This booklet contains the complete schedule of courses offered by the Math Department in the Spring 2016 semester, as well as descriptions of our upper-level courses (from Math 61 [formally Math 22] and up). For descriptions of lower-level courses, see the University catalog.

If you have any questions about the courses, please feel free to contact one of the instructors.

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Course Renumbering

Starting Fall, 2012, the lower level math courses will have new numbers. The matrix below gives the map between the current numbers and the new numbers. The course numbers on courses you take before Fall 2012 will not change, and the content of these courses will not change.

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* Course coordinator
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[The graduate version of 150-03]
Math 61  Discrete Mathematics
Course Information  Spring 2016

**Block:** G  MWF 1:30-2:20  **Block:** D  M 9:30-10:20, TTh 10:30-11:20
**Instructor:** Moon Duchin  **Instructor:** Zachary Faubion
**Email:** moon.duchin@tufts.edu  **Email:** zachary.faubion@tufts.edu
**Office:** Bromfield-Pearson 113  **Office:** Bromfield-Pearson 105
**Office hours (Fall 2015):** by appt  **Office hours (Fall 2015):** TWThF 9-10:20
**Phone:** 7-5970  **Phone:** 7-2352

**Prerequisites:** One semester of calculus or computer science, or instructor’s consent

**Text:** Richmond and Richmond, *A Discrete Transition to Advanced Mathematics.*

**Course description:**
This course is an introduction to *discrete mathematics*. In mathematics, “discrete” is a counterpart of “continuous,” describing things that vary in jumps rather than smoothly. Calculus studies (mostly) continuous phenomena; the mathematics of the discrete largely fits into the research area called *combinatorics*, where the core questions have to do with counting or enumeration. Our topics will include sets and permutations, equivalence relations, graph theory, propositional logic, cardinality, and much more if time allows.

This course is intended as a bridge from the more computationally-oriented classes like calculus to upper-level courses in mathematics and computer science. We will spend a lot of time learning to read, troubleshoot, and write proofs. This is where you get a big injection of “mathematical maturity”!

Math 61, which is co-listed as Comp 61, is required for computer science majors. It counts toward the math major and is highly recommended for math majors (or possible math majors) who want a first glimpse of higher mathematics.
Instructor: Yusuf Mustopa

E-mail: Yusuf.Mustopa@tufts.edu

Office Hours: Bromfield-Pearson 106, TBA

Course Meeting Time: Block C (Tuesday, Wednesday and Friday, 9:30AM-10:20AM).

Prerequisites: Math 32 (formerly Math 11), or instructor’s consent.


Course Description: Number theory is the search for hidden relationships among the positive integers. Its problems—many of which can stated using only basic arithmetic—have captivated some of the greatest mathematical minds from antiquity up to the present day. Indeed, the long-unsolved question of whether there are infinitely many pairs of “twin prime numbers” (e.g. 3 and 5, 137 and 139) has seen spectacular advances in just the past few years!

We will begin with a thorough treatment of some basic proof techniques. High levels of mathematical rigor may be unsuitable for first courses in calculus or differential equations, but they are absolutely necessary here. After having covered the elementary study of divisibility and prime numbers, we will discuss modular arithmetic; this generalizes the “clock arithmetic” we all do on a daily basis, and yields powerful insights into ordinary arithmetic. The high point of the course is the beautiful Quadratic Reciprocity Law of Gauss. If time and interest permit, we will also discuss applications to cryptography.

Your grade will be based on a midterm exam and a final exam, as well as weekly assignments. These will constitute a significant part of your grade.
Math 70 Linear Algebra
Course Information

Spring 2016

Block: D (Mon. 9:30-10:20, Tues., Thurs. 10:30-11:20)
Instructor: Mary Glaser
Email: Mary.Glaser@tufts.edu
Office: Bromfield-Pearson 004
Office hours: (Fall 2015) Wed. 2:30-4:30, Fri. 11-12.
Phone: (617) 627-5045

Block: E (Mon., Wed., Fri. 10:30-11:20)
Instructor: Hao Liang
Email: Hao.Liang@tufts.edu
Office: Bromfield-Pearson 109
Office hours: (Fall 2015) Tues. 2:30-4:30, Thurs. 2:30-3:30
Phone: (617) 627-2678

Block: F (Tues., Thurs., Fri. 12:00-12:50)
Instructor: Todd Quinto (course coordinator)
Email: Todd.Quinto@tufts.edu
Office: Bromfield-Pearson 204
Office hours: (Fall 2015) Tues., Fri. 1:30-3:00
Phone: (617) 627-3402

Block: H (Tues., Thurs. 1:30-2:20, Fri. 2:30-3:20)
Instructor: Jessica Dyer
Email: Jessica.Dyer@tufts.edu
Office: Bromfield-Pearson 217
Office hours: (Fall 2015) Tues., Thurs., Fri. 10-11
Phone: (617) 627-0359

Prerequisites: Math 34 or 39 (in the old numbering, Math 12 or 17) or consent.


Course description: In Math 70 we start by studying systems of linear equations. For example, $2x + 3y = 5$ is a linear equation in the unknowns $x$ and $y$ since it describes a line in the plane, whereas $e^x = y$ is nonlinear. The study of linear equations quickly leads to beautiful deep concepts including vector spaces, dimension (you will learn about four-, five-, and infinite-dimensional spaces!), linear transformations, and eigenvalues. These abstract ideas will help you solve linear equations efficiently, and more importantly, they fit together in a beautiful whole that will give you a deeper understanding of these ideas.

Linear algebra arises everywhere in mathematics (you will use it in almost every upper level math course) and in physics, chemistry, economics, biology, and a range of other fields. Even when a problem involves nonlinear equations, as is often the case in applications, linear systems still play a central role, since the most common methods for studying nonlinear systems approximate them by linear systems.

