Mathematics

See also Applied Mathematics (http://catalog.yale.edu/ycps/subjects-of-instruction/applied-mathematics).

Director of undergraduate studies: Andrew Casson, 216 LOM, 432-7056, andrew.casson@yale.edu; math.yale.edu

FACULTY OF THE DEPARTMENT OF MATHEMATICS

Professors Andrew Casson, Ronald Coifman, Igor Frenkel, Alexander Goncharov, Roger Howe, Peter Jones, Mikhail Kapranov; Gregory Margulis, Yair Minsky, Vincent Moncrief, Hee Oh, David Pollard, Vladimir Rokhlin, Peter Schultheiss (Emeritus), Van Vu, Gregg Zuckerman

Associate Professor Sam Payne

J. W. Gibbs Assistant Professors Asher Auel, Xiuyuan Cheng, Asaf Ferber, Steven Frankel, José González, Michael Magee, You Qi, Manas Rachh, Ilia Smilga, Stefan Steinerberger, Sam Taylor, Giulio Tiozzo, Guy Wolf

Adjunct Professors Michael Frame, Gil Kalai, Alex Lubotzky

Lecturers Marketa Havlickova, Miriam Logan, James Rolf

Helmsley Postdoctoral Teaching Scholars Lake Bookman, Brett Smith

Statistics Faculty Andrew Barron, Joseph Chang, John Hartigan (Emeritus), David Pollard

Mathematics has many aspects: it is the language and tool of the sciences, a cultural phenomenon with a rich historical tradition, and a model of abstract reasoning. The course offerings and the major in Mathematics reflect these multiple facets. The Mathematics major provides a broad education in various areas of mathematics in a program flexible enough to accommodate many ranges of interest.

Placement in courses The department offers a three-term sequence in calculus, MATH 112, 115, and 120. Students who have not taken calculus at Yale and who wish to enroll in calculus must take the mathematics online placement examination; a link to the online examination and additional information are available on the departmental Web site (http://math.yale.edu/undergrad/placement-exam). A calculus advising session will be held at the beginning of the fall term to answer student questions about placement.

MATH 112 is an introductory course that presupposes basic skills in high school algebra, geometry, and trigonometry. Enrolling students are expected to know the basic definitions of the trigonometric functions, synthetic division, factorization, and elementary area and volume formulas of plane and solid geometry. MATH 115 presupposes familiarity with the topics covered in MATH 112. MATH 120 presupposes familiarity with the topics covered in MATH 115.

MATH 230, 231 is an advanced course sequence in linear algebra and introductory analysis for students with exceptionally strong backgrounds in mathematics. Students who wish to enroll in MATH 230 should consult with the instructor of the course. After MATH 115, students with a strong interest in abstract mathematics should consider taking MATH 230, 231.

B.A. and B.S. degree programs The prerequisite for each program is calculus through the level of MATH 120 or the equivalent.

Each program normally consists of ten term courses in Mathematics numbered 222 or higher, including MATH 480. These ten may include no more than five term courses from other institutions. Each student is expected to take vector calculus and linear algebra: either MATH 230 and 231, or one of MATH 222 or 225 and MATH 250. To acquire both depth and breadth in the field, students are required to take at least two term courses in each of three of the following five categories: analysis, algebra and number theory, statistics and applied mathematics, geometry and topology, and logic and foundations. Each major program must also include at least one course in at least two of the three core areas: real analysis, algebra, and complex analysis. Taking courses from all three core areas is strongly recommended. To be eligible for Distinction in the Major, a student must have completed at least one course from each of the three core areas. The categories and core areas to which each course belongs are indicated in the course listings.

A candidate for the B.S. degree must take at least two advanced term courses in the physical sciences, such as CHEM 328, 332, 333, or PHYS 401, 402, in addition to the ten term courses required for the B.A. degree. Such courses require the approval of the director of undergraduate studies; written approval is advised.

Any student interested in pursuing further study in pure mathematics should include MATH 301, 305, 310, 350, 370, and 430 in his or her program, and should consider taking one or more graduate-level courses. Students interested in applications of mathematics should include MATH 300 or 301, 310, 350, and a selection of courses from MATH 241, 242, 244, 246, 251, 260, and CPSC 440.

Senior requirement During the senior year students majoring in Mathematics normally take the senior seminar (MATH 480). Alternatively, with the consent of the director of undergraduate studies, highly qualified students may write a senior essay in MATH 475 under the guidance of a faculty member, and give an oral report to the department. Students wishing to write a senior essay should consult the director of undergraduate studies early in the fall term.

