of introductory logic. The Completeness theorem for first-order logic and related metalogical results. Theory of computability (Turing machines and recursive functions). Axiomatic systems of arithmetic. Limitative results: undesirability and incompleteness). Supplementary topics may include extended logics (modal and second-order) and non-classical logics (intuitionist and many-valued) logics.

Prerequisite: Senior Standing

Books:

1. Richard E. Hodel, *An Introduction to Mathematical Logic*, Dover Publications, 2013.
2. Herbert B. Enderton, *A Mathematical Introduction to Logic*, 2nd edition, Academic Press, 2001.
3. Elliot Mendelson, *Introduction to Mathematical Logic*, 5th edition, Chapman Hall/CRC Press, 2009.
4. Stephen Cole Keene, *Mathematical Logi*c, Dover Publications, 2002.
5. Joseph R. Shoenfield, *Mathematical Logic*, AK Peters/CRC Press, 2001.
6. Michal Walicki, *Introduction to Mathematical Logic*, World Scientific Publishing Company, 2011.

MAT 431 Tensor Analysis (3 credits)

Coordinates, Vectors and tensors: Curvilinear coordinates, Kronecker delta, summation convention, space of N dimensions, Euclidean and Riemannian space, coordinate transformation, Contravariant and covariant vectors, the tensor concept, symmetric and skew-symmetric tensors; Riemannian metric and metric tensors: Basis and reciprocal basis vectors, Euclidean metric in three dimensions, reciprocal or conjugate tensors, conjugate metric tensor, associated vectors and tensor's length and angle between two vectors, Christoffel symbols; Covariant differentiation of tensors and applications: Covariant derivatives and its higher rank tensor and covariant curvature tensor, Ricci tensor, zero tensor, intrinsic derivative, Bianchi identity, flat space; Applications of tensor analysis to elasticity theory and electromagnetic theory.

Prerequisite: MAT 230, MAT 325

Books:

1. Richard L. Bishop, Samuel L. Goldberg, *Tensor Analysis on Manifolds*, Dover Publications, 1980.
2. Pavel Greenfield, *Introduction to Tensor Analysis and the Calculus of Moving Surfaces*, Springer, 2013.
3. Richard A. Silverman, A. I. Borisenko, I. E. Tarapov, *Vector and Tensor Analysis with Applications*, Dover Publications, 1979.
4. Albert J. McConnell, *Applications of Tensor Analysis*, Dover Publications, 2011.
5. Ivan S. Sokolnikoff, *Tensor Analysis: Theory and Applications to Mechanics and the Theory of Continua*, 2nd edition, John Wiley, 1964.
6. Leonid P. Lebedev, Michael J. Cloud, *Tensor Analysis*, World Scientific Publishing Company, 2003.
7. George E. Hay, *Vector and Tensor Analysis*, Dover Publications, 2012.

MAT 432 Differential Geometry (3 credits)

Curves in space: Vector functions of one variable, space curves, unit tangent to a space curve, equation of a tangent line to a curve, Osculating plane (or Plane of curvature); Vector functions of two variables; Tangent and normal plane to the surface $f(x, y, z) = 0$; Principal normal, bi-normal and fundamental planes, equation of principal normal and bi-normal line, curvature and torsion, Serret-Frenet formulae, theorems on curvature and torsion; Helices and their properties, circular helix. spherical indicatrix of tangent, normal and bi-normal, curvature and torsion of spherical indicatrices, involutes and evolutes, Bertand curves; Surface: curvilinear coordinates, parametric curves, analytical representation, Monge's form of the surface, first fundamental form or metric geometrical representation of metric, relation between coefficients E, F, G; properties of metric, angle between any two directions and parametric curves, condition of orthogonality of parametric curves, elements of area, unit surface normal, tangent plane, Weingarten equations (or derivatives of surface normal).
Second fundamental form, Normal curvature, Meusrier's theorem, curvature directions, condition of orthogonality of curvature direction, Principal curvatures, lines of curvature, first curvature, mean curvature, Gaussian curvature, centre of curvature, Rodrigues's formula; Euler theorem, elliptic, hyperbolic and parabolic points, Dupin indicatrix, asymptotic lines, third Fundamental form, theorem of Beltrami-Ennerper.

Prerequisite: MAT 325

Books:

1. Andrew N. Presley, *Elementary Differential Geometry*, 2nd edition, Springer, 2012.
2. Erwin Kreyszig, *Differential Geometry*, Dover Publications, 1991.
3. Wolfgang Kuhnel, *Differential Geometry: Curves, Surfaces, Manifold*, 2nd edition, American Mathematical Society, 2005.
4. Manfredo P. DoCarmo, *Differential Geometry of Curves and Surfaces*, Pearson, 1976.
5. Heinrich W, Guggenheimer, *Differential Geometry*, Dover Publications, 1977.
6. Barrett O'Neil, *Elementary Differential Geometry*, 2nd edition, Academic Press, 2006.

MAT 433 Foundations of Geometry and Non-Euclidean Planes (3 credits)

Absolute Geometry: Incidence axiom and ruler postulate, betweenness, segments, rays and convex sets, angles and triangles, Pasch's postulate and plane separation postulate, crossbar and quadrilaterals, measuring angles and the protractor postulates, Hilbert's axioms, congruence and the penultimate postulate, perpendiculars, reflections, circles, Euclid's parallel postulate; non-Euclidean geometry: parallels and the ultimate axiom, cycles, rotations, translations and horolation, classification of isometries, symmetry, horocircles, the fundamental formula.