This course introduces students to axiomatic mathematics and proofs as well as fundamental mathematical ideas. You will develop your logic skills and mathematical talents. Mathematics majors and minors are required to take linear algebra (Math 70 or Math 72) and are urged to take it as early as possible, as it is a prerequisite for most upper-level mathematics courses. The course is also useful to majors in computer science and engineering, as well as those in the natural and social sciences.

There will be three exams in this course, two during the semester and one at the end, and there will be regular assignments (either twice a week or daily) and regular quizzes.
Course Information

Block: F (TThF 12:00 - 12:50 PM)
Instructor: Kye Taylor
Email: kye.taylor@tufts.edu
Office: Bromfield-Pearson 114
Office hours: (Fall 2015) TTh 5:00p-7:00p & F 12:00p-12:50p
Prerequisites: Math 34 or 39, or instructor consent.

Text: none

Course Description:
This course is about using elementary mathematics and computing to solve practical problems. Single-variable calculus is a prerequisite; other mathematical and computational tools, such as elementary probability, matrix algebra, elementary combinatorics, and computing in MATLAB, will be introduced as they come up.

Mathematical modeling is an important area of study, where we consider how mathematics can be used to model and solve problems in the real world. This class will be driven by studying real-world questions where mathematical models can be used as part of the decision-making process. Along the way, we’ll discover that many of these questions are best answered by combining mathematical intuition with some computational experiments.

Some problems that we will study in this class include:

1. The managed use of natural resources. Consider a population of fish that has a natural growth rate, which is decreased by a certain amount of harvesting. How much harvesting should be allowed each year in order to maintain a sustainable population?

2. The optimal use of labor. Suppose you run a construction company that has fixed numbers of tradespeople, such as carpenters and plumbers. How should you decide what to build to maximize your annual profits? What should you be willing to pay to increase your labor force?

3. Project scheduling. Think about scheduling a complex project, consisting of a large number of tasks, some of which cannot be started until others have finished. What is the shortest total amount of time needed to finish the project? How do delays in completion of some activities affect the total completion time?

Using basic mathematics and calculus, we will address some of these issues and others, such as dealing with the MBTA T system and penguins (separately of course...). This course will also serve as a good starting point for those interested in participating in the Mathematical Contest in Modeling each Spring.
BLOCK: G (Mon Wed Fri, 1:30–2:20 p.m.)
INSTRUCTOR: Loring Tu
EMAIL: loring.tu@tufts.edu
OFFICE: Bromfield-Pearson 206
OFFICE HOURS: (Fall 2015) Mon 2:20–2:50 (Math 135 only), Mon 4:15–5:15, Wed 4:15–4:45, Wed
7:30–8:30 (Putnam)
PHONE: (617) 627-3262

PREREQUISITES: Math 135 or consent.

(ISBN: 978-0-8218-4791-6)

COURSE DESCRIPTION:
This course is a continuation of Math 135. In Math 135 we laid the foundation of real analysis by
studying the topology of a metric space and the concept of continuity. Math 136 applies these tools
to give a rigorous treatment of derivatives and integrals of real-valued and vector-valued functions
on $\mathbb{R}^n$.

The derivative of a function $f : \mathbb{R}^n \rightarrow \mathbb{R}^m$ is defined to be a linear transformation, representable
by a matrix of partial derivatives. Using this definition, we prove rules for differentiation (including
the product rule and the chain rule) and the mean-value theorem. These are results you’ve
encountered in calculus courses, but now you will know when and why they are true.

Two new results are the implicit function theorem, giving conditions under which an equation
can be solved locally, and the inverse function theorem, giving conditions under which a function
is locally invertible.

The second half of the course makes precise the notions of “area” and “volume” and develops
the theory of Riemann integrals. As before, we prove some familiar theorems such as Fubini’s
theorem and the change of variables formula.

We will end the course with Fourier series, which has important applications to engineering and
physics.

As in Math 135, apart from laying the theoretical foundation of calculus, a companion goal of
the course is to hone your ability to formulate precisely mathematical ideas and to read and write
proofs.
Math 146  Abstract Algebra II  Spring 2016
Course Information

BLOCK: H+ (Tuesday, Thursday 1:30-2:45)
INSTRUCTOR: Kim Ruane
EMAIL: kim.ruane@tufts.edu
OFFICE: CLIC, 574 Boston Ave, Suite 211, Room I
OFFICE HOURS: (Fall 2015) Mon 1:45-2:45, Wed 9:30-11, Thurs 1-2
PHONE: (617) 627-2006

PREREQUISITES: Math 145


COURSE DESCRIPTION: This course is a continuation of Math 145. We will continue our study of abstract algebraic structures such as groups, rings and fields in order to prove that there is no formula for solving a general polynomial equation of degree 5 or higher. The main ingredient in this result is a beautiful connection between groups and the roots of a polynomial discovered by Galois in the early 1800’s. Along the way we will see the formulas for the general cubic and quartic polynomial equation discovered by the Italians in the 1500’s.

There will be homework sets, a mid-term, and a final exam in the course.
**Math 150-01**  
**Data Mining and Analysis**  
**Course Information**  
**Spring 2016**

**Block:** D+ (Tu, Th 10:30–12:00)  
**Instructor:** Christoph Börgers  
**Email:** cborgers@tufts.edu  
**Office:** Bromfield-Pearson 215  
**Office hours:** (Fall 2015) Tu, Th, Fr 11–12  
**Phone:** (617) 627-2366

**Prerequisite:** Math 70 (Linear Algebra) or Math 72 (Abstract Linear Algebra), and willingness to do Matlab programming. (Matlab experience is helpful, but not absolutely necessary.)