Credit/D/Fail Courses taken Credit/D/Fail may not be counted toward the requirements of the major.
Courses related to mathematics Each Mathematics major is urged to acquire additional familiarity with the uses of mathematics by taking courses in Applied Mathematics (http://catalog.yale.edu/ycps/subjects-of-instruction/applied-mathematics), Computer Science (http://catalog.yale.edu/ycps/subjects-of-instruction/computer-science), Engineering and Applied Science (http://catalog.yale.edu/ycps/subjects-of-instruction/engineering-applied-science), Economics (http://catalog.yale.edu/ycps/subjects-of-instruction/economics), Philosophy (http://catalog.yale.edu/ycps/subjects-of-instruction/philosophy), Physics (http://catalog.yale.edu/ycps/subjects-of-instruction/physics), Statistics (http://catalog.yale.edu/ycps/subjects-of-instruction/statistics), or other departments. In some instances a limited number of such courses may be counted among the ten courses required for the major in Mathematics, with the approval of the director of undergraduate studies.

Each year the Mathematics and Statistics departments offer a large number of graduate courses, some of which are accessible to undergraduates with advanced preparation in mathematics. Further information may be obtained from the director of undergraduate studies whose permission, with that of the relevant director of graduate studies, is required for admission.

The intensive major Candidates for a degree with an intensive major in Mathematics must take courses in all three of the core areas: real analysis, algebra, and complex analysis. Intensive majors are also expected to include at least two graduate term courses in the Mathematics department, or equivalent independent study, in their programs. Familiarity with the material of the following courses is prerequisite to graduate courses in each category: algebra: two courses between 350 and 399; analysis: MATH 301, 305, 310; algebraic topology: MATH 301, 350; logic and foundations: MATH 270.

Combined B.S./M.S. degree program Students who, by the end of their senior year, complete the requirements of the department for the M.S. in Mathematics are eligible to receive this degree at their Senior Commencement. Required are: (1) eight term courses numbered 500 or higher, most of which must be completed with grades of B or better; (2) satisfactory performance on a general oral examination.

The master’s program is in no sense a substitute for the B.A. or B.S. program; rather, it is designed to accommodate a very few exceptional students who, by means of accelerated or independent study, can satisfy the department as to their command of the content of the normal undergraduate program by the end of the junior year. Candidates must submit a proposal that foresees this level of achievement to the director of undergraduate studies no later than the last day of classes in their fifth term of enrollment in Yale College.

If approved by the department, the proposal is forwarded to the Yale College Dean’s Office. Students' status and progress are reviewed before they are permitted to continue in the program in the senior year. For more information on Yale College requirements for the program, see “Simultaneous Award of the Bachelor’s and Master’s Degrees” in Section K, Special Arrangements (http://catalog.yale.edu/ycps/academic-regulations/special-arrangements), in the Academic Regulations.

Students take at least two graduate term courses in the junior year (normally courses in algebra or analysis are the first graduate courses taken). The general oral examination covers a list of topics available from the director of graduate studies and is accepted in lieu of the usual senior oral presentation. Details concerning the requirements for the master’s degree may be obtained from the director of graduate studies.

REQUIREMENTS OF THE MAJOR

Prerequisite MATH 120 or equivalent

Number of courses B.A. — 10 term courses numbered 222 or higher, incl MATH 480; B.S. — same, with 2 addtl courses in physical sciences

Specific courses required MATH 230 and 231; or MATH 222 or 225, and MATH 250

Distribution of courses B.A. — 2 courses in each of 3 categories chosen from analysis, algebra and number theory, stat and applied math, geometry and topology, logic and foundations; courses from 2 of 3 core areas, as specified; B.S. — same, with 2 addtl advanced courses in physical sciences approved by DUS

Substitution permitted With DUS permission, certain courses in Applied Math, Comp Sci, Engineering & Applied Science, Econ, Phil, Physics, Stat

Intensive major Courses in all 3 core areas; 2 grad courses or equivalent independent study counted among the required courses

Senior requirement Senior sem (MATH 480) or, with DUS permission, senior essay (MATH 475) and oral report

MATH 101, Geometry of Nature

* MATH 107a, Mathematics in the Real World Brett Smith

The use of mathematics to address real-world problems. Applications of exponential functions to compound interest and population growth; geometric series in mortgage payments, amortization of loans, present value of money, and drug doses and blood levels; basic probability, Bayes’s rule, and false positives in drug testing; elements of logic. No knowledge of calculus required. Enrollment limited to students who have not previously taken a high school or college calculus course. Q8

