

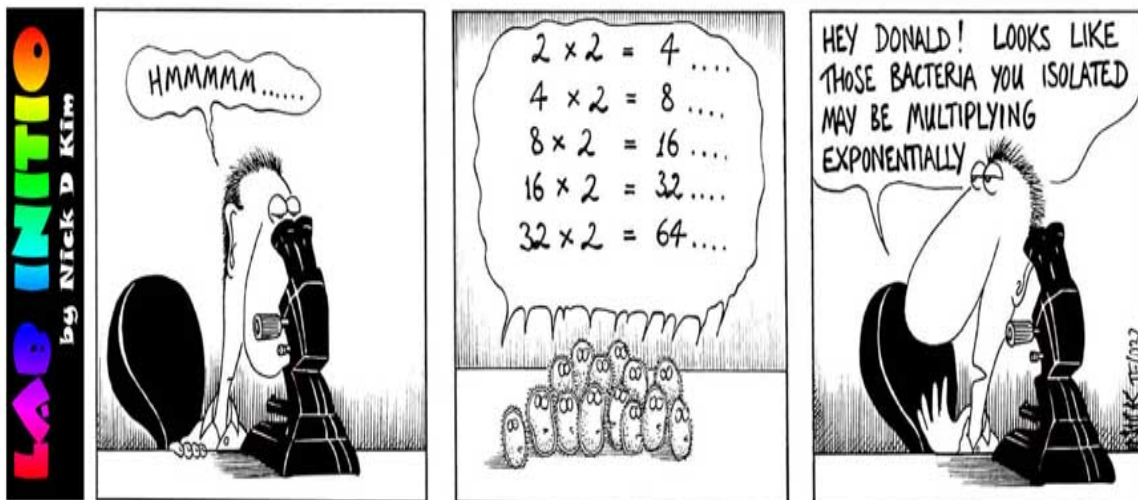
*Claremont Colleges*

# *Mathematics Courses*

*offered the*

*2008 - 2009*

*Academic Year*



## *Mathematics Courses for the 2008-2009 Academic Year*

The list of Claremont Colleges mathematics courses included in this booklet is prepared annually for the convenience of students and faculty. Since the preparation of this catalog is completed prior to the beginning of the academic school year, changes in scheduled classes and / or instructors may occur. As a result, readers will need to verify courses and acquire day / time scheduling from respective on-line catalogs prior to registration.

Some remarks on the course numbering system are appropriate. A subcommittee of the Field Committee chooses the course numbers. With few exceptions, courses at different colleges having the same numbers will have equivalent content. Courses with numbers below 100 are lower division courses. Upper division courses are assigned numbers according to sub-fields in mathematics. **Please do not assume that larger numbers indicate higher levels of difficulty.** Courses that may be taken for either graduate or undergraduate credit are "double-numbered" (e.g. 151 / 251). Seminars on selected topics are listed at the end of the 130-180 decades (e.g. 139). A rough guide to the numbering system follows:

110-119	Applied Analysis (see also 180's)
120-129	Foundations, Logic, and Advanced Calculus
130-139	Analysis
140-149	Geometry and Topology
150-159	Probability and Statistics
160-169	Numerical Analysis and Related Courses
170-179	Algebra and Number Theory
180-189	Differential Equations, Applied Analysis, and Operations Research
190-199	Clinics, general seminars, reading courses, etc.
200-489	Graduate courses

### Math 001

***Mathematics, Philosophy, and the "Real World":*** Throughout history, mathematics has changed the way people look at the world. This course will focus on two examples: Euclidean geometry (which suggested to philosophers that certainty was achievable by human thought), and probability and statistics (which gave scientists a way of dealing with events that did not seem to follow any laws but those of chance). Readings and problems will be taken from three types of sources: (1) Euclid's elements of geometry; (2) modern elementary works on probability and its applications to the study of society and to gambling; (3) the writings of philosophers whose views were strongly influenced by mathematics, such as: Plato, Aristotle, Pascal, Spinoza, Kant, Laplace, Helmholtz, and Thomas Jefferson. Prerequisite: high school algebra and geometry. Enrollment is limited to Pitzer and Pomona students.

Pitzer

Fall

J Grabiner

### Math 006

***Pencil and Paper Games:*** This class will focus on the analysis of games in which chance is not a factor. Familiar examples range from tic-tac-toe to chess. This analysis leads to direct applications in the social

sciences, as well as to such mathematical oddities as *surreal numbers*. Offered in alternate years. Prerequisite: high school algebra.

Math 007

***Math of Games and Gambling:*** An introduction to probability and game theory. Topics will be drawn from combinations, permutations, probability, expected value, Markov chains, graph theory, and game theory. Specific games such as keno, roulette, craps, poker, bridge, and backgammon will be analyzed. The course will provide excellent preparation for statistics courses as well as for uses of game theory in the social sciences. Offered in alternate years. Prerequisite: two years of high school algebra.

Math 008

***Mathematics, Art, and Aesthetics:*** Addresses topics in mathematics that have figured prominently in the history of art and architecture. Explores the role of aesthetics within mathematics and the concept of mathematics itself as an art form. Readings from material by philosophers, mathematicians, artists, and art historians ranging from the ancient Greeks to modern times. Students will solve mathematical problems, learn to write short mathematical expositions, and create artwork in various media. Prerequisite: high school algebra and geometry.

Math 010

***Cartography:*** Studies various aspects of the history and mathematics of map making. Topics include surveying, finding longitude and latitude, globe projections and spherical trigonometry.

Math 010G

***Mathematics in Many Cultures:*** Mathematical ideas are found in many cultures, among both literate and non-literate peoples. This course examines both the mathematics and the role it plays in culture. Examples will be chosen from the mathematical ideas of present-day peoples of Africa, Asia, Oceania, and the Americas, as well as historic Egypt, Mesopotamia, Greece, China, and the ancient Near East. Students will learn the modern mathematical concepts necessary to understand examples.

Math 010B

***The Mathematical Mystery Tour:*** Introduces students to beautiful topics in mathematics that do not require a great deal of sophistication or previous knowledge. While ideally suited to liberal arts students, the course should be of interest to science majors as well. Stresses the intuition, creativity and aesthetics involved in one area of mathematics. The area of focus will vary from year to year. No prerequisite.

Math 010H3

***Topology:*** This course explores the shape of 1, 2, 3 and 4-dimensional space. Is the universe curved or flat? Could an astronaut return from a long journey as the mirror image of her former self? How can space be “constructed” from “ordinary” space using knots? The course will be very visual—we will draw pictures and make paper and wire models to gain insight. Intended for the liberal arts student, there are no mathematical prerequisites.

Math 010HA

***Rubik's Cube & Other Math Puzzles***

Pitzer

Fall

J Hoste

Math 011

***Theories of Electoral Systems:*** In this course we will analyze various voting procedures (majority rule, Borda counts, instant runoff voting, proportional representation, etc.) as well as ways of assessing voting power and other kinds of power. We consider the U.S. Electoral College, the use of the initiative in California, and the election for governor in California. This course satisfies Pitzer's formal reasoning objective.

Math 011

**Calculus of Real or Complex Variables:** Complex numbers; limits; formal epsilon-delta limit definition; derivatives and differentiation rules; proofs by contradiction and induction; infinite series; integration; applications of the calculus; introduction to calculus of complex-valued functions. Prerequisite: One year of high school calculus.

HMC	Fall (2 sections)	A Benjamin
HMC	Fall (2 sections)	Staff

Math 012

**Intro to Linear Algebra / Dynamic Systems:** Matrix representation of systems of equations; matrix operations; determinants; linear independence and dependence; bases; inner products; eigenvalues and eigenvectors; examples of discrete dynamical systems; fixed points; chaos; stability; bifurcations; Sarkovskii's Theorem. Prerequisite: Math 11 or equivalent. 2 credit hours.

HMC	Fall (2 sections)	M Orrison
HMC	Fall (2 sections)	L dePillis
HMC	Fall (2 sections)	Staff

Math 013

**Differential Equations I:** Modeling physical systems, first order ordinary differential equations, existence- uniqueness, and long-term behavior of solutions; bifurcations, approximate solutions; first order systems of ordinary differential equations, applications; second order ordinary differential equations and their properties, applications. Prerequisite: Math 11. 1.5 credit hours.

HMC	Fall (2 sections)	R Levy
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Math 014

**Multivariable Calculus I:** Vectors, dot and cross products; vector descriptions of lines and planes-partial derivatives and differentiability; gradients and directional derivatives; chain rule; higher order derivatives and Taylor approximations - double and triple integrals in rectangular and other coordinate systems; line integrals; vector fields, curl, and divergence; introduction to Green's theorem, divergence theorem, and Stokes' theorem. Prerequisite: Math 11. 1.5 credit hours.