Prerequisite: Senior Standing

Books:

1. Stefan Kulczycki, Stanislaw Knapkowski, *Non-Euclidean Geometry*, Dover Publications, 2008.
2. Harold E. Wolfe, *Introduction to Non-Euclidean Geometry*, Dover Publications, 2012.
3. Rudolf B. Rucker, *Geometry, Relativity and the Fourth Dimension*, Dover Publications, 1977.
4. Harold S. M. Coxeter, *Non-Euclidean Geometry*, 6th edition, Mathematical Society of America, 1998.

5. Roberto Bonola, Nicholas Lobachevski, John Boylai, H. S. Carlslaw, Fredrigo Enriques, *Non-Euclidean Geometry: A Critical and Historical Study of its Development*, Dover Publications, 2010.
6. George E. Martin, *The Foundations of Geometry and the Non-Euclidean Plane*, Springer, 1998.

MAT 434 Graph Theory (3 credits)
Basic definitions, isomorphisms, walks, cycles and bipartite graphs; components, cut-edges, Eulerian graphs, Hamiltonian graphs, vertex degrees and degree sequences, directed graphs; Eulerian digraphs, trees and distance; counting spanning trees and the matrix tree theorem, minimal spanning trees and shortest paths; Matchings, Hall's theorem and coverings, maximum matchings, factors; cuts and connectivity; network flow problems, max-flow min-cut theorem; vertex colorings, bounds on chromatic numbers and Mycielski's construction; chromatic polynomials, chordal graphs, planar graphs; Euler's formula and Kuratowski's theorem, five and four color theorems.
Prerequisite: Senior Standing
Books:
1. Gary Chartrand, *A First Course in Graph Theory*, Dover Publications, 2012.
2. Ronald Gould, *Graph Theory*, Dover Publications, 2012.
3. Jonathan L. Gross, Jay Yellen, *Graph Theory and its Applications*, 2nd edition, Chapman/ CRC, 2005.
4. Maarten van Steen, *Graph Theory and Complex Networks*, Maarten van Steen, 2010.
5. Douglas B. West, *Introduction to Graph Theory*, 2nd edition, Pearson, 2000.
6. Geir Agnarsson, Raymond Greenlaw, *Graph Theory: Modeling, Applications and Algorithms*, Pearson, 2006.
7. Jonathan L. Gross, Jay Yellen, Ping Zhang, *Handbook of Graph Theory*, 2nd edition, Chapman and Hall/CRC, 2013.

MAT 435 Probability Theory (3 credits)
Basic probability models, random variables, family of discrete and continuous probability distributions, calculation, mathematical expectation and variance, joint probability distribution, simple limit theorems, weak law of large numbers, convergence of series, strong law of large numbers, application, central limit theorem, Chebyshev’s inequality, independence, sampling distributions, simulations about probability.
Prerequisite: MAT 225
Books:
1. Yuri Alexi Rozanov, *Probability Theory: A Concise Course*, Dover Publications, 1977.
2. Edwin T. Jaynes, G. Larry Bretthorst, *Probability Theory: The Logic of Science*, Cambridge University Press, 2003.
3. Alexander MacFarlane, Franklin A Graybill, Duane C. Boes, *Introduction to the Theory of Statistics*,3rd edition, McGraw Hill, 1973.
4. Aram Arutiu͡novich Sveshnikov, *Problems in Probability Theory, Mathematical Statistics and Theory of Random Functions*, Dover Publications, 1979.
5. Sathamangalam Ranga Iyengar Srinivasa Varadhan, *Probabililty Theory*, American Mathematical Society, 2001.
6. Robert B. Ash, *Basic Probability Theory*, Dover Publications, 2008.

MAT 436 Mathematical Statistics (3 credits)

Random variables, distribution functions, expectation and moment generating functions, joint and conditional distributions, stochastic independence, conditional expectation, distributions of functions of random variables, convergence concepts, and parametric estimation by maximum likelihood, sampling distributions, order statistics, point estimation, maximum likelihood estimators, consistency, unbiasedness, mean square error, Cramer-Rao lower bound, asymptotics of statistics, sufficient statistics, uniformly minimum variance and unbiased (UMVU) estimators, lemma of Neyman Pearson, and statistical decision theory.

Prerequisite: MAT 225

Books:

1. Dennis Wackerley, William Mendenball, Richard L. Schaeffer, *Mathematical Statistics with Applications*, 7th edition, Cengage Learning, 2007.
2. Jun Shao, *Mathematical Statistics*, 2nd edition, Springer, 2008.
3. Robert V. Hogg, Joseph McKean, Allen T. Craig, *Introduction to Mathematical Statistics*, 7th edition, Pearson, 2012.
4. Jay L.Devore, Kenneth N. Berk, *Modern Mathematical Statistics with Applications*, 2nd edition, Springer, 2012.
5. Richard J. Larsen, Morris L. Marx, *Introduction to Mathematical Statistics and its Applications*, 5th edition, Pearson, 2011.
6. John A. Rice, *Mathematical Statistics with Data Analysis*, 3rd edition, Cengage Learning, 2006.

MAT 437 Stochastic Processes (3 credits)

Basic theory of the Poisson process, renewal processes, Markov chains in discrete and continuous time, Brownian motion, random walks, applications of these stochastic processes are emphasized by examples, which are drawn from inventory and queuing theory, reliability and replacement theory, finance, population dynamics and other biological models.