MATH 108b, Estimation and Error Miriam Logan

A problem-based investigation of basic mathematical principles and techniques that help make sense of the world. Estimation, order of magnitude, approximation and error, counting, units, scaling, measurement, variation, simple modeling. Applications to demographics,
* MATH 112a or b, Calculus of Functions of One Variable I  
Staff
Limits and their properties. Definitions and some techniques of differentiation and the evaluation of definite integrals, with applications. Use of the software package Mathematica to illustrate concepts. No prior acquaintance with calculus or computing assumed.  

* MATH 115a or b, Calculus of Functions of One Variable II  
Staff
A continuation of MATH 112. Applications of integration, with some formal techniques and numerical methods. Improper integrals, approximation of functions by polynomials, infinite series. Exercises involve the software package Mathematica. After MATH 112 or equivalent; open to freshmen with some preparation in calculus. May not be taken after MATH 116.  

* MATH 116a or b, Mathematical Models in the Biosciences I: Calculus Techniques  
Michael Frame
Introduction to topics in mathematical modeling that are applicable to biological systems. Discrete and continuous models of population, neural, and cardiac dynamics. Stability of fixed points and limit cycles of differential equations. Applications include Norton’s chemotherapy scheduling and stochastic models of tumor suppressor gene networks. After MATH 112 or equivalent. May not be taken after MATH 115.  

* MATH 118a or b, Introduction to Functions of Several Variables  
Staff
A combination of linear algebra and differential calculus of several variables. Matrix representation of linear equations, Gauss elimination, vector spaces, independence, basis and dimension, projections, least squares approximation, and orthogonality. Three-dimensional geometry, functions of two and three variables, level curves and surfaces, partial derivatives, maxima and minima, and optimization. Intended for students in the social sciences, especially Economics. May not be taken after MATH 120 or 222. Prerequisite: MATH 112.  

* MATH 120a or b, Calculus of Functions of Several Variables  
Staff
Analytic geometry in three dimensions, using vectors. Real-valued functions of two and three variables, partial derivatives, gradient and directional derivatives, level curves and surfaces, maxima and minima. Parametrized curves in space, motion in space, line integrals; applications. Multiple integrals, with applications. Divergence and curl. The theorems of Green, Stokes, and Gauss. After MATH 115, or with permission of instructor. May not be taken after MATH 121.  

* MATH 160b / AMTH 160b, The Structure of Networks  
Alexander Cloninger
Network structures and network dynamics described through examples and applications ranging from marketing to epidemics and the world climate. Study of social and biological networks as well as networks in the humanities. Mathematical graphs provide a simple common language to describe the variety of networks and their properties.  

MATH 190a or b, Fractal Geometry  
Michael Frame
A visual introduction to the geometry of fractals and the dynamics of chaos, accessible to students not majoring in science. Study of mathematical patterns repeating on many levels and expressions of these patterns in nature, art, music, and literature.  

MATH 222a or b / AMTH 222a or b, Linear Algebra with Applications  
Staff
Math: Algebra/Number Theory  

MATH 225a or b, Linear Algebra and Matrix Theory  
Staff
An introduction to the theory of vector spaces, matrix theory and linear transformations, determinants, eigenvalues, and quadratic forms. Some relations to calculus and geometry are included. After or concurrently with MATH 120. May not be taken after MATH 222.  
Psychology: AdvSci NeuroTrk  
Math: Algebra/Number Theory  

[ MATH 228, From Euclid to Einstein ]

* MATH 230a, Vector Calculus and Linear Algebra I  
Giulio Tiozzo
A careful study of the calculus of several variables, combined with linear algebra.  
Math: Algebra/Number Theory  

* MATH 231b, Vector Calculus and Linear Algebra II  
Giulio Tiozzo
Continuation of MATH 230. Application of linear algebra to differential calculus. Inverse and implicit function theorems; the idea of a manifold; integration of differential forms; general Stokes’ theorem.  
Math: Analysis  

* MATH 235b, Reflection Groups  
Asher Auel
Concepts of linear algebra are used to explore the algebraic and geometric properties of groups generated by reflections. Examples from reflection groups introduce elements of group theory, Lie algebras, and representation theory. Reflections in a real Euclidean space, groups generated by reflections, crystallographic groups, and Coxeter groups. Preference to sophomores majoring in mathematics or the sciences. Prerequisite: MATH 222 or 225.  