Math 015

**Math for Teachers I: Numbers & Operations**

Pitzer	Fall	S Brown
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Math 020

**Elementary Functions:** Review of intermediate algebra and geometry. Linear, quadratic, higher degree polynomial, and rational functions and their graphs. Applications of these topics. The sequence of Math 20 and 23 is designed to prepare students for calculus. Prerequisite: Placement exam.

Pitzer	Fall	S Brown
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Math 021

**Introductory Calculus with Computing:** Introduction to the methods of single and multivariable calculus with applications to the social and behavioral sciences. Topics include graphical analysis, differentiation and integration of algebraic functions, partial differentiation, and an introduction to programming and the use of digital computers. Prerequisite: Placement exam.

Math 023

**Transcendental Functions and Introduction to Calculus:** A continuation of Math 20. Exponential, logarithmic, and trigonometric functions and their applications. Enrollment is limited. Prerequisite: C or above in Math 20 or placement exam.

Math 023

**Transcendental Functions:** This course is intended as a preparation for the calculus sequence. We will study general notions associated with functions such as domain and range, rate of change, concavity, composition, and invertibility. We will concentrate on the standard transcendental functions: exponential, logarithmic, trigonometric, and inverse trigonometry. Applications will be introduced throughout the course. Prerequisite: Math 20 or placement exam.

Pitzer	Fall	J Grabiner
Scripps	Fall	A Chaderjian
Scripps	Spring	Staff

Math 029

**Advanced Problem Solving:** Course will teach students to solve hard problems that arise in the sciences and social sciences. Emphasis placed on translating complex word problems into mathematics and developing mathematical techniques to solve the problems. This course is independent of the Calculus curriculum, and is intended to help students studying chemistry or economics.

Pomona	Fall	E Flapan
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Math 030

**Calculus I:** Single variable calculus. Differentiation and integration of algebraic and transcendental functions with applications to the social and physical sciences. Prerequisite: Placement exam.

CMC	Fall (2 sections)	J Pinter-Lucke
CMC	Fall (2 sections)	R Valenza
CMC	Fall (2 sections)	A Jedwab
CMC	Fall	G Bradley
CMC	Fall	M O'Brien
CMC	Fall	C Peterson

Math 030

**Calculus I:** Introduction to the basic concepts of the calculus, including slopes, rates of change, limits, the derivative and the integral, and the relationships between these concepts, especially the fundamental theorem of calculus, with applications to the natural and social sciences. Each concept will be treated from numerical, analytic, and geometric perspectives. Prerequisite: C or above in Math 23, placement exam, or instructor permission. Enrollment is limited.

Pitzer	Fall	J Hoste
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Math 030

**Calculus I:** Mathematics 30 is the first course of a standard three-course sequence in calculus. The topics covered include differentiation, integration, mean value theorem, transcendental functions and trigonometric functions. Prerequisite: Math 23 or placement exam.

Scripps	Fall	W Ou
Scripps	Spring	Staff

Math 030

**Calculus I:** Mathematics 30, 31, and 32 comprise a standard course in the calculus of one and several variables. This course focuses on: limits, derivatives, integrals, mean-value theorems, and the fundamental theorem of calculus. Prerequisite: Satisfactory placement exam score. Non-Pomona need written permission.

Pomona	Fall (2 sections)	G Karaali
Pomona	Spring	E Flapan

Math 031

**Calculus II:** A second course in single variable calculus with an introduction to vector methods in geometry and analysis. Techniques of integration; introduction to differential equations; vector algebra; polar coordinates and parametric representation of curves; improper integrals and indeterminate forms; infinite series and power series representation of a function. Applications to problems from the physical and social sciences. Prerequisite: Math 30.

CMC	Fall (2 sections)	D German
CMC	Fall (2 sections)	S Nelson
CMC	Fall	C Peterson

Math 031

**Calculus II:** Transcendental functions, techniques of integration, infinite series, related topics, and applications. Again, each concept will be treated from numerical, analytic, and geometric perspectives. Prerequisite: C or above in Math 30. Enrollment is limited.

Pitzer	Fall	R Trapp
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Math 031

**Calculus II:** Topics covered include techniques and applications of integration, infinite series, and related material. Prerequisite: Math 30 or placement exam.

Scripps	Fall	Staff
Scripps	Spring	Staff

Math 031

**Calculus II:** Transcendental functions, techniques of integration, infinite series, and related material. Prerequisite: Math 30 with C- or above or satisfactory placement exam score. Non-Pomona need written permission.

Pomona	Fall	S Grabiner
Pomona	Fall	S Garcia
Pomona	Fall	A Limon
Pomona	Spring	A Limon

Math 031H

**Honors Topics in Calculus II:** Explores selected topics from Calculus II in greater depth than Math 31 and relates these topics to other areas of mathematics. This course is intended for students who have already seen some of the Calculus II material but are not yet ready for Calculus III or Linear Algebra. Prerequisite: Math 30 or 30H with C- or above or satisfactory placement exam score. Non-Pomona need written permission.

Pomona	Fall	S Shahriari
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Math 031S

**Calculus II with Applications to the Life Sciences:** This course presents the core topics of Math 31 as well as an introduction to modeling, differential equations, matrix algebra and computing in the context of problems from the life sciences. It provides an excellent background for students who intend to go on to Math 32 and exposes students who intend to take no further mathematics courses to the depth and excitement of the discipline by showing them its relevance in the world around us. Prerequisite: Math 30 with C- or above or satisfactory placement exam score. Non-Pomona need written permission.

Math 032

**Calculus III:** Multi-variable calculus and vector analysis with applications to physical and social sciences: functions of several variables, partial differentiation, the method of Lagrange multipliers, multiple integration, calculus of vector functions. Prerequisite: Math 31.

CMC

Fall

A Jedwab

Math 032

**Calculus III:** Vectors and vector functions, partial derivatives and differentiability of functions of several variables, multiple integrals. Prerequisite: Math 31, equivalent, or placement exam.

Pitzer

Fall

J Hoste

Math 032

**Calculus III:** Vectors and vector functions, partial derivatives and differentiability of functions of several variables, multiple integrals. Prerequisite: One of Math 31, 31H, 31S with C or above, or satisfactory placement exam score. Students can receive credit for only one of 32, 32H, or 107. Non-Pomona need written permission.

Pomona

Fall (2 sections)

A Limon

Pomona

Spring

G Sarkis

Math 032

**Calculus III:** This is the third course of a standard three-course sequence in calculus. The course covers calculus of multivariable and vector-valued functions. Topics include partial derivatives, the gradient, Lagrange multipliers, multiple integrals, change of variables, parameterized curves and surfaces, vector fields, line integrals, flux integrals, Green's Theorem, the Divergence Theorem, and Stokes' Theorem. Prerequisite: Math 31 or placement exam. Offered each semester.

Scripps

Fall

A Chaderjian

Scripps

Spring

Staff

Math 032H

**Honors Seminar in Calculus III:** Open by invitation only to freshmen, this course is an introduction to rigorous mathematics for students having a substantial background and demonstrated interest in mathematics. The topics covered will be those of Calculus III with more emphasis on rigor and deeper understanding of the underlying mathematics. First semester.

CMC

Fall

S Nelson

Math 035

**Subcalculus Seminar**

Scripps

Fall

W Ou

Math 036

**Mathematical and Computational Methods in the Life Sciences:** Mathematical models motivated by problems in biology will provide the motivation for studying a suite of mathematical concepts. We will cover topics in probability, discrete models, differential equations, linear algebra and statistics. Some computational techniques will also be introduced to lend power to the theory. This course is not a substitute for full semester courses in any of these topics, but is intended to provide essential analytical and computational tools to the life scientist. Prerequisite: One of Math 31, 31H, 31S or satisfactory placement exam score. Non-Pomona need written permission.

Pomona

Spring

A Radunskaya

Math 050

**Discrete Mathematics:** Topics include combinatorics, number theory, and graph theory with an emphasis on creative problem solving and learning to read and write rigorous proofs. Possible applications include probability, analysis of algorithms, cryptography, and mathematical magic tricks. 3 credit hours.

Math 055

**Discrete Mathematics:** Topics include combinatorics, number theory, and graph theory with an emphasis on creative problem solving and learning to read and write rigorous proofs. Possible applications include probability, analysis of algorithms, cryptography, and mathematical magic tricks. 3 credit hours, both semesters. Prerequisite: Math 12 or permission of instructor.

HMC

Fall

Staff

Math 057 / Psych 103

**Social Statistics:** An introduction to descriptive and inferential statistics. Although intended primarily for students in psychology, economics, and other social sciences, this course is appropriate for anyone interested in acquiring skill at applied statistical analysis, including use of statistical software. This course meets the Scripps mathematics requirement as well as the statistics requirement for the psychology, economics, or anthropology major. Prerequisite: High school algebra.