**Text:** Mohammed Zaki and Wagner Meira, Data Mining and Analysis, Cambridge University Press (2014).

**Course description:** *Data mining* is about the computational analysis of large data sets. Abstractly, given points \( \mathbf{x}_i \in \mathbb{R}^d \), \( i = 1, 2, \ldots, n \), the goal is to use a computer to extract interesting information about their spatial distribution. Often \( n \) is very large, and \( d \) may be very large as well. The figure shows an example with \( n = 1200 \) and \( d = 2 \). You see 4 clusters, and some points that don’t belong to any cluster. We will study clustering algorithms for detecting clusters automatically. Two of the clusters are round, and the other two have elongated shapes. Principal component analysis detects such features automatically; it is the singular value decomposition (SVD) from Linear Algebra, in thin disguise. You will learn about the SVD, and how it applies to the analysis of data.

There are countless important applications of tools of these sorts. Principal component analysis is a *dimension reduction* technique. One might, for instance, ask patients 20 questions about their nutritional and exercise habits. Each of the answers can be interpreted as a point in \( \mathbb{R}^{20} \). If principal component analysis reveals that the variations are in essence in three directions in \( \mathbb{R}^{20} \) only, this reduces \( d \) from 20 to 3. Clustering algorithms are useful to detect groups of items that have something in common — groups of people with similar genetic makeups, assemblies of neurons in the brain with similar firing patterns, families of genes with similar biochemical function, etc.

Other topics include *sequence mining* (for instance, searching for patterns in nucleic acid sequences), *graph clustering* (for instance, detecting social groupings in larger populations), and *support vector machines* (classifying data points into two groups, given a set of examples). Matlab will be used throughout to illustrate the methods.
BLOCK: C TWF, 9:30-10:20 AM
INSTRUCTOR: Patricia Garmirian
EMAIL: patricia.garmirian@tufts.edu
OFFICE: Bromfield-Pearson 201
OFFICE HOURS: MW 3:00-4:30 P.M.
PHONE: (617) 627-2682

PREREQUISITES: Math 42 or consent.


COURSE DESCRIPTION: An option is a contract to buy or sell stock at a predetermined fixed
price at some future date. One can see that buying stock at a price below its actual value is
a good deal, while buying stock at a price above its actual value is not a good deal. In the
first situation, one could make a profit by selling the stock, and in the second situation one
would choose not to exercise the contract. Of course, the difficulty in deciding whether or
not to buy an option is a result of the randomness of stock prices: we do not know what the
actual price of the stock will be at a future date. A natural question therefore arises: How
do we determine the fair price for the option?

In this course, we will learn how to determine the fair price for an option in both the
discrete setting of binary trees and the continuous setting of the Black Scholes model. Other
topics discussed in this course will include basic mathematical concepts behind derivative
pricing and portfolio management of derivative securities, an introduction to the theory of
Stochastic Calculus, the Martingale Representation Theorem, and change of measure, and
applications of the developed theory to a variety of actual financial instruments.

The course will have weekly homework, two midterm exams, and a final exam.
A Lie algebra is a vector space $\mathfrak{g}$ over a field $\mathbb{F}$ together with a binary operation $[\ ,
abla] : \mathfrak{g} \times \mathfrak{g} \to \mathfrak{g}$ which satisfies the following properties:

$$
[aX + bY, Z] = a[X, Z] + b[Y, Z] \\
[X, Y] = -[Y, X] \\
[X, [Y, Z]] + [Y, [X, Z]] + [Z, [X, Y]] = 0.
$$

for all $X, Y,$ and $Z$ in $\mathfrak{g}$ and $a$ and $b$ in $\mathbb{F}$. Lie algebras were introduced by Sophus Lie in the 1870’s (who named them “infinitesimal transformations”), while studying differential equations. Lie discovered that the action of continuous groups on geometric objects called manifolds could be better understood by “linearizing” them; i.e., studying their infinitesimal actions as vector fields. The binary operation above is just an infinitesimal version of the group multiplication. The term “Lie algebra” was introduced by Hermann Weyl in the 1930s while developing the theory of compact groups.

For example, the group of rotations of $\mathbb{R}^3$ has as its infinitesimal rotations the vector space $\mathbb{R}^3$, and the corresponding bracket operation is the cross product.

Lie algebras are used mainly to understand geometric objects such as manifolds and their continuous transformation groups (Lie groups). An understanding of Lie algebra theory is therefore quite necessary in many fields of mathematics and physics. Unfortunately, many courses in these fields often provide only a cursory treatment of the subject; my aim in this course is to provide a complete treatment of the basic notions of Lie algebra theory and to demonstrate how rich the theory is. This will provide the student with the some of tools necessary to conduct further study and research in a wide variety of fields.

In particular, we will cover Cartan’s classification of the finite-dimensional complex simple Lie algebras, as well as some aspects of representation theory.

This course is also intended to serve as a second course in abstract linear algebra for upper level undergraduates and beginning graduate students. As such, it will be useful preparation for advanced graduate level courses which require a more specialized knowledge of linear algebra than what is taught in Math 70/72.

There will be weekly problem sets and a take-home final exam.
Math 152  Nonlinear Partial Differential Equations  Spring 2016
Course Information

Block: H+ (Tu, Th 1:30–2:45)
Instructor: Christoph Börgers
Email: cborgers@tufts.edu
Office: Bromfield-Pearson 215
Office hours: (Fall 2014) Tu, Th, Fr 11–12
Phone: (617) 627-2366

Prerequisites: Math 151 or consent.

Text: None. (Notes will be distributed electronically.)

Course description: We will begin the course with a review of the most fundamental linear partial differential equations (PDEs): The wave equation, the diffusion equation, and the Poisson equation, with emphasis on Fourier analysis and its use in understanding linear PDEs. In the process, we will give a more detailed treatment of Fourier series and the Fourier transform than time permitted in the fall.

We will then move on to examples of nonlinear PDEs, in particular Burgers’ equation and the Fisher-Kolmogorov equation. As in Math 151, strong emphasis will be put on understanding what these equations describe, and why. We will discuss the most fundamental numerical methods for solving these equations as well; their study supports conceptual understanding, and is practically important and mathematically interesting.

Burgers’ equation is the simplest example of a nonlinear first-order wave equation that allows the formation of shock waves, similar to the shock waves arising in supersonic flight. The same equation can also be derived from a model of traffic flow; the “shock waves” are then traffic jams forming spontaneously as a result of heavy traffic.