Math: Algebra/Number Theory

MATH 241a / STAT 241a, Probability Theory  Harrison Zhou
Introduction to probability theory. Topics include probability spaces, random variables, expectations and probabilities, conditional probability, independence, discrete and continuous distributions, central limit theorem, Markov chains, and probabilistic modeling. After or concurrently with MATH 120 or equivalent.  QR
Math: Stat/Applied Math

MATH 242b / STAT 242b, Theory of Statistics  Andrew Barron
Study of the principles of statistical analysis. Topics include maximum likelihood, sampling distributions, estimation, confidence intervals, tests of significance, regression, analysis of variance, and the method of least squares. Some statistical computing. After STAT 241 and concurrently with or after MATH 222 or 225, or equivalents.  QR
Math: Stat/Applied Math

MATH 244a / AMTH 244a, Discrete Mathematics  Asaf Ferber
Basic concepts and results in discrete mathematics: graphs, trees, connectivity, Ramsey theorem, enumeration, binomial coefficients, Stirling numbers. Properties of finite set systems. Recommended preparation: MATH 115 or equivalent.  QR
Math: Stat/Applied Math
Math: Algebra/Number Theory

MATH 246a or b, Ordinary Differential Equations  Staff
First-order equations, second-order equations, linear systems with constant coefficients. Numerical solution methods. Geometric and algebraic properties of differential equations. After MATH 120 or equivalent; after or concurrently with MATH 222 or 225 or equivalent.  QR
Math: Analysis
Math: Stat/Applied Math

MATH 247b / AMTH 247b / G&G 247b, Partial Differential Equations  Ronald Coifman
Introduction to partial differential equations, wave equation, Laplace’s equation, heat equation, method of characteristics, calculus of variations, series and transform methods, and numerical methods. Prerequisites: MATH 222 or 225, MATH 246, and ENAS 194, or equivalents.  QR
Math: Stat/Applied Math

MATH 250a, Vector Analysis  Andrew Casson
Calculus of functions of several variables, using vector and matrix methods. The derivative as a linear mapping. Inverse and implicit function theorems. Transformation of multiple integrals. Line and surface integrals of vector fields. Curl and divergence. Differential forms. Theorems of Green and Gauss; general Stokes’ theorem. After MATH 120, and 222 or 225 or equivalent.  QR
Math: Analysis
Math: Stat/Applied Math

MATH 251b / ENAS 496b / STAT 251b, Stochastic Processes  Amin Karbasi
Introduction to the study of random processes including linear prediction and Kalman filtering, Poison counting process and renewal processes, Markov chains, branching processes, birth-death processes, Markov random fields, martingales, and random walks. Applications chosen from communications, networking, image reconstruction, Bayesian statistics, finance, probabilistic analysis of algorithms, and genetics and evolution. After STAT 241 or equivalent.  QR
Math: Stat/Applied Math

MATH 260a / AMTH 260a, Basic Analysis in Function Spaces  Stefan Steinerberger
Diagonalization of linear operators, with applications in physics and engineering; calculus of variations; data analysis. MATH 260 is a natural continuation of PHYS 301. Prerequisites: MATH 120, and 222 or 225.  QR
Math: Analysis
Math: Stat/Applied Math

MATH 270a, Set Theory  Gregg Zuckerman
Algebra of sets; finite, countable, and uncountable sets. Cardinal numbers and cardinal arithmetic. Order types and ordinal numbers. The axiom of choice and the well-ordering theorem. After MATH 120 or equivalent.  QR
Math: Logic/Foundations

MATH 290a, Fractal Geometry: Concepts and Applications  Hee Oh
An examination of mathematical patterns repeating on many levels. Mathematical concepts of fractals and chaos, and application of these tools to modeling natural phenomena. Prerequisites: MATH 120 and 222 or equivalent.  QR
Math: Geometry/Topology

MATH 300b, Topics in Analysis  Stefan Steinerberger
An introduction to analysis, with topics chosen from infinite series, the theory of metric spaces, and fixed-point theorems with applications. Students who have taken MATH 230, 231 should take MATH 301 instead of this course. After MATH 250 or with permission of instructor.  QR
Math: Core Real Analysis
Math: Analysis

* MATH 301a, Introduction to Analysis  Peter Jones
Foundations of real analysis, including metric spaces and point set topology, infinite series, and function spaces. After MATH 230, 231 or equivalent. QR
Math: Core Real Analysis
Math: Analysis