Math 058

**Introduction to Statistics:** An introduction to the methodology and tools that are vital to the researcher in both the sciences and social sciences. Topics include introduction to probability, binomial, normal, Students'-t, and chi-square distributions; testing hypotheses; confidence intervals; analysis of variance; and regression and correlation analysis. Concepts will be applied to current data using statistical computer software. Not recommended for students who have taken AP Statistics. Prerequisite: Math 30 or satisfactory score on placement exam.

Pomona

Fall

A Rumbos

Math 058B

**Introduction to Biostatistics:** An introduction to the methodology and tools that are vital to research in the biological health sciences and medicine. Topics include: probability; distributions of random variables; testing hypotheses; confidence intervals; analysis of variance; regression analysis; odds ratios; sensitivity and specificity; and nonparametric methods. Concepts will be applied to current data using statistical computer software. Prerequisite: Math 30 or equivalent. Not recommended for students who have taken AP Statistics. Non-Pomona need written permission.

Pomona

Spring

J Hardin

Math 060

**Linear Algebra:** This course emphasizes vector spaces and linear transformations. Topics include linear independence, bases, nullity and rank of a linear transformation, The Dimension Theorem, the representation of linear transformations as matrices, eigenvalues and eigenvectors, and determinants. Additional topics may include inner product spaces and Gram-Schmidt orthogonalization. Prerequisite: Math 32.

CMC

Fall

L Fukshansky

Scripps

Fall

A Chaderjian

Math 060

**Linear Algebra:** A course in linear algebra emphasizing vector spaces and linear transformations. Topics will include: linear independence and bases, nullspaces and ranks of linear transformations, the algebra of linear transformations, and the representation of linear transformations by matrices. Additional topics may

include: Gaussian elimination, inner product spaces, determinants, eigenvalues, and applications of linear algebra. Prerequisite: One of Math 31, 31H, 31S, or 32.

Pomona	Fall	S Grabiner
Pomona	Fall	S Shahriari
Pomona	Fall	G Sarkis
Pomona	Spring	A Rumbos
Pomona	Spring	S Garcia
Pomona	Spring	A Limon

Math 061

**Multivariable Calculus II:** Review of basic multivariable calculus; optimization and the Second Derivative Test; constrained optimization using Lagrange multipliers; conservative and nonconservative vector fields; Green's theorem; parametrized surfaces and surface integrals; divergence theorem, outline of proof, and applications; Stokes' theorem, outline of proof, and applications; unification of the major vector theorems. Prerequisite: Math 14. 1.5 credit hours.

HMC	Fall (2 sections)	F Su
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Math 062

**Introduction to Probability and Statistics:** Sample spaces, events, axioms for probabilities; conditional probabilities and Bayes' theorem; random variables and their distributions, discrete and continuous; expected values, means and variances; covariance and correlation; law of large numbers and central limit theorem; point and interval estimation; hypothesis testing;  $\chi^2$  goodness of fit; simple linear regression; introduction to analysis of variance; applications to analyzing real data sets. Prerequisite: Math 11. 1.5 credit hours.

HMC	Fall (2 sections)	F Su
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Math 063

**Linear Algebra II:** Review of basic linear algebra; vector spaces; row and column spaces of matrices, rank-nullity theorem; orthogonal bases and Gram-Schmidt procedure, orthogonal expansion and Fourier coefficients; projections and Bessel's inequality; linear transformations; change of basis and similarity, eigenvalues, eigenvectors and characteristic polynomials; diagonalization of symmetric matrices; applications of eigenvalues to systems of ordinary differential equations. Prerequisite: Math 12. 1.5 credit hours.

Math 064

**Differential Equations II:** Review of basic ordinary differential equations, especially systems; undriven linear systems; orbital portraits; stability and conservative systems; Lyapunov functions; cycles and long term behavior of solutions, Sturm-Liouville problems; series solutions near ordinary and regular singular points; Bessel functions; chaos. Prerequisite: Math 13 and 63. 1.5 credit hours.

Math 080

**Science and Technology in the Ancient Medieval World**

Math 081

**Science and Technology in the Early Modern World**

Math 082

**Science and Technology in the Modern World**

Math 090

**Linear Algebra:** An introduction to the methods of linear algebra with applications to the physical and social sciences. Topics will include: linear equations and matrices, determinants, vector spaces, linear

transformations, inner product spaces and quadratic forms, eigenvalues and canonical forms. Prerequisite: Math 32.

Math 91

**Mathematics Colloquium:** Attendance at talks given by senior math majors, the Claremont Colleges Mathematics Colloquium, and other suitable talks in Claremont. Offers students the opportunity to sample the wide range of active research areas and current trends in mathematics. Not open to senior math majors. Prerequisite: any math course numbered 100 or above. Non-credit.

Pomona

Spring

A Rumbos

Math 101

**Introduction to Analysis:** A workshop course on how to write proofs in the context of analysis. We will focus on the construction and presentation of rigorous proofs. Students will learn how to use the language of analysis to prove results about sequences, limits, and continuity. Students will regularly present proofs in both written and oral form. Prerequisite: Math 60.

Pomona

Fall

G Karaali

Pomona

Spring

E Flapan

Math 102

**Differential Equations and Modeling:** Introduction to theory of ordinary differential equations, with applications to modeling in physical, biological, and social sciences. Emphasis is placed on qualitative study of differential equations via analytic methods or numerical techniques using standard mathematical software packages. A good understanding of theory of vector spaces and linear transformations is assumed. Prerequisites: Math 32 or 107, and 60.

Pomona

Fall

R Elderkin

Pomona

Spring

R Elderkin

Math 102

**Ordinary Differential Equations:** A rigorous introduction to the classical theory of ordinary differential equations. Topics will include the existence and uniqueness theorem (unrigorously) and various methods for solving specific classes of problems (integrating factors, Picard's method of iteration, variation of parameters, reduction of order, power series, Frobenius's method, etc.). Prerequisite: Math 32. Offered spring semesters.

Scripps

Fall

C Towse

Math 103

**Combinatorial Mathematics:** An introduction to the techniques and ideas of combinatorics including counting methods, generating functions, Ramsey theory, graphs, networks, and extremal combinatorics. Prerequisite: Math 60.

Pomona

Fall

S Shahriari

Math 103

**Combinatorics:** An introduction to the techniques and ideas of combinatorics including counting methods, generating functions, Ramsey theory, graphs, networks, and extremal combinatorics. Prerequisite: Math 60 or instructor permission. Offered alternate spring semesters.

Scripps

Spring

A Chaderjian

Math 104

**Graph Theory:** An introduction to graph theory with applications. Theory and application of trees, matchings, graph coloring, planarity, graph algorithms, and other topics. Prerequisite: Math 12.

Math 105

**Discrete and Continuous Modeling:** Basic modeling, discrete deterministic models, discrete stochastic modes, states and classes, empirical modeling, continuous models, continuous stochasticity. Prerequisite: Math 31.

Math 105

**Introduction to Number Theory:** Covers important ideas in elementary number theory and applications. Topics include divisibility and primes, modular arithmetic, Fermat's Little Theorem, quadratic residues and Gaussian integers. Exciting recent applications will be explored. Prerequisite: Math 60.

Math 106

**Combinatorics:** Counting methods, generating functions, and partially ordered sets. Prerequisite: Math 55 or permission of the instructor.

Math 107

**Vector Calculus:** Building on linear algebra (Math 60), and on previous exposure to single-variable calculus, this class gives a streamlined introduction to multivariable (or "vector") calculus, based on the fact that a derivative is actually a linear map. Topics include different types of integral (line, double, surface, triple) and derivative (partial, directional, total); the famous div, grad and curl operators; why the chain rule is easy and fun; the all-time best version of the fundamental theorem of calculus (by Stokes); and an answer to the vexing question "What is  $dx$ ?" Prerequisite: Math 60. Students can receive credit for only one of Math 32 or 107.

Pomona  
Pomona

Fall  
Spring

A Rumbos  
A Rumbos

Math 108

**History of Mathematics:** A survey of the history of mathematics from antiquity to the present. Topics emphasized will include: the development of the idea of proof, the "analytical method" of algebra, the invention of the calculus, the psychology of mathematical discovery, and the interactions between mathematics and philosophy. Prerequisite: One year of university-level calculus, Math 31, or equivalent.

Math 109

**Introduction to the Mathematics of Finance:** This course emphasizes the math used in the valuation of derivative securities. Topics will include among others partial differential equations (diffusion equation), mathematical modeling of financial derivatives (calls, puts, etc.), and numerical methods for solving differential equations. These topics will aim at understanding the Black-Scholes Model. Prerequisite: Math 90.