Prerequisite: MAT 435

Books:

1. Sheldon M. Ross, *Introduction to Probability Models*, 10th edition, Academic Press.
2. Erhan Cinlar, *Stochastic Processes*, Dover Pulications, 2013.
3. Richard F. Bass, *Stochastic Processes*, Cambridge University Press, 2011.
4. Zdzislaw Brzeznak, Tomasz Zastawniak, *Basic Stochastic Processes*, Springer 2000.
5. Robert G. Gallagher, *Stochastic Process: Theory for Applications*, Cambridge University Press, 2014.
6. Samuel Kerlin, Howard M. Taylor, *A First Course in Stochastic Processes*, 2nd edition, Acaemic Press, 1975.
7. Gregory F. Lawler, *Introduction to Stochastic Processes*, 2nd edition, Chapman and Hall/ CRC, 2006.

MAT 438 Econometrics (3 credits)

Introduction, scope and purpose of econometrics; econometric model, economic theory; data and data problems; single equation models: general linear regression model, Gauss Markov theorem, general linear regression model, multicollinearity, heteroskedasticity, autocorrelation, dynamic models, Almon polynomial distributed models, Koyck transformation, adaptive expectations, instrumental variable estimation, multiple equation models

Prerequisite: Senior Standing

Books:

1. James H. Stock, Mark W. Watson, *Introduction to Econometrics*, 3rd edition, Addison Wesley, 2010.
2. Christopher Dougherty, *Introduction to Econometrics*, 4th edition, Oxford University Press, 2011.
3. Jeffrey M. Woldridge, *Introductory Econometrics: A Modern Approach*, 5th edition, Cengage Learning, 2012.
4. Leighton R. Thomas, *Modern Econometrics: An Introduction*, Longman Group, 1997.

MAT 439 Mathematical Cryptography (3 credits)

Introduction, symmetric and asymmetric ciphers, discrete logarithm problems, Diffie-Hellman key exchange, Elgamal public key cryptosystem, RSA public key cryptosystem, digital signatures RSA, digital signatures Elgamal, lattice cryptography, primality testing, factorizing, Pollard rho method, Pollard p-1 method, elliptic curve cryptography, Lenstra's algorithm.

Prerequisite: Senior Standing

Books:

1. Christof Par, Jan Pelzl, Bart Preneel, U*nderstanding Cryptography: A Textbook for Students and Practitioners*, Springer, 2011.
2. Niels Fergusen, Bruce Schneier, Tadoyashi Kohno, *Cryptography Engineering: Design Principles and Practical Applications*, Wiley, 2010.
3. Jeffrey Hoffstein, Jill Pipher, J. H. Silverman, *An Introduction to Mathematical Cryptography*, Springer, 2008.
4. Fred Piper, Sean Murphy, *Cryptography: An Introduction*, Oxford University Press, 2002.
5. William Stallings, *Cryptography and Network Security: Principles and Practice*, 6th edition, Prentice Hall, 2013.
6. Jonathan Katz, Yehuda Lindell, I*ntroduction to Modern Cryptography: Principles and Protocols*, Chapman and Hall, 2007.

MAT 440 Mathematical Coding Theory (3 credits)

Introduction, basic definitions, maximum likelihood decoding, syndrome decoding, perfect codes, Hamming codes, sphere–packing bound, Self–Dual codes, Golay codes, Reed–Muller codes; Finite fields, structure of a finite field, cyclic codes, the generator polynomial, generator polynomial of the dual code; Group of a code, quadratic residue codes, permutation decoding, cyclic codes given in terms of roots, BCH codes, Reed-Solomon codes; Weight distributions, MacWilliams equations, Pless power moments, Gleason polynomials.

Prerequisite: Senior Standing

Books:

1. Todd K. Moon, *Error Correction Coding, Mathematical Methods and Algorithms*, Wiley, 2005.
2. William C. Huffman, Vera Pless, *Fundamentals of Error Correcting Codes*, Cambridge University Press, 2010.

3. Florence J. MacWilliams, Neils J. A. Sloane, *The Theory of Error-Correcting Codes*, North Holland Publishing Company, 1977.
4. Oliver Pretzel, *Error Correcting Codes and Finite Fields*, Oxford University Press, 1996.
5. Vera Pless, *Introduction to the Theory of Error Correcting Codes*, Wiley, 1998.

MAT 450 Computational Methods II (3 credits)

Numerical solution of ordinary differential equations, Taylor method, Euler and modified Euler methods, Runge-Kutta methods, multistep methods, Adams-Moulton method, Milne method, system of ordinary differential equations; numerical solution of partial differential equations, finite difference, finite elements and finite volume methods, forward, backward and central difference, convergence criterion, Crank-Nicholson method, solution of parabolic, hyperbolic and elliptic boundary value problems, Lax-Wendroff scheme, Courant-Friedrich-Lewy condition; energy method and Galerkin method.

Prerequisite: MAT 340, MAT 350

Books:

1. John C. Butcher, *Numerical Methods for Ordinary Differential Equations*, 2nd edition, Wiley, 2008.
2. Claes Johnson, *Numerical Solution of Partial Differential Equations by Finite Elements Methods*, Dover Publications, 2009.
3. Alfredo Bellen, Marino Zennaro, *Numerical Methods for Delay Differential Equations*, Oxford University Press, 2013.
4. David F. Griffith, Desmond J. Hingham, *Numerical Methods for Ordinary Differential Equations: Initial Value Problems*, Springer, 2010.
5. Mark S. Gockenbach, *Partial Differential Equations: Analytical and Numerical Methods*, 2nd edition, SIAM Publications, 2010.
6. Gordon D. Smith, *Numerical Solution of Partial Differential Equations: Finite Difference Method*, 3rd edition, Oxford University Press, 2010.