MATH 305b, Real Analysis  Yair Minsky
The Lebesgue integral, Fourier series, applications to differential equations. After MATH 301 or with permission of instructor. QR
Math: Core Real Analysis
Math: Analysis

MATH 310a, Introduction to Complex Analysis  Gregory Margulis
Math: Core Complex Analysis
Math: Analysis
Math: Stat/Applied Math

* MATH 315b, Intermediate Complex Analysis  Giulio Tiozzo
Continuation of MATH 310. Topics may include argument principle, Rouché’s theorem, Hurwitz theorem, Runge’s theorem, analytic continuation, Schwarz reflection principle, Jensen’s formula, infinite products, Weierstrass theorem. Functions of finite order, Hadamard’s theorem, meromorphic functions. Mittag-Leffler’s theorem, subharmonic functions. After MATH 310. QR RP
Math: Core Complex Analysis
Math: Analysis

* MATH 320a, Measure Theory and Integration  Guy Wolf
Construction and limit theorems for measures and integrals on general spaces; product measures; Lp spaces; integral representation of linear functionals. After MATH 305 or equivalent. QR RP
Math: Core Real Analysis
Math: Analysis

* MATH 325b, Introduction to Functional Analysis  Michael Magee
Hilbert, normed, and Banach spaces; geometry of Hilbert space, Riesz-Fischer theorem; dual space; Hahn-Banach theorem; Riesz representation theorems; linear operators; Baire category theorem; uniform boundedness, open mapping, and closed graph theorems. After MATH 320. QR RP
Math: Core Real Analysis
Math: Analysis

MATH 330b / STAT 330b, Advanced Probability  David Pollard
Measure theoretic probability, conditioning, laws of large numbers, convergence in distribution, characteristic functions, central limit theorems, martingales. Some knowledge of real analysis assumed. QR
Math: Stat/Applied Math

* MATH 345a, Modern Combinatorics  Van Vu
Recent developments and important questions in combinatorics. Relations to other areas of mathematics such as analysis, probability, and number theory. Topics include probabilistic method, random graphs, random matrices, pseudorandomness in graph theory and number theory, Szemeredi's theorem and lemma, and Green-Tao's theorem. Prerequisite: MATH 244. QR
Math: Stat/Applied Math
Math: Algebra/Number Theory

MATH 350a, Introduction to Abstract Algebra  Asher Auel
Group theory, structure of Abelian groups, and applications to number theory. Symmetric groups and linear groups including orthogonal and unitary groups; properties of Euclidean and Hermitian spaces. Some examples of group representations. Modules over Euclidean rings, Jordan and rational canonical forms of a linear transformation. After MATH 222 or equivalent. QR
Math: Core Algebra
Math: Algebra/Number Theory

[ MATH 353, Introduction to Representation Theory ]

* MATH 354b, Number Theory  Ilia Smilga
Prime numbers; quadratic reciprocity law, Gauss sums; finite fields, equations over finite fields; zeta functions. After MATH 350. QR
Math: Algebra/Number Theory
MATH 360a, Introduction to Lie Groups  Ilia Smilga
Lie groups as the embodiment of the idea of continuous symmetry. The exponential map on matrices and applications; spectral theory; examples and structure of Lie groups and Lie algebras; connections with geometry and physics. After MATH 231 or 250 or equivalent. MATH 300 or 301 and MATH 350 recommended.  QR
Math: Geometry/Topology
Math: Algebra/Topology

MATH 370b, Fields and Galois Theory  Marketa Havlickova
Rings, with emphasis on integral domains and polynomial rings. The theory of fields and Galois theory, including finite fields, solvability of equations by radicals, and the fundamental theorem of algebra. Quadratic forms. After MATH 350.  QR
Math: Algebra/Number Theory
Math: Core Algebra

MATH 373a, Algebraic Number Theory  Alexander Goncharov
Structure of fields of algebraic numbers (solutions of polynomial equations with integer coefficients) and their rings of integers; prime decomposition of ideals and finiteness of the ideal class group; completions and ramification; adeles and ideles; zeta functions. Prerequisites: MATH 310 and 370.  QR
Math: Algebra/Number Theory

MATH 380a, Modern Algebra I  Samuel Payne
A survey of algebraic constructions and theories at a sophisticated level. Topics include categorical language, free groups and other free objects in categories, general theory of rings and modules, artinian rings, and introduction to homological algebra. After MATH 350 and 370.  QR RP
Math: Algebra/Number Theory
Math: Core Algebra