The Fisher-Kolmogorov equation describes the density of a population that grows logistically while diffusing in space. It is the simplest example of a reaction-diffusion equation. We will analyze its traveling wave solutions, i.e., waves describing the invasion of an uninhabited region in space by the population modeled by the equation.
Math 158          Complex Variables          Spring 2016
Course Information

Block: D+TR, Tue Thu 10:30-11:45 AM
Instructor: Fulton Gonzalez
Email: fulton.gonzalez@tufts.edu
Office: Bromfield-Pearson 203
Office hours: (Fall 2015) on leave
Prerequisites: Math 34; Math 42 is recommended.


Course description:
This course is an introduction to the theory of complex numbers and complex-valued functions, a subject with wide-ranging applications and one which is fascinating in its own right, with many elegant and surprising results.

The student will learn the spirit of analytic function theory, including Cauchy’s theorem and integral formula, Taylor and Laurent series, contour integration, the Maximum Principle, analytic continuation, harmonic functions, conformal mappings, and Möbius transformations. We will also explore some of the many applications of complex analysis, such as two-dimensional potential theory and possibly a bit of Fourier series.

The course will be taught rigorously, with plenty of theorem-proving, but also with many computational examples and practical calculus-style problems. It will be appropriate for mathematics, science, and engineering majors.

Course Requirements: There will be weekly problem sets, two midterm exams, and a final exam.
BLOCK: E+MWF, 10:30-11:45 AM  
INSTRUCTOR: Patricia Garmirian  
EMAIL: patricia.garmirian@tufts.edu  
OFFICE: Bromfield-Pearson 201  
OFFICE HOURS: MW 3:00-4:30 P.M.  
PHONE: (617) 627-2682

PREREQUISITES: Math 161 or Consent.


COURSE DESCRIPTION: Suppose I claim that I make 75 percent of my basketball free throws. To test my claim, you ask me to shoot 40 free throws and I make only 24 of the 40. Do you believe my claim?

Statistics is the science of gaining information from numerical data. Our technological world generates data at an enormous rate. However, all too often the data is improperly obtained and/or improperly assessed. Important everyday decisions for individuals, corporations, societies, and governments hinge on a proper understanding and assessment of data. Every facet of industry, science, engineering, economics and business benefits from a solid knowledge of statistics.

Statistics uses the major ideas and concepts from probability. Only via the use of probability can a proper assessment be made of data collected for real-world problems. Math 162 provides opportunities to experience and learn the statistical thinking a functioning statistician must develop and use constantly. It also provides preparation for actuarial exams, graduate work in applied mathematics, and courses in physical/social sciences requiring statistical methodology. Topics to be covered include 1) estimating an unknown parameter of the underlying population, 2) turning data into evidence, as in testing a hypothesis, 3) determining existence and strength of a correlation between several variables, 4) making predictions, 5) testing models for goodness-of-fit, etc.

The course will have weekly homework, two midterm exams, and a final exam.
Block: D (M 9:30-10:20, TTh 10:30-11:20)
Instructor: George McNinch
Email: George.McNinch@tufts.edu
Office: Bromfield-Pearson 112
Office hours: Fall 2015: Tue 10:00-12:00, Wed 13:30-15:30

Prerequisites: Math 215, or consent of instructor.

Course description:

The graduate algebra syllabus found here:

http://math.tufts.edu/graduate/qualifyingExams.htm

is covered in Math 215 and the first four or five weeks of Math 216. A good reference for the syllabus material is the text Abstract Algebra, 3rd Edition by Dummit and Foote (John Wiley and Sons inc), and I'll follow this text while covering material on the syllabus.

Once the syllabus material has been completed, the course will focus on commutative algebra. I don’t plan to follow a single text, but I will consult the following sources (in addition to [Dummit-Foote]):

- Commutative Algebra with a View Toward Algebraic Geometry by David Eisenbud (Graduate Texts in Mathematics. Springer-Verlag).
- Local Algebra by Jean-Pierre Serre (Translated from the French by CheeWhye Chin; Springer Monographs in Mathematics. Springer-Verlag).
- Introduction to commutative algebra by M.F. Atiyah and I. G. MacDonald (Addison-Wesley).

Commutative algebra is a fundamental tool in the study of algebraic geometry and algebraic number theory, and it is an integral part of the study of modern algebra. The methods I'll emphasize are “local” (mainly we consider local rings, or rather the localizations of interesting commutative rings). As we proceed through the course, I hope to include discussion of the relevance and motivation of the results from the point of view of geometry and number theory.

Here is a list of topics/results I intend to cover in the course:

- integral dependence and integral extensions of commutative rings; Hilbert’s Nullstellensatz and Noether’s Normalization Lemma
- dimension of a commutative ring; Krull’s Principal Ideal Theorem; Hilbert polynomial
- regular local rings; discrete valuation rings; Dedekind domains
- module of differentials; the Jacobian criterion for regularity
- quick sketch of methods of homological algebra; definition of Tor and Ext for modules over a ring A.
- Koszul complexes; homological characterization of regular local rings

Your grade in the course will be based on your performance on regularly assigned problem sets.
Course Information

Spring 2016

Block: I+ (Mon Wed, 3:00–4:15 p.m.)
Instructor: Loring Tu
Email: loring.tu@tufts.edu
Office: Bromfield-Pearson 206
Office hours: (Fall 2015) Mon 2:20–2:50 (Math 135 only), Mon 4:15–5:15, Wed 4:15–4:45, Wed 7:30–8:30 (Putnam)
Phone: (617) 627-3262

Prerequisites: Math 135, 136, and 145.


Course description:

Undergraduate calculus progresses from differentiation and integration of functions on the real line to functions on the plane and in 3-space. Then one encounters vector-valued functions and learns about integrals on curves and surfaces. Real analysis extends differential and integral calculus from $\mathbb{R}^3$ to $\mathbb{R}^n$. This course is about the extension of calculus from curves and surfaces to higher dimensions.