Math 110

**Introduction to Engineering Mathematics:** Ordinary differential equations, line and surface integrals, elementary linear algebra, systems of differential equations, and Fourier analysis. Continuous modeling with applications to mechanics, electricity, magnetism, heat, and sound.

Math 111

**Differential Equations:** An introduction to the general theory and applications of differential equations. Linear systems, nonlinear systems, and stability. Prerequisite: Math 32.

CMC

Fall

G Bradley

Math 112

**Introduction to Dynamical Discrete Systems and Chaos:** The study of discrete dynamical systems in dimensions one and higher is motivated and presented with examples taken from the recent research literature, including mathematical models of biological processes and neural networks. Among the topics

introduced will be routes of chaos, bifurcation analysis, and Sarkovskii's Theorem. Prerequisites: Math 32, 32H, or 107 and 60.

Math 112

**Discrete Dynamical Systems & Chaos:** The studies of discrete dynamical systems in dimensions one and higher is motivated and presented with examples taken from recent research literature, including mathematical models of biological processes and neural networks. Among the mathematical topics introduced will be routes to chaos, bifurcation analysis, and Sarkovskii's Theorem. Prerequisites: Math 32, 32H, or 107, and 60.

Math 113

**Cryptography:** This course provides an overview of private and public key ciphers, including RSA, DES, NTRU, digital signatures, and protocols. Topics from complexity, probability, and number theory will be developed as needed. Prerequisite: Math 60.

Pomona

Spring

G Sarkis

Math 115 / CGU 215

**Fourier Series and Boundary Value Problems:** Sturm-Liouville theory, orthogonal expansions, convergence properties of Fourier series, separation of variables for partial differential equations, regular singular point theory, Bessel functions, and Legendre polynomials. May not be included in a mathematics major program. Students may not receive credit for both Mathematics 115 and 180. Prerequisite: Math 64.

HMC

Fall

D Yong

Math 118

**Mathematical Biology I:** Mathematical models of biological processes emphasizing continuous models. May include models in epidemiology, population dynamics, cancer modeling, and disease treatment modeling. Prerequisite: One semester of linear algebra (Math 12, 63) and one semester of ordinary DEs (Math 13, 64). 2 units.

Math 119

**Mathematical Biology II:** Mathematical models of biological processes emphasizing discrete and continuous models. May include one- and two-locus population genetics, meta-populations, and matrix population models as well as models in physiology and neurobiology. Prerequisites: Math 62, one semester of linear algebra (Math 12, 63) and one semester of ordinary DEs (Math 13, 64). 2 units.

Math 122

**Seminar in Logic:** Selected topics from the general area of logic. Prerequisite: Instructor permission.

Math 123

**Logic:** Propositional and first order predicate logic, including the completeness, compactness and Loewenheim-Skolem theorems, decidable theories, and their application to other areas of mathematics (e.g., nonstandard analysis). Prerequisite: Math 12 or 60.

Math 131 / CGU 231

**Principles of Real Analysis I:** Countable sets, least upper bounds, and metric space topology including compactness, completeness, connectivity, and uniform convergence. Related topics as time permits. HMC Prerequisites: Math 12 and 14 (Math 55 recommended). Pomona Prerequisites: Math 32 or 107, and 60; a proof-based math course above 100 is strongly recommended.

Pomona

Fall

E Flapan

Math 131 / CGU 231

**Mathematical Analysis I:** By looking carefully at the concept of distance and the notion of an abstract metric space, we will gain a deeper understanding of the real numbers and of what makes calculus work.



on  $\mathbb{R}$ ; Lebesgue integral and limit theorems; product measures and the Fubini theorem; additional related topics as time permits. Prerequisite: Math 132.

CMC  
Math 138 / CGU 332

Fall

M O'Neill

**Real and Functional Analysis II / Graduate Analysis II:** Continuation of Math 137. Topics covered include Banach and Hilbert spaces,  $L^p$ -spaces, complex measures and the Radon-Nikodym theorem. Prerequisite: Math 137.

CMC  
Math 141 / CGU 241

Spring

M O'Neill

**Hyperbolic Geometry:** An introduction to hyperbolic geometry in dimensions two and three. Topics will include: Poincaré disk model, upper half-space model, hyperbolic isometries, linear fractional transformations, hyperbolic trigonometry, cross-ratio, hyperbolic manifolds, and hyperbolic knots. Prerequisite: Math 060.

Math 142 / CGU 242

**Differential Geometry:** Curves and surfaces; Gaussian curvature; isometries; tensor analysis and covariant differentiation with applications to physics and geometry (intended for physicists and mathematicians). HMC Prerequisite: Math 64. Pomona Prerequisite: Math 32 or 107, and 60.

Pomona  
Math 143 / CGU 243

Spring

G Karaali

**Topics in Geometry:** Selected topics in Riemannian and pseudo-Riemannian geometry, low dimensional manifold theory, contemporary applications in mathematics and physics. Prerequisite: instructor permission.

Math 144 / CGU 244

**Fourier Analysis:** The subject now known as Fourier analysis or harmonic analysis can be said to have started with Fourier's work on the heat equation early in the nineteenth century. The development of the theory has been central in all of analysis. The applications are so numerous that it should perhaps come as a surprise when Fourier analysis cannot be profitably applied to a given problem. In this course we will study the classical theory of Fourier analysis, Fourier transforms, and discrete Fourier analysis. We will see how the theory can be applied to solve partial differential equations and produce accurate medical imaging. We will also use Fourier analysis to prove Dirichlet's theorem on the distribution of prime numbers in arithmetic progressions. Prerequisite: Math 131.

Math 145 / CGU 245

**Topics in Geometry and Topology:** Topic varies from year to year and will be chosen from: differential topology, Euclidean and non-Euclidean geometries, knot theory, algebraic topology, and projective geometry. Prerequisite: Math 60, Math 171 is recommended.

Math 146 / CGU 246

**Differential Forms and Cohomology:** This course begins with differential forms, the modern equivalent of vector calculus. We will then define manifolds and look at applications. These include foliations and contact structures, Maxwell's equations, and most notably, DeRham cohomology. Prerequisite: Math 32 or instructor permission.

Math 147 / CGU 247

**Topology:** Topological spaces, product spaces, quotient spaces, Hausdorff spaces, compactness, connectedness, path connectedness, fundamental groups, homotopy of maps and covering spaces. Prerequisite: Math 131.

Math 148 / CGU 248

**Knot Theory:** An introduction to the theory of knots and links from combinatorial, algebraic, and geometric perspectives. Topics will include knot diagrams; p-colorings; Alexander, Jones, and HOMFLY polynomials; Seifert surfaces; genus; Seifert matrices; the fundamental group; representations of knot groups; covering spaces; surgery on knots; and important families of knots. Prerequisite: Math 147, Math 171, or instructor permission.

Pitzer	Fall	J Hoste
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Math 149 / CGU 249

**Special Topics: Discrete Geometry**

CMC	Fall	L Fukshansky
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Math 151 / CGU 251

**Probability:** Probability spaces, discrete and continuous random variables, conditional and marginal distributions, expectation, independence, generating functions, transformations, central-limit theorem. CMC Pre/Co requisite: Math 90 or instructor permission. Pomona prerequisites: Math 32 or 107, and 60.

CMC	Fall	M O'Neill
Pomona	Spring	A Radunskaya
CGU	Fall / Spring	A Nguyen

Math 152 / CGU 252

**Statistical Theory:** Introduction to statistical inference. Sufficiency, estimation of parameters, confidence intervals, and tests of hypotheses. Prerequisite: Math 151 (251).

Pomona	Fall	J Hardin
CGU	Spring	A Nguyen

Math 153 / CGU 253

**Advanced Topics in Statistical Inference:** Selected topics in statistical inference, such as Bayesian inference, bootstrapping, and distribution-free methods.

Math 155 / CGU 255

**Statistical Analysis of Genetic Data:** Introduction to the statistical methods used in analyzing microarray data (quantitative measurements of genetic activity). We will discuss all relevant stages of the analysis from image analysis to filtering to statistical methods applied to data. Though we will work primarily on microarray data, all topics will be relevant for many other types of data. Topics include data normalization, outlier detection, systematic biases, class prediction, class comparisons, and multiple comparisons. Prerequisites: Math 30 and one of: Math 58, Math 152, Econ 57, Psych 158, or AP Statistics.

Math 156 / CGU 256

**Stochastic Processes:** Continuation of Mathematics 151. Properties of independent and dependent random variables, conditional expectation. Topics chosen from Markov processes, second order processes, stationary processes, ergodic theory, Martingales, and renewal theory. HMC prerequisites: Math 63 and 151 or instructor permission. Pomona prerequisite: Math 151.