MAT 451 Mathematical Modeling (3 credits)

Modeling change with difference equations, Approximating change with difference equations, Solutions to dynamical systems, Systems of difference equations; Modeling process, Proportionality, and Geometric similarity; Fitting models to data graphically, Analytical methods of model fitting, Applying the least square techniques; Experimental modeling, High order polynomial modeling, Cubic spline models; Simulation modeling. Discrete probabilistic modeling. Discrete optimization modeling; Dimensional analysis and similitude. Graphs of functions as models; Modeling with differential equations. Modeling with systems of differential equations

Prerequisite: MAT 350

Books:

1. Mark M. Meerschaert, *Mathematical Modeling*, 4th edition, Academic Press, 2013.
2. Frank R. Giodarno, William P. Fox, Steven B. Horton, *A First Course in Mathematical Modeling*, 5th edition, Cengage Learning, 2013.
3. Walter J. Meyer, *Concepts of Mathematical Modeling*, Dover Publications, 2004.
4. Stefan Heinz, *Mathematical Modeling*, Springer, 2011.
5. Neil Gershenfeld, *The Nature of Mathematical Modeling*, Cambridge University Press, 1998.

6. Kai Velten, M*athematical Modeling and Simulation: Introduction for Scientists and Engineers*, Wiley, 2009.

MAT 453 Special Functions and Transforms (3 credits)

Fourier Series: Fourier series and its convergence. Fourier sine and cosine series. Properties of Fourier series. Operations on Fourier series. Complex form. Applications of Fourier series; Special functions: Gamma function, Error function; Hypergeometric function: hypergeometric equation, special hypergeometric function, generalized hypergeometric function, special confluent hyperbolic functions; Legendre functions: Generating function, recurrence relations and other properties of Legendre polynomials, Expansion theorem, Legendre differential equation, Legendre function of first and second kinds, associated Legendre functions; Bessel functions: Generating function, recurrence relations, Bessel differential equation, Integral representations, Orthogonality relations, Modified Bessel functions; Hermite polynomials, Laguerre polynomials: Generating function, Rodrigue's formula, orthogonal properties, Hermite and Laguerre differential equations, recurrence relations, expansion theorems; Laplace transforms: Basic definitions and properties, Existence theorem. Transforms of derivatives. Relations involving integrals. Transforms of Bessel functions; Laplace transforms of periodic functions, transforms of convolutions, inverse transform, use of contour integration to find inverse Laplace transforms, applications to boundary differential equations; Fourier transforms: Fourier transforms, inversion theorem, sine and cosine transforms, transform of derivatives, transforms of rational function, convolution theorem, Parseval's theorem, applications to boundary value problems and integral equation.

Prerequisite: MAT 340

Books:

1. George Andrews, Richard Askey, Ranjan Roy, *Special Functions*, Cambridge University Press, 2001.
2. William W. Bell, *Special Functions for Scientists and Engineers*, Dover Publications, 2004.
3. Richard Beals, Roderick Wong, *Special Functions*, Cambridge University Press, 2010.
4. Arthur F. Nikiforov, Vasilii B. Uvarov, *Special Functions of Mathematical Physics*, Birkhauser, 2013.
5. Refaat L. Attar, *Special Functions and Orthogonal Polynomials*, Longman, 2006.
6. Nico M. Temme, *Special Functions: An Introduction to the Classical Functions of Mathematical Physics*, Wiley, 1996.

MAT 454 Perturbation Methods (3 credits)

Asymptotics: Asymptotic equivalence. Asymptotic expansions. Properties of asymptotic series. Watson's lemma; Asymptotic solutions of second-order linear equations, expansions near an irregular singularity, expansion for large arguments, equations containing a large parameter, equations involving a small parameter; Perturbation methods**:** Method of strained coordinates. Method of matched asymptotic expansions, method of composite expansions, method of averaging. Method of multiple scales.

Prerequisite: MAT 330

Books:

1. Edward J. Hinch, *Perturbation Methods*, Cambridge University Press, 1991.

2. Mark H. Holmes, *Introduction to Perturbation Methods*, 2nd edition, Springer, 2012.
3. Carl M. Bender, Steven A. Orszag, *Advanced Mathematical Methods for Scientists and Engineers*, Springer, 1999.
4. James G. Simmonds, James E. Mann Jr, *A First Look at Perturbation Theory*, 2nd edition, Dover Publications, 1997.
5. Ali H. Nayfeh, *Perturbation Methods*, Wiley, 1973.
6. Giorgio Eugenio Oscare Giacaglia, *Perturbation Methods in non-Linear Systems*, Springer, 1972.
7. Jirair Kevorkian, J. D. Cole, *Perturbation Methods in Applied Mathematics*, Springer, 1981.

MAT 456 Discrete Dynamical Systems (3 credits)
Introduction, topology of real numbers, periodic points and stable sets, Sarkovskii's theorem, differentiability and its implications, functions and bifurcations, logistic functions: Cantor set and chaos, topological conjugacy, period-doubling cascade, symbolic dynamics, dynamics of complex functions Mandelbrot set, Julia sets, strange attractors, fractals.
Prerequisite: MAT 345
Books:
1. Oded Galor, *Discrete Dynamical Systems*, Springer 2010.
2. Richard Holmgren, *A First Course in Discrete Dynamical Systems*, 2nd edition, Springer, 2000.
3. James T. Sandefur, *Discrete Dynamical Systems: Theory and Applications*, Oxford University Press, 1990.
4. Wei-Bin Zhang, *Discrete Dynamical Systems, Bifurcations and Chaos*, Elsevier, 2006.
5. Mustafa R. S Kulenovic, Orlando Merino, *Discrete Dynamical Systems and Difference Equations*, Chapman and Hall/CRC, 2002.
6. Shlomo Sternberg, *Dynamical Systems*, Dover Publications, 2010.
7. Jacques M. Bahi, Christophe Guyeux, *Discrete Dynamical Systems and Chaotic Machines: Theory and Applications*, CRC Press, 2013.
8. Luis Barreira, Claudia Valls, *Dynamical Systems: An Introduction*, Springer, 2012.
9. Stephen Lynch, *Dynamical Systems with Application in MATLAB*, Birkhauser, 2004.