The higher-dimensional analogues of smooth curves and surfaces are called manifolds. The constructions and theorems of vector calculus become simpler in the more general setting of manifolds; gradient, curl, and divergence are all special cases of the exterior derivative, and the fundamental theorem for line integrals, Green’s theorem, Stokes’ theorem, and the divergence theorem are different manifestations of a single general Stokes’ theorem for manifolds.

Higher-dimensional manifolds arise even if one is interested only in the three-dimensional space which we inhabit. For example, if we call a rotation followed by a translation an affine motion, then the set of all affine motions in $\mathbb{R}^3$ is a six-dimensional manifold. As another example, the zero set of a system of equations is often, though not always, a manifold. We will study conditions under which a topological space becomes a manifold. Combining aspects of algebra, topology, and analysis, the theory of manifolds has found applications to many areas of mathematics and even classical mechanics, general relativity, and quantum field theory.

Topics to be covered included manifolds and submanifolds, smooth maps, tangent spaces, vector bundles, vector fields, Lie groups and their Lie algebras, differential forms, exterior differentiation, orientations, and integration.

There will be weekly problem sets, a midterm, and a final. Students who have not take Math 136 (Real Analysis II) may take it concurrently with this course. Undergraduates who have done well in the prerequisite courses should find this course within their competence.
BLOCK: G+ Monday Wednesday 1:30-2:45 PM  
INSTRUCTOR: Genevieve Walsh  
EMAIL: genevieve.walsh@tufts.edu  
OFFICE: 574 Boston Avenue 211G  
OFFICE HOURS: (Fall 2015) Thur 2-4 Fri 1-2  
PREREQUISITES: Graduate standing or consent of the instructor. 135 and 145 or equivalent.


COURSE DESCRIPTION: Algebraic Topology is the study of algebraic invariants associated to topological spaces. This course will approach this study from a decidedly geometric viewpoint. We will begin by reviewing some underlying geometric notions, such as homotopy. We will then define the fundamental group, and compute it for lots of examples, using Van Kampen’s theorem as our main tool. We will also use the fundamental group to understand covering spaces, and define a correspondence between subgroups of the fundamental group of a space and covers of that space. Given a group $G$, we will construct a space whose homotopy type depends only on its fundamental group $G$.

Next we will turn to an abelian theory, homology. Although somewhat more complicated to define, this is an extremely useful tool. This theory assigns a sequence of abelian groups to a space, called the homology groups. The first of these groups is the abelianization of the fundamental group. Homology groups can be computed naturally using a cell complex. Finally, we will study cohomology and Poincare duality for manifolds.

Throughout, examples and geometric constructions will be emphasized, with a particular emphasis on 2- and 3-dimensional manifolds, graphs, and 2-dimensional complexes.

This course is contains some preparation for the qualifying exam in Algebraic Topology.
Course Information

**Block:** G+MW
**Instructor:** Misha Kilmer
**Email:** misha.kilmer@tufts.edu
**Office:** Bromfield-Pearson 103
**Office Hours:** (Fall 2015) By appt.

**Prerequisites:** Math 70, Comp 11 or equivalent


**Course Description:**
We will study the algorithms and the relevant matrix theory for computing the solution to several linear algebra problems of great interest in a wide variety of science and engineering applications. The list of linear algebra problems we will consider includes solving linear systems through direct and iterative techniques, (orthogonal) matrix factorization, and eigenvalue/eigenvector computation. We will build on the basic linear algebra concepts (i.e., range, null space, vector subspaces, orthogonal projections) and tools from a standard linear algebra course. While paying attention to computer storage, operations counts and finite precision arithmetic, we will learn how tools from linear algebra can be used to solve real-world problems. In-class examples and homework problems will feature some of these applications (e.g., optimization, data mining, and image processing). Because this is a graduate course, we will also cover state-of-the-art algorithms/theory and open research problems in the field.

Homework problems will consist of proofs as well as computer programming assignments in MATLAB (or your favorite programming language).
Math 250-01 Graph Algorithms Spring 2016

Course Information

Block: F+ (Tuesday, Friday 12:00-1:15 PM)
Instructor: Xiaozhe Hu
Email: Xiaozhe.Hu@tufts.edu
Office: Bromfield-Pearson 212
Office hours: (Fall 2015) Tuesday 3:00-4:30 pm, Wednesday 1:00-2:30 pm, or by appointment
Prerequisites: Math 128 or 228, or consent. Some programming ability in a language such as C, C++, Fortran, Matlab, etc.

Text: TBD

Course description:

Graphs, which are mathematical structures used to model pairwise relations between objects, are among the most fundamental data structures in computer science. Graphs are widely used to model many types of relations and processes in physical, biological, social, and information systems. Graph algorithms are the algorithms that operate on the graphs and become more and more important because of their applications to modern life, for example, the power grid, computer networks, machine learning, social network, and computational linguistic.

The course will focus on the development of graph algorithms and the primary objective of the course is to understand the construction of graph algorithms, application of them, and more importantly, the applicability and limits of their usages. We will look at graph related problems and motivate them by practical interpretations. We will use an algorithmic point of view and mainly interested in how to find an (nearly) optimal algorithm as efficient as possible. We will discuss the theoretical foundations of graph algorithms and also discuss their computational complexity, storage, and applications. Moreover, we will discuss graph algorithms in the language of linear algebra whenever possible. The topics include: basic graph theory, shortest path, spanning tree, connectivity, coloring, matching, spectral of graphs, and clustering. In-class example, homework, and projects will feature some of the practical applications of these algorithms to solve real-world problems. Homework problems will consist written problems as well as computer programming assignments in Matlab (or your favorite programming language).
Math 150-03/250-02

Lie algebras

Spring 2016

Course Information

BLOCK: H+TR, Tue Thu 1:30-2:45 PM
INSTRUCTOR: Fulton Gonzalez
EMAIL: fulton.gonzalez@tufts.edu
OFFICE: Bromfield-Pearson 203
OFFICE HOURS: (Fall 2015) on leave
PREREQUISITES: Math 42; Math 145 is recommended.