HMC	Fall	H Krieger
CGU	Fall	A Nguyen
CGU	Spring	A Nguyen

Math 157 / CGU 257

**Probability:** Continuous random variables; distribution functions; joint density functions; marginal and conditional distributions; functions of random variables; conditional expectation; covariance and

correlation; moment generating functions; law of large numbers; Chebyshev's theorem and central limit theorem. Prerequisite: Math 62 or instructor permission. 2 credit hours.

Math 157 / CGU 257

**Statistical Methods for Clinical Trials Data:** A second course in Biostatistics. Emphasis on the most commonly used statistical methods used in pharmaceutical and other medical research. Topics may include design of clinical trials, power and sample size determination, contingency table analysis, odds ratio and relative risk, survival analysis. Statistical analyses will be carried out on real data using statistical software. Prerequisites: Math 30 and one of: Math 58, Math 152, Econ 57, Psych 158, or AP Statistics.

Pomona

Fall

J Hardin

Math 158 / CGU 258

**Statistical Data Analysis:** An introduction to analysis of variance (including one-way and two-way fixed effects ANOVA) and linear regression (including simple linear regression, multiple regression, variable selection, stepwise regression and analysis of residual plots). Emphasis will be on both methods and applications to data. Statistical software will be used to analyze data. Prerequisites: one of Math 58 or Math 152 or Econ 57 or Psych 158 or AP Statistics or instructor permission. Offered alternate years.

Pomona

Spring

J Hardin

Math 159 / CGU 259

**Experimental Design:** The theory of experimental design and data analysis. Topics may include: hypothesis testing, analysis of variance, randomized blocks, latin squares, factorial and composite designs, response surface methods, random factors, and robust design.

Math 159 / CGU 259P

**Applied Nonparametric Analysis:** Covering both traditional and modern techniques in nonparametrics, this course will focus on analyzing data under appropriate assumptions by investigating the mathematical derivations as well as the computational aspects of various techniques, including sign and rank tests, goodness-of-fit tests, Fisher's exact test, bootstrapping, and permutation tests. Programming skills needed to run these tests will also be developed. Prerequisites: Math 30 and one of the following: Math 58, Math 152, Econ 57, Psych 158, or AP Statistics.

Math 164 / CGU 264

**Scientific Computing:** Computational techniques applied to problems in the sciences and engineering; modeling of physical problems; computer implementation; analysis of results; use of mathematical software; numerical methods chosen from solutions of linear and nonlinear algebraic equations, solutions of ordinary and partial differential equations, finite elements, linear programming, optimization algorithms, and fast-Fourier transforms. Prerequisites: Math 64, CS 60. 3 credit hours.

CGU

Spring

A Percus

Math 165 / CGU 265

**Numerical Analysis:** An introduction to the theory and methods for numerical solution of mathematical problems. Core topics include: analysis of error and efficiency of methods; solutions of linear systems by Gaussian elimination and iterative methods; calculation of eigenvalue and eigenvectors; interpolation and approximation; numerical integration; solution of ordinary differential equations. Prerequisite: Math 64 and a knowledge of elementary computer programming or instructor permission. Pomona prerequisite: Math 102.

HMC

Fall

L de Pillis

Math 167 / CGU 267

**Theory of Computation:** Specific topics include finite automata; pushdown automata; Turing machines and their corresponding languages and grammars; undecidability; complexity classes, reductions, and hierarchies. Prerequisite: CS 52.

HMC

Fall: Complexity Theory

R Libeskind-Hadas

Math 168 / CGU 268

**Algorithms:** Algorithm design, computer implementation, and analysis of efficiency. Discrete structures, sorting and searching, parsing, pattern-matching, and data management. Reducibility and theoretical limitations. Prerequisite: CS 60 and Math 55.

HMC

Fall

N Pippenger

Math 170 / CGU 270

**Finite Fields and Applications:** Designed to appeal to students in mathematics, computer science, and electrical engineering, the course will introduce students to the elementary theory of finite fields, as well as an introduction to more basic algebraic structures, such as groups and rings. Students will also be exposed to some of the more common applications of finite fields in coding theory, cryptography, computational complexity, and finite geometry.

Math 171 / CGU 271

**Abstract Algebra I: Groups and Rings:** This course covers basic structures that appear throughout mathematics, including groups and rings. Topics in group theory will include isomorphism theorems, orbits and stabilizers, and coset partitions. Topics in ring theory will include ideals, quotient rings, and prime and maximal ideals. Ring and field extensions may also be introduced. HMC prerequisites: Math 12 and 55. Pomona prerequisites: Math 60; a proof-based math course above 100 is strongly recommended.

HMC

Fall

M Orrison

HMC

Fall

Staff

Pomona

Fall

G Sarkis

Math 172 / CGU 272

**Abstract Algebra II:** Continuation of Math 171. Selected topics in the theories of rings, modules, groups, and fields. Typical specific topics include Galois theory of equations and the structure of finitely generated modules over Euclidean and/or principal ideal domains with applications to linear algebra and finitely generated Abelian groups. Prerequisite: Math 171.

Math 172 / CGU 272

**Abstract Algebra: Galois Theory:** Topics covered will include polynomial rings, field extensions, classical constructions, splitting fields, algebraic closure, separability, fundamental theorem of Galois Theory, Galois groups of polynomials, and solvability. This course is independent from Math 174 and may be taken by students who have taken Math 174. Prerequisite: Math 171.

Pomona

Spring

S Shahriari

Math 173 / CGU 273

**Advanced Linear Algebra:** Topics will be chosen from among: similarity of matrices and the Jordan form; the Cayley Hamilton Theory; limits of sequences and series of matrices; iterative solutions of large systems

of linear algebraic equations; the Perron-Frobenius theory of nonnegative matrices; estimating eigenvalues of matrices. Prerequisite: completion of a semester course in linear algebra.

Pomona

Fall

S Garcia

Math 174 / CGU 274

**Abstract Algebra II: Representation Theory:** Topics covered will include group rings, characters, orthogonality relations, induced representations, application of representation theory, and other select topics from module theory. Prerequisite: Math 171. This course is independent from Math 172 and may be taken by students who have taken Math 172.

Math 175 / CGU 275

**Number Theory:** Properties of integers, congruences, Diophantine problems, quadratic reciprocity, number theoretic functions, and primes. Prerequisite: Math 55. Pomona prerequisite: Math 60.

HMC

Fall

A Benjamin

Math 175 / CGU 275

**Number Theory:** Number theory is often considered one of the most beautiful and elegant topics in mathematics. We will study properties concerning the integers, such as divisibility, congruences, and prime numbers. More advanced topics include encryption, quadratic reciprocity, and diophantine approximation. Finally, we will introduce elliptic curves and see how these curves relate to the proof of Fermat's last theorem. Prerequisite: Linear Algebra.

Math 177 / CGU 277

**Advanced Topics in Algebra:** Topic varies from year to year and will be chosen from: representation theory, algebraic geometry, commutative algebra, algebraic number theory, coding theory, algebraic combinatorics, algebraic graph theory, matroid theory. Prerequisite: Math 171 or instructor permission.

Math 180 / CGU 280

**Applied Analysis:** Orthogonal series and Sturm-Liouville problems, Fourier series and boundary value problems for partial differential equations, special functions of mathematical physics, integral transforms. Prerequisite: Math 131. Students may not receive credit for both Math 115 and 180.

HMC

Fall

R Levy

Math 180 / CGU 280

**Partial Differentiation Equations:** Theory and applications of quasi-linear and linear equations of first order, including: higher order linear and non-linear equations; classical methods of solutions of the wave; heat and potential equations; Green's function; similarity solutions; variational techniques. Prerequisite: Math 115, 180, or instructor permission.

Math 181 / CGU 281

**Dynamical Systems:** This course will consider both discrete and continuous dynamics. In any given year it will include most of the following topics: linear and nonlinear systems; bifurcation theory; routes to chaos; symbolic dynamics; Sharkovii's theorem and chaos; existence and uniqueness theory and dependence on data; Hartman-Grobman and Poincaré-Bendixson theorems; Lyapunov stability theory and stable manifold theory. HMC Prerequisite: Math 115 or 180. Pomona Prerequisite: Math 101, 102 or 131.

Pomona  
CGU

Fall  
Fall

A Radunskaya  
M Martelli

Math 183 / CGU 283P

**Mathematical Modeling:** Introduction to the construction and interpretation of deterministic and stochastic models in the biological, social, and physical sciences, including simulation studies. Students are required to develop a model in an area of their interest. Prerequisite: Math 102.