MAT 459 : Astronomy (3 credits)
Spheres and spherical triangles, the celestial sphere, problems connceted with diurnal motion, astronomical refraction, astronomical instruments, finding the latitude of a place, conversion of coordinates fixing, the ecliptic and the first point of Aries, Kepler's laws, equations of time, unit of time, geocentric parallax, the moon, local line, eclipses, the solar system, precession and mutation, annual parallax, aberration of light, the stellar universe, modern findings of astronomical objects, working process of the Hubble telescope and its findings.

Prerequisite: Senior Standing

Books:

1. Glen Van Brummelen, *Heavenly Mathematics, The Forgotten Art of Spherical Trigonometry*, Princeton University Press, 2012.
2. A. E. Roy and D. Clarke, *Astronomy, Principles and Practise*, 4th edition, CRC Press, 2003.
3. Robin M. Green, *Spherical Astronomy*, Cambridge University Press, 1985.
4. William Marshall Smart, *Textbook on Spherical Astronomy*, 6th edition, Cambridge University Press, 1977.

MAT 460 Astrophysics (3 credits)

Introduction, Astronomical Context: Angular and positional measurements, Brightness measurements, Spectra, Velocity and Distance measurements; Radiation: Photon description of light, Wave description of light, Black body radiation; Classical Dynamics: Newtonian gravity, The 2-body problem, orbits, binary starts, supernovae, Tides and Roche effects, Virial Theorem; Stars and Stellar Structure: Nuclear reactions, Stellar structure, The Lane-Emden equation, Specific cases of polytropic models, White dwarf stars, Beyond the Chandrasekhar mass: Inverse fi decay, Neutron stars and pulsars, Black hole.

Prerequisite: Senior Standing

Books:

1. Jean Dufay, *Introduction to Astrophysics*, Dover Publications, 2012.
2. Bradley W. Carroll, Dale A. Ostlie, *An Introduction to Modern Astrophysics*, 2nd edition, Addison-Wesley, 2006.
3. Leonard S. Kisslinger, *Astrophysics and the Evolution of the Universe*, World Scientific Publishing Company, 2014.
4. Arnab Rai Chaudhuri, *Astrophysicist for Physicists*, Cambridge University Press, 2013.
5. Barbara Ryden, Bradley M. Petersen, *Foundations of Astrophysics*, Addison-Wesley, 2010.
6. Kenneth R. Lang, *Essential Astrophysics*, Springer, 2013.
7. Francis LeBlanc, *Introduction to Stellar Astrophysics*, Wiley, 2010.

MAT 461 Classical Mechanics (3 credits)

Newtonian Mechanics, motion, momentum, energy; Oscillations and harmonic motion; Calculus of variations, Lagrange Equations; Two-body motion, Kepler orbits; non-inertial frames; Rotational motion of rigid bodies; Coupled Oscillations; non-linear mechanics and chaos; Hamiltonian mechanics; collision theory; special relativity; continuum mechanics.

Prerequisite: MAT 330

Books:

1. John R. Taylor, *Classical Mechanics*, University Science Books, 2005.
2. Herbert Goldstein, Charles P. Poole, *Classical Mechanics*, 3rd edition, Addison-Wesley, 2001.
3. Tom W. B. Kibble, Frank H. Birkshire, *Classical Mechanics*, 5th edition, World Scientific Publishing Company, 2004.
4. David Morin, *Introduction to Classical Mechanics*, Cambridge University Press, 2008.
5. Georg Joos, Ira M. Freedman, *Theoretical Physics*, Dover Publications, 1987.
6. Leonard Susskind, George Hrabovsky, *Classical Mechanics*, Penguin Books, 2014.

MAT 462 Quantum Mechanics (3 credits)

Origin of Quantum Mechanics, wave-particle duality, Heisenberg uncertainty principle; Mathematical tools of quantum mechanics, Hilbert space, Dirac notation, vector spaces, Hermitian operators; Postulates of quantum mechanics; One-dimensional problem; Angular momentum; three-dimensional problems; identical particles; stationary states; time-dependent perturbation theory.

Prerequisite: MAT 461

Books:

1. Brian H. Bransden, Charles J. Joachain, *Introduction to Quantum Mechanics*, Longman Publishing Group. 1989.
2. Shan Gao, *Quantum Mechanics: A Comprehensive Introduction*, 3rd edition, Cengage Learning, 2014.
3. Sy M. Blinder, *Introduction to Quantum Mechanics: in Chemistry, Material Science and Biology*, Academic Press, 2000
4. Robert Scherrer, *Quantum Mechanics: An Introduction*, Addison-Wesley, 2006.
5. Nouredine Zettili, *Quantum Mechanics: Concepts and Applications*, 2nd edition, Wiley, 2009.
6. David J. Griffith, *Introduction to Quantum Mechanics*, 2nd edition, Pearson Prentice Hall, 2004.
7. Arthur C. Phillips, *Introduction to Quantum Mechanics*, Wiley, 2003.

MAT 463 Theory of Relativity (3 credits)

Inertial frame, Galilean transformations, Michelson-Morley experiment, Lorentz transformations, postulates of the special theory of relativity, Minkowski's space and its properties, equivalence of mass and energy, relativistic mechanics, relativistic optics, relativistic electrodynamics, principle of covariance, principle of equivalence, relativistic field equations, energy-momentum tensor, Principle of Mach and Einstein's law of gravitation, Schwarzschild's solution of Einstein's equation, tests of general relativity, Cosmology, unified field theory.