TEXT: Lecture Notes on Lie algebras, by Fulton Gonzalez, available for download on Trunk and on the instructor's web site.

Course description:
A Lie algebra is a vector space \( g \) over a field \( \mathbb{F} \) together with a binary operation \([ , , ] : g \times g \to g\) which satisfies the following properties:

\[
[aX + bY, Z] = a[X, Z] + b[Y, Z]
\]

\[
[X, Y] = -[Y, X]
\]

\[
[X, [Y, Z]] + [Y, [X, Z]] + [Z, [X, Y]] = 0.
\]

for all \( X, Y, \) and \( Z \) in \( g \) and \( a \) and \( b \) in \( \mathbb{F} \). Lie algebras were introduced by Sophus Lie in the 1870’s (who named them “infinitesimal transformations”), while studying differential equations. Lie discovered that the action of continuous groups on geometric objects called manifolds could be better understood by “linearizing” them; i.e., studying their infinitesimal actions as vector fields. The binary operation above is just an infinitesimal version of the group multiplication. The term “Lie algebra” was introduced by Hermann Weyl in the 1930s while developing the theory of compact groups.

For example, the group of rotations of \( \mathbb{R}^3 \) has as its infinitesimal rotations the vector space \( \mathbb{R}^3 \), and the corresponding bracket operation is the cross product.

Lie algebras are used mainly to understand geometric objects such as manifolds and their continuous transformation groups (Lie groups). An understanding of Lie algebra theory is therefore quite necessary in many fields of mathematics and physics. Unfortunately, many courses in these fields often provide only a cursory treatment of the subject; my aim in this course is to provide a complete treatment of the basic notions of Lie algebra theory and to demonstrate how rich the theory is. This will provide the student with the some of tools necessary to conduct further study and research in a wide variety of fields.

In particular, we will cover Cartan’s classification of the finite-dimensional complex simple Lie algebras, as well as some aspects of representation theory.

This course is also intended to serve as a second course in abstract linear algebra for upper level undergraduates and beginning graduate students. As such, it will be useful preparation for advanced graduate level courses which require a more specialized knowledge of linear algebra than what is taught in Math 70/72.

There will be weekly problem sets and a take-home final exam.
# Mathematics Major Concentration Checklist

For students matriculating Fall 2012 and after (and optionally for others)
(To be submitted with University Degree Sheet)

<table>
<thead>
<tr>
<th>Name:</th>
<th>I.D.#:</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-Mail Address:</td>
<td>College and expected graduation semester/year:</td>
</tr>
<tr>
<td>Other Major(s):</td>
<td>(Note: Submit a signed checklist with your degree sheet for each major.)</td>
</tr>
</tbody>
</table>

Please list courses by number. For transfer courses, list by title, and add “T”. Indicate which courses are incomplete, in progress, or to be taken.

*Note: If substitutions are made, it is the student’s responsibility to make sure the substitutions are acceptable to the Mathematics Department.*

## Ten courses distributed as follows:

### I. Five courses required of all majors. (Check appropriate boxes.)
If “in progress” or future semester, note semester.

<table>
<thead>
<tr>
<th>1. Math 42: Calculus III or Math 44: Honors Calculus</th>
<th>Grade:</th>
<th>4. Math 145: Abstract Algebra I</th>
<th>Grade:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Math 70: Linear Algebra or Math 72: Abstract Linear Algebra</td>
<td>Grade:</td>
<td>5. Math 136: Real Analysis II or Math 146: Abstract Algebra II</td>
<td>Grade:</td>
</tr>
</tbody>
</table>

We encourage all students to take Math 70 or 72 before their junior year. To prepare for the proofs required in Math 135 and 145, we recommend that students who take Math 70 instead of 72 also take another course above 50 (in the new numbering scheme) before taking these upper level courses.

### II. Two additional 100-level math courses.

1. ___________________ Grade: _____ 2. ___________________ Grade: _____

### III. Three additional mathematics courses numbered 50 or higher (in the new numbering scheme);
up to two of these courses may be replaced by courses in related fields including:
- Chemistry 133, 134; Computer Science 15, 126, 160, 170; Economics 107, 108, 154, 201, 202;
- Electrical Engineering 18, 107, 108, 125; Engineering Science 151, 152; Mechanical Engineering 137, 138, 150, 165, 166; Philosophy 33, 103, 114, 170; Physics 12, 13 any course numbered above 30; Psychology 107, 108, 140.

| 1. ___________________ | Grade: | 3. ___________________ | Grade: |
| 2. ___________________ | Grade: |

Student’s signature: ___________________________ Date: ____________
Advisor’s signature: ___________________________ Date: ____________
Chair’s signature: _____________________________ Date: ____________

*Note: It is the student’s responsibility to return completed, signed degree sheets to the Office of Student Services, Dowling Hall.*
(form revised September 2, 2015)
## APPLIED MATHEMATICS MAJOR CONCENTRATION CHECKLIST
(To Be Submitted with University Degree Sheet)

Name: | I.D.#: \\
---|---
E-Mail Address: | College and expected graduation semester/year: \\
Other Major(s): | (Note: Submit a signed checklist with your degree sheet for each major.)

Please list courses by number. For transfer courses, list by title, and add “T”. Indicate which courses are incomplete, in progress, or to be taken.

Note: If substitutions are made for courses listed as “to be taken”, it is the student’s responsibility to make sure the substitutions are acceptable.

### Thirteen courses beyond Calculus II. These courses must include:

#### I. Seven courses required of all majors. (Check appropriate boxes.)

- If “in progress” or future semester, note semester.