Pomona

Spring

R Elderkin

Math 184 / CGU 284

**Topics in Applied Analysis**

Math 185 / CGU 284

**Introduction to Wavelets and their Applications:** An introduction to the mathematical theory of wavelets, with applications to signal processing, data compression and other areas of science and engineering. Prerequisite: Math 115 or 180.

Math 186 / CGU 286

**Stochastic Operations Research:** Stochastic models of inventory, reliability, queuing, sequencing, and transportation. Applications of these models to problems arising in industry, government, and business. Prerequisite: Mathematics 151 / 251.

Math 187 / CGU 287

**Deterministic Operations Research:** Linear, integer, nonlinear, and dynamic programming; classical optimization problems; network theory. CGU prerequisites: multivariable calculus and linear algebra. CMC prerequisites: Math 32 or 36, and 174. Pomona prerequisites: Math 32 or 107, and 60. HMC prerequisite: Math 12.

Math 188C / CGU 288C

**Game Theory:** Games in extensive form; combinatorial games; strategic equilibrium; matrix games and minimax theorem; computation of optimal strategies; co-operative and non-cooperative solutions of bi-matrix games; coalitional games and the core; indices of power; bargaining set; nonatomic games. Prerequisite: Math 90 (Math 151 recommended).

Math 188H / CGU 288H

**Social Choice and Decision Making:** This course focuses on the modeling of individual and group decisions using techniques from game theory. Topics will include: basic concepts of game theory and social choice theory, representations of games, Nash equilibria, utility theory, non-cooperative games, cooperative games, voting games, paradoxes, impossibility theorems, Shapley value, power indices, fair division problems, and application. This course meets the “Integrative Experience” requirement for Harvey Mudd students. Prerequisites: Math 63 and 55 (recommended) or instructor permission.

Math 189 / CGU 289

**Special Topics in Mathematics:** A course devoted to exploring topics of current interest to faculty or students. Prerequisite: instructor permission. 1-3 credit hours.

HMC

Fall: Introduction to Mathematical Physiology

J Milton

HMC

Fall: Topics in Algebraic Geometry

D Karp

Math 190

**Seminar in Mathematical Exposition:** Directed study for majors. Seminar will discuss how to do a literature search in mathematics, how to read research papers in mathematics, how to write a mathematics paper, and how to present a mathematics talk. Students will give oral presentations on the background material and major questions in the area of their senior research. Attendance is required. Required for senior majors. Half-course. Letter grade only.

Pomona

Fall

R Elderkin

Math 191

**Putnam Seminar:** A problem-solving seminar designed to prepare students for the undergraduate Putnam competition in December.

HMC

Fall

F Su / N Pippenger

Math 191

**Senior Thesis in Mathematics**

Math 191

**Senior Thesis:** Preparation and presentation of senior thesis for completion of the major. Required for senior majors; attendance is required. Half-course. Letter grade only.

Pomona

Spring

A Rumbos

Math 193

**Mathematics Clinic:** Participation in applied mathematics projects involving student teams and a faculty supervisor. Prerequisite: director permission.

HMC

Fall

A Castro / A Bernoff

Math 196

**Independent Study**

Math 197

**Senior Thesis:** A research or expository paper based on independent work done under the supervision of a faculty member. The paper must be submitted to the Mathematics Department in a form suitable for publication in a mathematics journal. Prerequisite: departmental permission.

HMC

Fall

Pippenger

Math 198

**Math Forum:** The goal of this course is to improve students' ability to communicate mathematics, both to a general and technical audience. Students will present material on assigned topics and have their presentations evaluated by students and faculty. This format simultaneously exposes students to a broad range of topics from modern and classical mathematics. Required of all math majors; recommended for all joint CS-Math majors and Mathematical Biology majors, typically in their junior year. One credit hour.

HMC

Fall

R Levy

Math 199

**Independent Study in Mathematics**

Math 199

**Math Colloquium:** Students will attend the weekly Claremont Math Colloquium, offered through the cooperative efforts of the mathematics faculty at the Claremont Colleges. Most of the talks discuss current research in mathematical sciences and are accessible to undergraduates.

HMC

Fall

Staff

Scripps

Fall

Staff

Math 306

**Optimization:** The course emphasizes nonlinear programming. It covers numerical methods for finite-dimensional optimization problems with fairly smooth functions. Both constrained and non-constrained optimizations will be discussed. Certain degree of emphasis will be given to the convergence analysis of the numerical methods. Prerequisite: multivariable calculus and numerical linear algebra.

Math 331 / Math 137

***Principles of Real Analysis I***

CMC

Fall

M O'Neill

Math 332 / Math 138

***Principles of Real Analysis II***

CMC

Spring

M O'Neill

Math 333

***Differential Equations and Complex Analysis in Applied Mathematics:*** This will be a survey course encompassing the areas of ordinary differential equations, partial differential equations, and complex analysis. The level will be at that met in a full semester undergraduate course and the emphasis will be on solution techniques.

Math 334 / HMC 134

***Complex Analysis II***

Math 335

***Integral Transforms and Applications:*** Transforms covered will include: Fourier, Laplace, Hilbert, Hankel, Mellin, Radon and Z. The course will be relevant to mathematicians and engineers working in communications, signal and image processing, continuous and digital filters, wave propagation in fluids and solids, etc.

Math 336

***Image Processing:*** In fields ranging from entertainment to medicine, computational image processing methods are having major impact. Computer graphics can provide stunning visual effects. Quantitative image analysis allows for accurate identification of features and tracking of motion. A wide variety of problems can be understood and analyzed with the mathematical, statistical, and numerical techniques developed in this course. Basic mathematical structures for representing and manipulating image data will be discussed, leading the way for tackling problems of filtering and image reconstruction, warping and compositing, feature detection, motion capture and tracking, and tomography. Computational implementation and application of the image processing methods will be emphasized throughout the course. Prerequisites: BS in computer science, engineering, mathematics, or physics. Undergraduate level courses in probability and statistics and/or linear systems theory would be helpful.

CGU

Fall

H Morris

Math 337

***Control Systems I:*** This is an introductory course. The intention is to expose math-major students to control systems theory and design - the well-established field of applied mathematics. Control systems specialists presently are in great demand in both industry and academia. The course is self-contained and assumes no prior knowledge of control from the students (see course prerequisites). Throughout the course both theoretical and application aspects of control systems will be presented and discussed. Homework will be given every two weeks. Students will be required to perform computer simulation experiments using Matlab. A mid-term and a final exam will be given. Final grades will depend on the following 4

factors: lecture attendance (10%), homework (30 %), mid-term exam (30 %), and final exam (30%). Prerequisites: linear algebra, ordinary differential / difference equations, numerical analysis (basic understanding), Matlab.

#### Math 338

**Systems Analysis Techniques:** This course provides the basic skills and analysis tools of classical control theory for continuous and discrete-time linear systems. Linearization of nonlinear systems, convolution and matrix transforms, and solution of dynamic equations will be reviewed. Focus will be on state space approaches. Key concepts of duality, controllability, and observability will be discussed in detail. Pole placement and state variable feedback controller design and implementation. Basic observer design and Kalman Filtering will be covered. Prerequisites: Calculus through multivariate, elementary complex analysis, linear algebra, statistics and Matlab programming are recommended.

#### Math 341

**Applied Stochastic Methods for Computational Biology I:** This is a 2-semester course involving the application of methods in probability, statistical theory, and stochastic processes to problems of interest to computational biologists. The course is designed to be accessible to students with a mathematical background roughly at the level of undergraduate engineering mathematics. It is expected that students who have taken both semesters of the course will have mastered the basic set of ideas required in order to carry out further research in computational biology methods and algorithms, or to use these ideas in industrial applications. While this is not a course in computer programming, algorithms that implement probabilistic / statistical approaches to computational biology will be discussed. **The course is designed for students from KGI, CGU Math, and Computational Science.** Pre-requisites: Basic understanding of elementary probability and statistics, calculus, linear algebra, and some knowledge of computing (i.e. a reasonable comfort level with at least one computer language used for numerical computation or the ability to quickly achieve it; examples include C/C++, Matlab, etc.). No knowledge of molecular biology will be assumed - such knowledge will be introduced as part of the course where necessary.

#### Math 342

**Applied Stochastic Methods in Bioinformatics:** This is the second in a 2-semester course involving the application of methods in probability, statistical theory, and stochastic processes to problems of interest to computational biologists. The course is designed to be accessible to students with a mathematical background roughly at the level of undergraduate engineering mathematics. It is expected that students who have taken both semesters of the course will have mastered the basic set of ideas required in order to carry out further research in computational biology methods and algorithms, or to use these ideas in industrial applications. While this is not a course in computer programming, algorithms that implement probabilistic / statistical approaches to computational biology will be discussed. **The course is designed for students from KGI, CGU Math, and Computational Science.** Prerequisites: Basic understanding of elementary probability and statistics, calculus, linear algebra, and some knowledge of computing (i.e. a reasonable comfort level with at least one computer language used for numerical computation or the ability to quickly achieve it; examples include C/C++, Matlab, etc.). No knowledge of molecular biology will be assumed - such knowledge will be introduced as part of the course where necessary.