Prerequisite: MAT 431, MAT 461

Books:

1. Sean Carroll, *An Introduction to General Relativity, Spacetime and Geometry,* Addison Wesley, 2003.
2. James, Hartle, *Gravity: An Introduction to Einstein's General Relativity,* Addison Wesley, 2002.
3. Bernard Shutz, *A First Course in General Relativity,* Cambridge University Press, 1985.
4. Charles W. Misner, Kip S. Thorne and John Archibald Wheeler, *Gravitation,*W. H. Freeman, 1973.
5. Sartori Lee, *Understanding Relativity,* University of California Press, 1996.
6. Wolfgang Rindler, *Introduction to Special Relativity,* 2nd edition, Oxford University Press, 1991.

MAT 464 Statistical Mechanics (3 credits)

Introduction, subjects of statistical mechanics, entropy, thermodynamics, quantum mechanics; Helmholtz free energy, simple harmonic oscillator; canonical ensemble, canonical probability; irreversibility; quantum ensembles; black-body radiation; harmonic solids;

quantum gases; Bose-Einstein statistics; Fermi-Dirac statistics; Boltzman statistics; insulators and semiconductors.

Prerequisite: MAT 461

Books:

1. Robert H. Swendsen, *An Introduction to Statistical Mechanics and Thermodynamics*, Oxford University Press, 2012.
2. John Dirk Walecka, *Introduction to Statistical Mechanics*, World Scientific Publishing Company, 2011.
3. David Chandler, *Statistical Mechanics*, Oxford University Press, 1987.
4. Terrel L. Hill. *Introduction to Statistical Thermodynamics*, Dover Publications, 1987.
5. Keith Stowe, *An Introduction to Thermodynamics and Statistical Mechanics*, 2nd edition, Cambridge University Press, 2007.
6. Norman Davidson, *Statistical Mechanics*, Dover Publications, 2003.
7. Raj Kumar Pathria, Paul D. Beale, *Statistical Mechanics*, 3rd edition, Academic Press.

MAT 465 Orbital Mechanics (3 credits)

Newton's law and the Kepler Problem, the gravitational two-body problem, reduction of two-body problem into one-body problem, Kepler problem in time, Kepler's equation, perturbation Theory, the Lindstedt-Poincare perturbation theory and its application to the theory of orbits, canonical perturbation theory and its use in the Doffing oscillator, Floquet theory and its use in the Sitnikov problem, the Restricted Three-Body Problem, Jacobian integral, Lagrange points, motion of Trojan asteroids, order and chaos, determination of presence of chaos in orbital motion, Liapunov exponents, deterministic chaos, post-Newtonian celestial mechanics, bending of star light, perihelion shift of Mercury, photon orbit.

Prerequisite: MAT 330

Books:

1. A. E. Roy, *Orbital Motion*, 4th edition, CRC Press, 2004.
2. Victor G. Szebehely and Hans Mark, *Adventures in Celestial Mechanics*, 2nd edition, Wiley, 1998.
3. Nathaniel Grossman, *The Sheer Joy of Celestial Mechanics*, Springer, 1996.
4. J. M. A. Danby, *Fundamentals of Celestial Mechanics*, 2nd edition, Willmann-Bell, 1988.

MAT 469 Atmospheric Physics and Meteorology (3 credits)

Structure of the atmosphere, elementary ideas about the sun and the laws of radiation, definitions and units of solar radiation, depletion of solar radiation in the atmosphere, terrestrial radiation, radiation transfer, heat balance in the atmosphere, heat budget, vertical temperature profile, radiation charts and their uses, composition of the atmosphere, mean molecular weight, humidity, mixing ratio, density and saturation vapor pressure, dynamic meteorology, units and dimension of parameters used in dynamic meteorology, fundamental forces governing the motion of the atmosphere, pressure gradient force, gravitational force, apparent forces in non-inertial frame of references, centrifugal force, coriolis force, structure of the static atmosphere, hydrostatic equation, different frames and coordinates, physical meaning of total and partial differentiation in meteorology, the basic conservation laws, the vector form of momentum equation in rotating coordinates, the component equation in spherical coordinates, continuity equation, the thermodynamic energy equation, thermodynamics of dry atmosphere, applications of the basic equations, balanced flow, trajectories and streamlines, thermal wind, vertical motion circulation and vorticity, elementary ideas of planetary boundary layer, condensation, precipitation and atmospheric electricity, microphysical processes, condensation nuclei, curvature and solute effects, cloud classification, general features, the general circulation of the atmosphere, elementary ideas, fronts, cyclones, the tephigram, tropical meteorology, definition of the region, zones of convergence, vertical structure of the winds, monsoon, depressions, tropical cyclones, elementary ideas about forcasting, synoptic charts, satellite meteorology.

Prerequisite: Senior Standing

Books:

1. J. Holton and G. J. Hakim, *An Introduction to Dynamic Meteorology*, 5th edition, Academic Press, 2012.
2. D.H. Mclntosh and A.S. Thorn, *Essentials of Meteorology*, Taylor and Francis, 1983.
3. H. R. Byers, *General Meteorology*, 4th edition, McGraw Hill, 1974.
4. R. G. Fleagle and J. A. businger, *An Introduction to Atmospheric Physics*, 2nd edition, Academic Press, 1980.
5. H. Riehl, *Tropical Meteorology*, McGraw Hill, 1954.