<table>
<thead>
<tr>
<th>Course</th>
<th>Grade</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math 42: Calculus III or Math 44: Honors Calculus III</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Math 70: Linear Algebra or Math 72: Abstract Linear Algebra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Math 51: Differential Equations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### II. One of the following:

1. ___________________________ Grade: ______

   - Math 145: Abstract Algebra I
   - Math 61/Comp 61: Discrete Mathematics
   - Comp 15: Data Structures
   - Math/Comp 163: Computational Geometry

#### III. One of the following three sequences:

1. ___________________________ Grade: ______

   - Math 126/128: Numerical Analysis/Numerical Algebra
   - Math 151/152: Applications of Advanced Calculus/Nonlinear Partial Differential Equations
   - Math 161/162: Probability/Statistics

#### IV. An additional course from the list below but not one of the courses chosen in section III:

1. ___________________________ Grade: ______

   - Math 126
   - Math 128
   - Math 151
   - Math 152
   - Math 161
   - Math 162

#### V. Two electives (math courses numbered 61 or above are acceptable electives. With the approval of the Mathematics Department, students may also choose as electives courses with strong mathematical content that are not listed as Math courses.)

1. ___________________________ Grade: ______ 2. ___________________________ Grade: ______

---

Student’s signature: ___________________________ Date: ____________
Advisor’s signature: ___________________________ Date: ____________
Chair’s signature: ___________________________ Date: ____________

Note: It is the student’s responsibility to return completed, signed degree sheets to the Office of Student Services, Dowling Hall.
(form revised September 2, 2015)
MATHEMATICS MINOR CONCENTRATION CHECKLIST

In addition to this form, students must complete the “Declaration of Major(s)/Minor/Change of Advisor for Liberal Arts Students” form.

<table>
<thead>
<tr>
<th>Name:</th>
<th>I.D.#:</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-Mail Address:</td>
<td>College and expected graduation semester/year:</td>
</tr>
<tr>
<td>Major(s):</td>
<td></td>
</tr>
<tr>
<td>Faculty Advisor for Minor (please print)</td>
<td></td>
</tr>
</tbody>
</table>

Please list courses by number. For transfer courses, list by title and add “T”. Indicate which courses are incomplete, in progress, or to be taken.

Courses numbered under 100 will be renumbered starting in the Fall 2012 semester. Courses are listed here by their new number, with the old number in parentheses.

Note: If substitutions are made for courses listed as “to be taken”, it is the student’s responsibility to make sure that the substitutions are acceptable.

Six courses distributed as follows:

I. Two courses required of all minors. (Check appropriate boxes.) If “in progress” or future semester, note semester.

<table>
<thead>
<tr>
<th>Grade:</th>
<th>Grade:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2.</td>
</tr>
</tbody>
</table>

1. Math 42 (old: 13): Calculus III or Math 44 (old: 18): Honors Calculus
2. Math 70 (old: 46): Linear Algebra or Math 72 (old: 54): Abstract Linear Algebra

II. Four additional math courses with course numbers Math 50 or higher (in the new numbering scheme). These four courses must include Math 135: Real Analysis I or 145: Abstract Algebra (or both).

Note that Math 135 and 145 are typically only offered in the fall.

<table>
<thead>
<tr>
<th>Grade:</th>
<th>Grade:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2.</td>
</tr>
<tr>
<td>3.</td>
<td>4.</td>
</tr>
</tbody>
</table>

Student’s signature: ___________________________ Date: __________
Advisor’s signature: ___________________________ Date: __________

Note: It is the student’s responsibility to return completed, signed degree sheets to the Office of Student Services, Dowling Hall.
(form revised September 2, 2015)
Jobs and Careers

The Math Department encourages you to discuss your career plans with your professors. All of us would be happy to try and answer any questions you might have. Professor Quinto has built up a collection of information on careers, summer opportunities, internships, and graduate schools and his web site (http://equinto.math.tufts.edu) is a good source.

Career Services in Dowling Hall has information about writing cover letters, resumes and job-hunting in general. They also organize on-campus interviews and networking sessions with alumni. There are job fairs from time to time at various locations. Each January, for example, there is a fair organized by the Actuarial Society of Greater New York.

On occasion, the Math Department organizes career talks, usually by recent Tufts graduates. In the past we had talks on the careers in insurance, teaching, and accounting. Please let us know if you have any suggestions.

The Math Society

The Math Society is a student run organization that involves mathematics beyond the classroom. The club seeks to present mathematics in a new and interesting light through discussions, presentations, and videos. The club is a resource for forming study groups and looking into career options. You do not need to be a math major to join! See any of us about the details. Check out http://ase.tufts.edu/mathclub for more information.

The SIAM Student Chapter

Students in the Society for Industrial and Applied Mathematics (SIAM) student chapter organize talks on applied mathematics by students, faculty and researchers in industry. It is a great way to talk with other interested students about the range of applied math that’s going on at Tufts. You do not need to be a math major to be involved, and undergraduates and graduate students from a range of fields are members. Check out https://sites.google.com/site/tuftsiam/ for more information.
### BLOCK SCHEDULE