#### Math 350

**Kalman Filtering:** Linear dynamical systems; random processes and stochastic systems; optimal linear filters, predictors, and smoothers; nonlinear applications; implementation issues and applications to problems in engineering, economics, and time series. Prerequisites: Calculus, probability (Math 251 or equivalent), linear algebra.

#### Math 351

**Time Series Analysis.** Analysis of time series data by means of particular models such as ARIMA. Associated methods of inference and applications. Additional topics may include spectral analysis and state-space models. Prerequisite: A course in probability and at least concurrent enrollment in statistics.

#### Math 352

**Nonparametric and Computational Statistics:** Treatment of statistical questions, which do not depend on specific parametric models. Examples are testing for symmetry of a distribution and testing for equality of two distributions. Topics may include bootstrapping and other computer intensive methods. Elementary combinatorial methods will play a major role in the course. Prerequisite: a statistics course at the level of 252 or instructor permission.

Math 353

**Asymptotic Methods in Statistics with Applications:** Modes of convergence for random variables and their distributions; central limit theorems; laws of large numbers; statistical large sample theory of functions of sample moments, sample quantiles, rank statistics, and extreme order statistics; asymptotically efficient estimation and hypothesis testing. Prerequisites: Math 251 and 252; linear algebra; undergraduate analysis (Math 131 and 132 or equivalent).

CGU

Spring

J Angus

Math 354

**Reliability Theory:** Structural properties and reliability of complex systems; classes of life distributions based on aging; maintenance and replacement models; availability, reliability, and mean time between failures for complex systems; Markov models for systems; elementary renewal theory. Prerequisite: Math 251. Math 256 would be helpful but not essential.

Math 355

**Linear Statistical Models:** A discussion of linear statistical models in both the full and less-than-full rank cases, the Gauss-Markov theorem, and applications to regression analysis, analysis of variance, and analysis of covariance. Topic in design of experiments and multivariate analysis. Prerequisites: Linear algebra and a year of probability and statistics.

CGU

Fall

J Angus

Math 356

**Game Theory:** Models of conflict and / or cooperation. Equilibrium outcomes for non-cooperative games, and cooperative solution concepts for coalitional games: core theory, stable sets, value theories, the nucleolus, and bargaining sets. Applications to economic markets, voting power, bargaining, joint cost allocation. Prerequisites: Graduate standing or instructor permission.

Math 357

**Advanced Topics and Applications in Probability Theory:** Probability spaces, expectation as integration in a probability space, independence, laws of large numbers, central limit theorems, dependent sequences, conditional expectation and probability, Markov and Martingale properties. Applications to the fields of engineering, computer and information science, reliability, statistics, economics and finance, games and gambling, physics, number theory, optimization / numerical analysis, and partial differential equations. Prerequisite: Math 251 (probability) and undergraduate analysis through advanced calculus, or instructor permission. Math 331 is recommended.

Math 358A

**Mathematical Finance:** This course emphasizes the mathematics used in the valuation of derivative securities. It will cover the necessary tools for modeling price fluctuations in the stock market including Brownian motion, simple stochastic differential equations, Ito's lemma, Arbitrage theory, and the Black-Scholes equation. Students will learn how to solve the basic parabolic partial differential equations arising in finance both explicitly and numerically. Prerequisites: Mature understanding of advanced calculus and probability (at the level of Math 251) and instructor permission. Math 256 and familiarity with simple partial differential equations is helpful.

CGU

Spring

H Schellhorn

Math 358B

**Advanced Financial Mathematics:** First and foremost, this is a course in mathematics that requires a background from the theory of measure and integration sufficient to work with modern developments in probability and stochastic processes. Some familiarity with more classical analysis also will help in relating these stochastic ideas to results involving partial differential equations. The focus will be in providing the student with a deeper understanding of the mathematics that has produced many important applications to finance in general and, in particular, to the pricing of contingent claims. Although the course assumes only a modest background, it moves quickly, and in the end, students can expect to have tools that are deep and rich enough to be relied on throughout their professional careers. Prerequisites: Math 358A or equivalent and sufficient analysis / probability background.

Math 359

**Simulation:** This course will introduce the students to the general concepts and tools of simulation analysis using pseudo random numbers generated on a computer. Starting with a background in calculus-based probability theory, students will learn how to combine the mathematics of probability with the utility of the computer to find approximate solutions to a variety of mathematical problems arising in analysis, probability, statistics, stochastic processes, optimization, and general modeling. In undertaking this study, students will discover that many otherwise intractable problems can often be attacked using simulation techniques that are relatively easy to implement, thus adding to their general problem solving capabilities. Prerequisite: Mastery of Math 251 or equivalent.

Math 361A

**Numerical Methods for Finance:** This course focuses on pricing derivatives. Whereas Math 358A shows the student how to price instruments using closed-form (analytical) formulae, this course focuses on the instruments that can be best analyzed with numerical methods. Topics include binomial tree (lattice), finite differences, Monte Carlo simulation. 2 unit course.

CGU

Spring

H Schellhorn

Math 361B

**Credit Risk:** This course starts with a description of the financial contracts subject to credit risk. After a survey of statistical and actuarial methods of credit risk management, we will study the modern option pricing methods of credit risk. This includes both the reduced form and the structural (Merton) approach. 2 unit course.

CGU

Spring

H Schellhorn

Math 362

**Numerical Methods for Partial Differential Equations:** Finite difference, finite element, and spectral methods for elliptic, parabolic and hyperbolic partial differential equations; discussion of discretization schemes, truncation error, consistency, stability, accuracy and convergence; explicit vs. implicit schemes; implementation of Dirichlet, Neumann and Robin boundary conditions; operator splitting; Godunov methods for hyperbolic systems; direct and iterative methods for elliptic systems; Gauss-Seidel, SOR and multigrid methods; Fourier and Chebyshev based spectral and pseudo-spectral methods. Prerequisites: partial differential equations and numerical analysis.

Math 364

**Introduction to Scientific Computing:** This course is intended to help students develop a basic competence in scientific computing in a PC/workstation environment, thus preparing them for the mathematics clinic, work in industrial applied mathematics, and research in applied mathematics. Students will be given a high-level introduction to computing in Matlab, database basics in MySQL, and the scientific typesetting language LaTeX. A broad collection of basic numerical techniques will be presented including iterative methods for solving nonlinear equations, approximate integration and differentiation, interpolation, and numerical linear algebra. Additional topics may be covered depending on the interests of students.

CGU

Fall

C Rangel

Math 368

**Advanced Numerical Analysis:** Numerical linear algebra including LU decomposition, Jacobi, Gauss-Seidel and SOR iterations, Krylov subspace methods (Conjugate Gradient, GMRES), QR and SVD factorization of matrices, eigenvalue problems via power, inverse, QR and Arnoldi iterations, error analysis, forward and backward stability; numerical integration of ODEs including Runge-Kutta and Adams formulas, predictor-corrector methods, stiff equation solvers and shooting method for BVPs; other numerical methods including interpolation via Lagrange and Chebyshev polynomials and cubic splines, integration and quadrature with trapezoidal and Simpson rules, Newton-Cotes formulae, Gaussian quadrature, and singular integrals, root-finding via one-point iteration, bisection, Newton and secant methods, numerical differentiation using finite differences, spectral and pseudo-spectral methods. Prerequisites: advanced calculus and elementary numerical analysis.

Math 369

**Monte Carlo & Quasi-Monte Carlo Methods:** This is an advanced course in which stochastically motivated mathematical methods are applied to problems of various kinds (e.g., radiation transport, semiconductor, geological and financial modeling, or statistical mechanics) that can be solved by simulations carried out on a computer. Problems studied in this way include those most naturally formulated as integral equations over relatively high dimensional phase spaces, as well as those in which estimates of integrals of functions of a large number of variables are sought. This should be regarded as an advanced course in the applications of probability theory to numerical analysis. Prerequisites include minimally a graduate course in probability theory, a basic course in numerical methods, and facility in programming a computer using a language such as Fortran, C, Basic, or Matlab.