MAT 470 Fluid Dynamics (3 credits)

Lagrangian and Eulerian description of fluid flow; Velocity and acceleration of fluid particles; steady and unsteady flows; streamlines; pathlines; vortexlines; velocity potential.; Bernoulli's equation; Rotational and irrotational flows; equations of continuity; Euler's equation of motion, conservative field of force; motion under conservative body force; vorticity equations; Motion in two-dimensions; stream function; Circulation and vorticity; Kelvin's circulation theorem; inviscid flow in two dimensions; sources, sinks and doublets, complex potential and complex velocity, stagnation points; Stokes stream function; Vortex motion; vortex tube; vortex pair; vortex rows; Free vortex, Forced vortex, spiral vortex; Wave motion, mathematical representation of wave, surface wave, Canal wave, long wave.

Prerequisite: MAT 340

Books:

1. Alexandre J. Chorin, Jarrold E. Marsden, *A Mathematical Introduction to Fluid Mechanics*, 3rd edition, Springer, 2000.
2. Clifford Truesdell, K. R. Rajagopal, *An Introduction to Mechanics of Fluids*, Birkhauser, 2008.
3. Rutherford Aris, *Vectors, Tensors, and the basic equations of Fluid Mechanics*, Dover Publications, 2012.
4. Pierre-Louis Lions, *Mathematical Topics in Fluid Mechanics: Volume 1, Incompressible Models*, Oxford University Press, 1996.
5. Pierre-Louis Lions, *Mathematical Topics in Fluid Mechanics: Volume 2, Compressible Models*, Oxford University Press, 1998.
6. George K. Batchelor, *An Introduction to Fluid Dynamics*, Cambridge University Press, 2000.
7. Richard E. Meyers, *Introduction to Mathematical Fluid Dynamics*, Dover Publications, 2012.

MAT 472 Mathematical Biology (3 credits)

Single species population dynamics: Linear and nonlinear first order discrete time models, differential equation models, Fibonacci sequences, Leslie Matrix; Population dynamics of interacting species: Predator-prey model, Lotka-Volterra differential equation, competing species, coexistence; Infection disease: Simple epidemic and SIR disease, SIR epidemic, vector-borne disease, basic model for macroparasitic disease; Population genetics and evolution: selection and mutation, Mendelian genetics, Wright's adaptive topography, Molecular and Cellular biology: Biochemical kinetics, metabolic pathways, neural modeling, immunology and AIDS; Pattern formation: Turing instability, Turing bifurcation, activator-inhibitor system; Tumor modeling: phenomenological model, diffusion-limited stage, moving boundary problem, growth promoters and inhibitors, vascularisation, immune system response.

Prerequisite MAT 451

Books:

1. James D. Murray, *Mathematical Biology: An Introduction*, 3rd edition, Springer, 2008.
2. Lee A. Segel, Leah Edelstein-Keshel, *A Primer on Mathematical Models in Biology*, SIAM, 2013.
3. Linda J. S. Allen, *An Introduction to Mathematical Biology*, Pearson, 2006.
4. Brian P. Ingalls, *Mathematical Models in Systems Biology: An Introduction*, MIT Press, 2013.
5. Ronald W. Shonkwiler, James Herod, *Mathematical Biology*, 2nd edition, Springer, 2009.
6. Stephen P. Ellner, John Guckenheimer, *Dynamic Models in Biology*, Princeton University Press, 2011.
7. Hugo van den Berg, *Mathematical Models of Biological Systems*, Oxford University Press, 2011.
8. Nicholas F. Britton, *Essential Mathematical Biology*, Springer, 2005.

MAT 473 Optimization (3 credits)

Unconstrained optimization, conditions for local minimization, Gradient method, Newton's method, Levenberg-Marquardt modification of Newton's method; conjugate direction method; quasi-Newton methods, DFP and BFGS algorithms; least-square analysis, Kaczmarz's algorithm; linear programming, introduction, simplex algorithm, duality, non-simplex method, Khachiyan's method, Karmarkar's method; non-linear programming, problems with equality constraints, tangent and normal spaces, Lagrange conditions; problems with inequality conditions, Karush-Kuhn-Tucker conditions; Convex optimization problems; algorithms for constrained optimization problems.

Prerequisite: Senior Standing

Books:

1. Edwin K. P. Chong, Stanislaw H. Zak, *An Introduction to Optimization*, 4th edition, Wiley, 2013.
2. Dmitri Bertsimas, John N. Tsitsiklis, *Introduction to Linear Optimization*, Athena, 1997.
3. Urmila Diwekar, *Introduction to Applied Optimization*, Springer, 2010.

4. Xin-She Yang, *Engineering Optimization: An Introduction with Metaheuristic Applications*, Wiley, 2010.
5. Stephen Boyd, Lieven Vandenberghe*, Convex Optimization*, Cambridge University Press, 2004.
6. Stephen Nash, Ariela Sofer, *Linear and Nonlinear Programming*, McGraw Hill, 1995.
7. Jorge Nochedal, Stephen Wright, *Numerical Optimization*, 2nd edition, Springer, 2006.