MATH 381b, Modern Algebra II  You Qi
Topics in commutative algebra: general extension of fields; Noetherian, local, and Dedekind rings. Introduction to valuation theory. Rudiments of algebraic geometry. After MATH 380.  QR RP
Math: Algebra/Number Theory
Math: Core Algebra

MATH 420a, Introduction to Ergodic Theory  Gregory Margulis
An introduction to ergodic theory. Recurrence, including Poincare recurrence theorem; ergodicity and ergodic theorems, including the mean ergodic theorem and the individual ergodic theorem; measure preserving transformations with discrete spectrum; mixing and weak mixing; entropy; topological dynamics and topological entropy; applications to combinatorial number theory; homogeneous dynamics with applications to number theory. Prerequisite: MATH 305.  QR

MATH 430b, Introduction to Algebraic Topology  Andrew Casson
The theory of fundamental groups and covering spaces, with particular reference to two-dimensional manifolds. After MATH 350, and 300 or 301, or equivalents.  QR
Math: Geometry/Topology

MATH 435, Differential Geometry

MATH 440b, Introduction to Algebraic Geometry  David Jensen
An introduction to algebraic geometry through the study of algebraic curves. Topics include curves in the projective plane and their intersection theory; Bezout's theorem; divisors and line bundles; the Riemann-Hurwitz formula; hyperelliptic curves; and the Riemann-Roch theorem. Prerequisites: MATH 310, 350, and some background in differential forms.  QR
Math: Algebra/Number Theory

MATH 470a or b, Individual Studies  Andrew Casson
Individual investigation of an area of mathematics outside of those covered in regular courses, involving directed reading, discussion, and either papers or an examination. A written plan of study approved by the student's adviser and the director of undergraduate studies is required. The course may normally be elected for only one term.

MATH 475a or b, Senior Essay  Andrew Casson
Highly qualified students may write a senior essay under the guidance of a faculty member, and give an oral report to the department. Students wishing to write a senior essay should consult the director of undergraduate studies early in the fall term.

MATH 480a or b, Senior Seminar: Mathematical Topics  Staff
A number of mathematical topics are chosen each term—e.g., differential topology, Lie algebras, mathematical methods in physics—and explored in one section of the seminar. Students present several talks on the chosen topic. One section each year is devoted to topics of interest to Economics and Mathematics majors, and is co-taught by a member of the Economics department.
OTHER COURSES RELATED TO MATHEMATICS

CPSC 201a or b, Introduction to Computer Science  Stephen Slade
Introduction to the concepts, techniques, and applications of computer science. Topics include computer systems (the design of
compilers and their languages); theoretical foundations of computing (computability, complexity, algorithm design); and artificial
intelligence (the organization of knowledge and its representation for efficient search). Examples stress the importance of different
problem-solving methods. After CPSC 112 or equivalent.  QR
Math: Stat/Applied Math

CPSC 365b, Design and Analysis of Algorithms  Daniel Spielman
Paradigms for problem solving: divide and conquer, recursion, greedy algorithms, dynamic programming, randomized and probabilistic
algorithms. Techniques for analyzing the efficiency of algorithms and designing efficient algorithms and data structures. Algorithms for
graph theoretic problems, network flows, and numerical linear algebra. Provides algorithmic background essential to further study of
computer science. After CPSC 202 and 223.  QR
Math: Stat/Applied Math

CPSC 440b, Numerical Computation  Vladimir Rokhlin
Algorithms for numerical problems in the physical, biological, and social sciences: solution of linear and nonlinear systems of equations,
interpolation and approximation of functions, numerical differentiation and integration, optimization. After CPSC 112 or an equivalent
introductory programming course; MATH 120; and MATH 222 or 225 or CPSC 202.  QR
Math: Stat/Applied Math

PHIL 267a, Mathematical Logic  Sun-Joo Shin
An introduction to the metatheory of first-order logic, up to and including the completeness theorem for the first-order calculus.
Introduction to the basic concepts of set theory. Prerequisite: PHIL 115 or permission of instructor.  QR
Math: Logic/Foundations

* PHIL 427b, Computability and Logic  Sun-Joo Shin
A technical exposition of Gödel's first and second incompleteness theorems and of some of their consequences in proof theory and model
theory, such as Löb's theorem, Tarski's undefinability of truth, provability logic, and nonstandard models of arithmetic. Prerequisite:
PHIL 267 or permission of instructor.  QR, HU
Math: Logic/Foundations