Math 374

**Encoding and Encryption:** The mathematical theory of data encoding and encryption, with much of the necessary abstract algebraic background developed in the course. Topics include: finite groups, rings, and fields; residue arithmetic, the Chinese Remainder Theorem, polynomial algebras over finite fields; basic notions of encoding and error correcting capabilities;  $(n, k)$  - linear codes with parity check: the Hamming code; cyclic codes: the BCH code; complexity-theoretic foundations of cryptography; one-way and trapdoor functions; secret key and public key encoding: the Data Encryption Standard, the RSA algorithm; the factorization problem: computer implementation of the arithmetic of large numbers, elementary algorithms, the quadratic sieve method; theory of zero-knowledge protocols. Prerequisites: linear algebra and a substantial course in programming, preferably C++.

Math 377

**Algebra I:** The Sylow theorems, normal series, and other topics from group theory. Topics from ring theory, including projective and injective modules, rings of quotients and localization, chain conditions, primary decomposition of noetherian modules, and the Wedderburn-Artin theorem for semi-simple rings. Prerequisite: one year of algebra equivalent to Math 171, 172.

Math 378

**Algebra II:** Topics in algebra selected according to the interests of the instructor and students. Prerequisite: Math 377 or instructor permission.

Math 380

**Topics in Applied Mathematics, Fluid Dynamics:** This course will cover the main components of theoretical fluid mechanics: introduction of the continuum description of a Newtonian fluid, viscous / inviscid flows, boundary-layer theory, compressible / incompressible flows, free-surface hydrodynamics and waves, linear / non-linear acoustics, shock waves. The prerequisites are undergraduate courses in vector calculus, complex analysis, ordinary and partial differential equations.

Math 381 / ALS 423 (KGI)

**Topics in Applied Mathematics: Theoretical & Computational Fluid Dynamics:** This is an advanced course in fluid dynamics which introduces the students to mathematical and computational modeling of

flow and transport phenomena. Topics include: review of vectors and tensors; derivation of the governing conservation equations (Navier-Stokes); constitutive equations; exact solutions; Stokes/Rayleigh problems; low Reynolds number (Stokes) flows; flow in Hele-Shaw cells; lubrication theory; thin films; boundary layer theory; hydrodynamic stability; Kelvin-Helmholtz and Rayleigh instabilities; stability of parallel shear flows; interfacial phenomena; surface tension; contact angles and contact lines; finite-difference computational methods; vorticity-streamline formulations; staggered grids; boundary integral and volume-of-fluid methods for flows with interfaces.

Math 382

***Perturbation and Asymptotic Analysis:*** Non-dimensionalization and scaling; regular and singular perturbation problems; asymptotic expansions; asymptotic evaluation of integrals with Laplace's approximation; Watson's lemma; steepest descents and stationary phase; perturbation methods in ordinary and partial differential equations; boundary layers and matched asymptotic expansions; method of multiple time scales; homogenization; WKB method, rays and geometrical optics. Prerequisite: differential equations.

Math 386

***Graph Modeling:*** Basics of theory and application, covering simple graphs through planar graphs, Euler's formula, Platonic graphs, coloring, the genus of graph, Euler walks, and Hamilton walks. Applications will include transportation problems, connection problems, party problems, diagraphs and mathematical models, games, puzzles, graphs and social psychology.

Math 388

***Continuous Mathematical Modeling:*** A course aimed at the construction, simplification, analysis, interpretation and evaluation of mathematical models that shed light on problems arising in the physical, biological and social sciences. Derivation and methods for solution of model equations, heat conduction problems, simple random walk processes, simplification of model equations, dimensional analysis and scaling, perturbation theory, and a discussion of self-contained modular units that illustrate the principal modeling ideas. Students will normally be expected to develop a modeling project as part of the course requirements.

Math 389

***Discrete Mathematical Modeling:*** A companion course to Mathematics 388 with emphasis on discrete, rather than continuous, models. Mathematical topics will normally be drawn from combinatorics, probability, statistics, and operations research and algorithms.

Math 392-393

***Mathematics Clinic:*** Participation in projects or problems with a substantial mathematical and / or computational content. Students will typically work in teams of 2-4 persons with appropriate faculty supervision. Problems will vary considerably depending upon student interest and program of study, but will normally require computer implementation and documentation. Prerequisite: Instructor permission.

CGU  
CGU

Fall / Spring  
Fall / Spring

H Morris  
A Nadim

Math 397

***Tutorial Reading***

Math 398

***Master's Independent Study***

Math 400

***Master's Continuous Registration***

Math 438

*Seminar in Chaotic Dynamics*

Math 439 / Math 139

*Seminar in Analysis*

Math 449

*Seminar in Topology*

Math 460

**Geometric Modeling:** Geometric modeling evokes a curious mix of the visual and the analytic in the eyes and minds of those of us who study and apply it. The visual response arises from its association with the simulation of shapes that define objects in the real world, from its association with the potential reality of the designer's work, and from its symbiosis with computer graphics. The analytical response arises from an awareness of the elegant and often subtle mathematics that is its foundation. Computer Aided Geometric Modeling (CAGM) plays a significant role in the construction designing and manufacturing of various objects. In addition to its critical importance in the traditional fields of automobile and aircraft manufacturing, shipbuilding, and general product design, more recently, the CAGM methods have also proven to be indispensable in a variety of modern industries, including computer vision, robotics, medical imaging, visualization, and even media. Topics in this course will address four problems: 1) How to represent elementary forms (for example, curves, surfaces, and solids), 2) How to shape and assemble those forms into more complex objects, 3) How to process the necessary geometry (for example, computation of intersections, offsets, and fillets) concurrently, and 4) What are the applications (we are going to use real world applications to motivate each of the above three topics through out the course). Prerequisites: calculus, linear algebra, analytic geometry, and vector and matrix methods. Recommended but not necessary: differential geometry and programming skills.

Math 461

**Level-Set Methods:** This course provides an introduction to level-set methods and dynamic implicit surfaces for describing moving fronts and interfaces in a variety of settings. Mathematical topics include: construction of signed distance functions; the level-set equation; Hamilton-Jacobi equations; motion of a surface normal to itself; re-initialization; extrapolation in the normal direction; and the particle level-set method. Applications will include image processing and computer vision, image restoration, de-noising and de-blurring, image segmentation, surface reconstruction from unorganized data, one- and two-phase fluid dynamics (both compressible and incompressible), solid/fluid structure interaction, computer graphics simulation of fluids (i.e. smoke, water), heat flow, and Stefan problems. Appropriate for students in applied and computational mathematics, computer graphics, science, or engineering. Prerequisite: advanced calculus, numerical methods, computer programming.

Math 462

**Bayesian Inference and Machine Learning:** This is a one-semester 4-unit course covering selected topics in Bayesian inference and machine learning. In the first half of the course, students will learn about exact Bayesian inference methods as well as approximate, heuristic methods, such as Monte Carlo sampling and variational methods. The second half of the course will focus on machine learning techniques, primarily neural networks and Gaussian processes. The course is expected to be useful for students with a broad array of backgrounds, including applied mathematics, computational science, computational biology, and financial engineering. Prerequisites: Elementary probability theory and the ability to program in Matlab/Octave/C/C++ or any other numerical programming language.

CGU

Spring

A Raval

Math 463

*Financial Time Series:*

CGU

Spring

H Morris

Math 464

***Seminar in Combinatorial Optimization and Discrete Algorithms:*** This seminar will study both exact and approximate algorithmic methods for discrete optimization problems. The focus will be on probabilistic aspects as well as on how these algorithms perform on typical problem instances drawn from an ensemble. Possible topics include: Markov Chain Monte Carlo, simulated annealing, spin models, average-case complexity, phase transitions in combinatorial optimization, solution clustering and message-passing algorithms. The format will be a combination of lecture, discussions, and student presentations. Prerequisites: probability and combinatorics. Helpful but not required: analysis of algorithms and statistical physics.

CGU

Spring

A Percus

Math 469

***Seminar in Neural Networks and Exotic Algorithms:*** This seminar studies neural networks and other methods such as genetic algorithms and simulated annealing that are highly parallel in nature and deal with problems of optimization that are global in character.

Math 470

***Research Seminar in Monte Carlo & Quasi-Monte Carlo Methods:*** A research seminar dealing with selected current topics from relevant clinic projects, student, and faculty research. 0 – 4 units arranged with instructor.

Math 473

***Seminar in Combinatorics:*** Seminar that consists of weekly talks given by participants in a wide range of combinatorial topics. Possible topics include: combinatorics of finite sets, graph theory, game theory, enumerative combinatorics, combinatorial matrix theory, and Ramsey theory. Registered students will be expected to give one or two talks during the semester. Prerequisite: instructor consent. Grading: Satisfactory / Unsatisfactory.

Math 489

***Seminar in Partial Differential Equations***

Math 498

***PhD Independent Study***

Math 499

***Doctoral Study***