MAT 474 Computer Graphics (3 credits)
Graphics devices; graphics coordinate systems; programming tools for graphics; lines and curves; turtle graphics; elementary clipping: Cohen–Sutherland algorithm; generating curves of pictures; affine transformation; elementary three-dimensional object modeling; orthographic and perspective projections.
Prerequisite: Senior Standing
Books:
1. David F. Rogers, J. Alan Adams, *Mathematical Elements for Computer Graphics*, 2nd edition, McGraw Hill, 1989.
2. Alexendre Hardy, Willi-Hans Steeb, *Mathematical Tools in Computer Graphics*, World Scientific Publishing Company, 2008.
3. John Vince, *Mathematics for Computer Graphics*, 4th edition, Springer, 2013.
4. Eric Lengyel, *Mathematics for 3D Game Programming and Computer Graphics*, 2nd edition, Cengage Learning, 2003.
5. John F. Hughes, Andries van Dam, Morgan McGuire, David F. Sklar, James D. Foley, Steven K. Feiner, Kurt Akeley, *Computer Graphics: Principles and Practice*, 3rd edition, Prentice Hall, 2013.
6. Steven J. Gortler, *Foundations of 3D Computer Graphics*, MIT Press, 2012.
7. Peter Shirley, Michael Ashikhmin, Steve Marschner, *Fundamental of Computer Graphics*, 3rd edition, AK Peters/CRC Press, 2009.

MAT 475 Financial Mathematics (3 credits)
This course is an introduction to the fundamental concepts of mathematical finance in an elementary setting. Topics include: risk, return, no arbitrage principle; basic financial derivatives: options, forwards and future contracts; risk free assets, time value of money, zero coupon bonds; risky assets, binomial tree model, fundamental theorem of asset pricing; portfolio management and capital asset pricing model; no arbitrage pricing of financial derivatives.
Prerequisite: Senior Standing
Books:
1. Ali Hirsa, Salih N. Neftci, *Introduction to Mathematics of Financial Derivatives*, 3rd edition, Academic Press, 2013.
2. Marek Capinski, Tomasz Zastawniak, *Mathematics for Finance: An Introduction to Financial Engineering*, 2nd edition, Springer, 2011.
3. Paul Wilmott, Sam Howison, Jeff Dewynne, *Mathematics of Financial Derivatives: An Introduction*, Cambridge University Press, 1995.

4. Desmond Higham, *An Introduction to Financial Option Valuation: Mathematics, Stochastic and Computation*, Cambridge University Press, 2004.
5. Robert J. Buchanan, *An Introduction to Financial Mathematics*, 2^{nd} edition, World Scientific Publishing Company, 2008.
6. Hansjoerg Albrecher, Andreas Binder, Volkmar Lautscham, Philipp Mayer, *Introduction to Quantitative Methods for Financial Markets*, Birkhauser, 2013.

MAT 476 Actuarial Mathematics (3 credits)

An introduction to actuarial work in non-life insurance. Decision theory concepts: game theory, optimum strategies, decision functions, risk functions, the minimax criterion and the Bayes criterion. Loss distributions with and without limits and risk-sharing arrangements; suitable, moments and moment generating functions, the gamma, exponential, Pareto, generalised Pareto, normal, lognormal, Weibull, Burr and other distributions suitable for modelling individual and aggregate losses; statistical inference. Risk models involving frequency and severity distributions; the basic short-term contracts, moments, moment generating functions and other properties of compound distributions. Reinsurance treaties; proportional, excess of loss, stop-loss, deriving the distribution, moments, moment generating functions and other properties of the losses to the insurer and reinsurer under all the models above. Ruin theory for continuous and discrete models. Fundamental concepts of Bayesian statistics; Bayes theorem, prior distributions, posterior distributions, conjugate prior distributions, loss functions, Bayesian estimators. Credibility theory; Bayesian models. Experience rating models and applications. Claims reserving: run-off triangles. Monte-Carlo simulation and applications in insurance.

Prerequisite: Senior Standing

Books:

1. S. David Promislow, *Fundamentals of Actuarial Mathematics*, 2^{nd} edition, Wiley, 2010.
2. Newton L. Bowers, Hans U. Gerber, James C. Hickman, Donald A. Jones and Cecil J. Nesbitt, *Actuarial Mathematics*, 2^{nd} edition, Society of Actuaries, 1997.
3. David C. M. Dickson, Mary R. Hardy and Howard R. Waters, *Actuarial Mathematics for Life Contingency Risks*, Cambridge University Press, 2013.
4. Arjun K. Gupta and Tamas Varga, *An Introduction to Actuarial Mathematics*, Springer, 2002.

MAT 489 Special Topics (3 credits)

Prerequisite: Senior Standing, Permission of Department

MAT 499 Senior Project (6 credits)

Prerequisite: Senior Standing, Permission of Department

4 year plan

Year	Semester	Courses	Total credits

1	Semester 1	1. Communication Skills 1 2. Numeracy 1 3. Natural Sciences 1 4. Humanities/Social Sciences 1	12-13
1	Semester 2	1. Communication Skills 2 2. Numeracy 2 3. Natural Sciences 2 4. Humanities/Social Sciences 2	12-13
1	Semester 3	1. Communication Skills 3 2. Humanities/Social Sciences 3 3. MAT 120 4. MAT 125	12
2	Semester 4	1. Computer Skills (CSC 101, CSC 101L) 2. Humanities/Social Sciences 4 3. MAT 225 4. MAT 222	13
2	Semester 5	1. Minor 1 2. MAT 215 3. MAT 325 4. MAT 230 5. MAT 199L	13
2	Semester 6	1. Minor 2 2. MAT 220 3. MAT 330 4. MAT 299L 5. LFE 201	13
3	Semester 7	1. Minor 3 2. MAT 340 3. MAT 345 4. MAT 306 5. MAT 306L	13
3	Semester 8	1. Minor 4 2. MAT 350 3. MAT 350L 4. Concentration 1 5. Concentration 2	13

3	Semester 9	1. Minor 5 2. Concentration 3 3. Concentration 4 4. MAT 399L	10
4	Semester 10	1. Optional 1 2. Optional 2 3. Optional 3 4. Optional 4	12
4	Semester 11	1. Optional 5 2. MAT 499	9
4	Semester 12	Completion of MAT 499	
			132-134