<table>
<thead>
<tr>
<th>50 and 75 Minute Classes</th>
<th>Mon</th>
<th>Mon</th>
<th>Tue</th>
<th>Tue</th>
<th>Wed</th>
<th>Wed</th>
<th>Thu</th>
<th>Thu</th>
<th>Fri</th>
<th>Fri</th>
<th>150/180 Minute Classes and Seminars</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:05-9:20 (A+, B+)</td>
<td>A+</td>
<td>0+</td>
<td>B+</td>
<td>1+</td>
<td>A+</td>
<td>2+</td>
<td>B+</td>
<td>3+</td>
<td>B+</td>
<td>4+</td>
<td>8:30-11:30 (0+, 1+, 2+, 3+, 4+)</td>
</tr>
<tr>
<td>8:30-9:20 (A, B)</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>2+</td>
<td>3+</td>
<td>4+</td>
<td>9-11:30 (0, 1, 2, 3, 4)</td>
</tr>
<tr>
<td>9:30-10:20 (A, C, D)</td>
<td>D</td>
<td>0+</td>
<td>C</td>
<td>1+</td>
<td>C</td>
<td>2</td>
<td>A</td>
<td>3</td>
<td>C</td>
<td>4+</td>
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</tr>
<tr>
<td>10:30-11:20 (D, E)</td>
<td>E</td>
<td>D</td>
<td>0</td>
<td>E</td>
<td>E</td>
<td>D</td>
<td>E</td>
<td>D</td>
<td>E</td>
<td>D+</td>
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</tr>
<tr>
<td>10:30-11:45 (D+, E+)</td>
<td>D+</td>
<td>E+</td>
<td>D+</td>
<td>E+</td>
<td>D+</td>
<td>E+</td>
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<td>E+</td>
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<td>E+</td>
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</tr>
<tr>
<td>12:00-12:50 (F)</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
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<td>F</td>
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<td></td>
</tr>
<tr>
<td>12:00-1:15 (F+)</td>
<td>F+</td>
<td>F+</td>
<td>F+</td>
<td>F+</td>
<td>F+</td>
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</tr>
<tr>
<td>1:30-2:20 (G, H)</td>
<td>G</td>
<td>5+</td>
<td>H</td>
<td>G+</td>
<td>G+</td>
<td>H</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>1:30-4:00 (5, 6, 7, 8, 9)</td>
</tr>
<tr>
<td>1:30-2:45 (G+, H+)</td>
<td>G+</td>
<td>5</td>
<td>H+</td>
<td>G+</td>
<td>G+</td>
<td>H+</td>
<td>G+</td>
<td>G+</td>
<td>G+</td>
<td>G+</td>
<td>1:20-4:20 (5+, 6+, 7+, 8+, 9+)</td>
</tr>
<tr>
<td>2:30-3:20 (H on Fri)</td>
<td>H</td>
<td>3+</td>
<td>J</td>
<td>H</td>
<td>H</td>
<td>J</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>3:00-3:50 (I, J)</td>
<td>I</td>
<td>I</td>
<td>J+</td>
<td>I</td>
<td>I+</td>
<td>J</td>
<td>I</td>
<td>J+</td>
<td>I+</td>
<td>I+</td>
<td>1:30-4:00 (5, 6, 7, 8, 9)</td>
</tr>
<tr>
<td>3:00-4:15 (J+, I+)</td>
<td>J+</td>
<td>J</td>
<td>I+</td>
<td>J+</td>
<td>J+</td>
<td>I+</td>
<td>J+</td>
<td>J+</td>
<td>J+</td>
<td>J+</td>
<td>1:20-4:00 (5+, 6+, 7+, 8+, 9+)</td>
</tr>
<tr>
<td>3:30-4:20 (I on Fri)</td>
<td>I</td>
<td>5</td>
<td>J</td>
<td>I</td>
<td>I</td>
<td>J</td>
<td>I</td>
<td>J</td>
<td>I</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>4:30-5:20 (K, L)</td>
<td>J/K</td>
<td>K+</td>
<td>L</td>
<td>J/K</td>
<td>J/K</td>
<td>L+</td>
<td>J/K</td>
<td>K+</td>
<td>L+</td>
<td>L+</td>
<td></td>
</tr>
<tr>
<td>4:30-5:20 (J on Mon)</td>
<td>J/K</td>
<td>K+</td>
<td>L</td>
<td>J/K</td>
<td>J/K</td>
<td>L+</td>
<td>J/K</td>
<td>K+</td>
<td>L+</td>
<td>L+</td>
<td></td>
</tr>
<tr>
<td>4:30-5:45 (K+, L+)</td>
<td>K+</td>
<td>L+</td>
<td>K+</td>
<td>L+</td>
<td>K+</td>
<td>L+</td>
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<td>L+</td>
<td>K+</td>
<td>L+</td>
<td></td>
</tr>
<tr>
<td>6:00-6:50 (M, N)</td>
<td>M+</td>
<td>10+</td>
<td>N</td>
<td>M+</td>
<td>M+</td>
<td>N+</td>
<td>M+</td>
<td>M+</td>
<td>N+</td>
<td>N+</td>
<td>6:00-9:00 (10+, 11+, 12+, 13+)</td>
</tr>
<tr>
<td>6:00-7:15 (M+, N+)</td>
<td>M+</td>
<td>10</td>
<td>N</td>
<td>M+</td>
<td>M+</td>
<td>N+</td>
<td>M+</td>
<td>M+</td>
<td>N+</td>
<td>N+</td>
<td>6:30-9:00 (10, 11, 12, 13)</td>
</tr>
<tr>
<td>7:30-8:15 (P, Q)</td>
<td>Q/P</td>
<td>P+</td>
<td>Q+</td>
<td>Q</td>
<td>Q</td>
<td>P+</td>
<td>Q+</td>
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</tr>
<tr>
<td>7:30-8:45 (P+, Q+)</td>
<td>P+</td>
<td>P</td>
<td>Q</td>
<td>Q</td>
<td>Q</td>
<td>P</td>
<td>Q+</td>
<td>Q+</td>
<td>Q+</td>
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<td></td>
</tr>
</tbody>
</table>

**Notes**

* A plain letter (such as B) indicates a 50 minute meeting time.
* A number (such as 2) indicates a 150 minute class or seminar. A number with a + (such as 2+) indicates a 180 minute meeting time.
* Lab schedules for dedicated laboratories are determined by department/program.
* Monday from 12:00-1:20 is departmental meetings/exam block.
* Wednesday from 12:00-1:20 is the AS&E-wide meeting time.
* If all days in a block are to be used, no designation is used. Otherwise, days of the week (MTWRF) are designated (for example, E+MW).
* Roughly 55% of all courses may be offered in the shaded area.
* Labs taught in seminar block 5+–9+ may run to 4:30. Students taking these courses are advised to avoid courses offered in the K or L block.