Department of Mathematics

Chairperson:	Bertrand, Florian J.
Professor Emeritus:	Muwafi, Amin
Professors:	Abi-Khuzam, Faruk F.; Abu-Khuzam, Hazar M.; Khuri-Makdisi, Kamal F.; Nassif, Nabil R.; Raji, Wissam V.; Shayya, Bassam H.
Associate Professors:	Alhakim, Abbas M.; Bertrand, Florian J.; Della Sala, Giuseppe; El Khoury, Sabine S.; Tlas, Tamer M.
Assistant Professors:	Andrist, Rafael; Monni, Stefano; Moufawad, Sophie M.; Roy, Tristan Cyrus; Sabra, Ahmad A.; Taati, Siamak;
Lecturers:	Fayyad, Dolly J.;Mroue, Fatima K.; Yamani, Hossam A.
Instructors:	Ashkar, Alice N.; Bou Eid, Michella J.; Fleihan, Najwa S.; Itani-Hatab, Maha S.; Khachadourian, Zadour A.; Nassif, Rana G.; Rahhal, Lina A.; Tannous, Joumana A.

The Department of Mathematics offers programs leading to the degree of Master of Science (MS) in Mathematics and Statistics.

Under Mathematics, students may choose between two tracks: a track in Pure Mathematics and a track in Applied Mathematics.

MS in Mathematics

Students who are admitted to one of the two MATH tracks, Pure or Applied, must complete the university requirements for graduate study in the Faculty of Arts and Sciences with at least 24 credits at the graduate level and a thesis. These 24 credits must include the following required core courses for both tracks: MATH 303, MATH 304, MATH 309, and MATH 341.

Students following the Pure Mathematics Track are required to take at least one of MATH 306 or MATH 314 and complete the 24 credits by choosing any 3 elective courses offered in the department, totaling 9 credits, in addition to writing and defending a thesis in an area of Pure Mathematics.

Students following the Applied Mathematics Track are required to take at least one of MATH 350 or MATH/STAT 338 and complete the 24 credits by choosing any 3 elective courses offered in the department, totaling 9 credits, in addition to writing and defending a thesis in an area of Applied Mathematics.

MA or MS in Statistics

Students must complete the university requirements for graduate study in the Faculty of Arts and Sciences, at least 24 credits at the graduate level and a thesis. At least 18 of the 24 credits must be taken in the department and must include MATH 303, STAT 331, STAT 332, STAT 333 and STAT 334. Students interested in taking courses outside the department may do so after obtaining approval from the department. The graduate program in statistics is currently frozen.

Course Descriptions

Mathematics

MATH 301 Graduate Tutorial Courses 1–3 cr.
Prerequisite: Graduate standing or consent of instructor. May not be repeated for credit.

MATH 303 Measure and Integration 3.0; 3 cr.
A first course in measure theory, including general properties of measures, construction of Lebesgue measure in R^n, Lebesgue integration and convergence theorems, L^p-spaces, Hardy-Littlewood maximal function, Fubini's theorem and convolutions. *Prerequisite: MATH 223 or graduate standing. Annually.*

MATH 304 Complex Analysis 3.0; 3 cr.
A second course in complex analysis, covering the homotopy version of Cauchy's theorem, the open mapping theorem, maximum principle, Schwarz's lemma, harmonic functions, normal families, Riemann mapping theorem, Riemannian metrics, method of negative curvature, Picard's theorem, analytic continuation, monodromy and modular function. *Prerequisite: MATH 227 or graduate standing. Annually.*

MATH 305 Functional Analysis 3.0; 3 cr.
Vector spaces, Hamel basis, Hahn-Banach theorem, Banach spaces, continuous linear operators and functionals, Hilbert spaces and weak topologies. *Prerequisite: MATH 223 or graduate standing. Occasionally.*

MATH 306 Calculus on Manifolds 3.0; 3 cr.
Manifolds, differentiable structure, vector fields, flows, differential forms, Stokes' theorem, basic Lie group theory. *Prerequisite: MATH 223 or graduate standing. Biennially.*

MATH 307 Topics in Analysis 3.0; 3 cr.

MATH 309 Functional Analysis and Partial Differential Equations 3.0; 3 cr.
The course aims to introduce students to deterministic/analytic tools to study problems which appear in several areas of science. The course introduces mathematical notions and objects such as: Hilbert spaces, weak derivatives, distributions and Sobolev spaces, adjoints of linear operators on infinite dimensional spaces, bounded linear operators, fixed point arguments, convolution and Fourier transform. This course connects to partial differential equations where existence of solutions to those elliptic/parabolic/hyperbolic uses the theory introduced in the first part of the course. Applications to

these linear differential equations in diffusion processes and population dynamics will be discussed throughout the course via examples from the literature. This course is self-contained. *Annually.*

MATH 310 Analysis of Partial Differential equations 3.0; 3 cr.
In this course, the study of Partial Differential Equations will be conducted by developing a proper weak formulation of PDEs and introducing the notion of generalized or weak solutions. After a short review on properties of weak solutions and Lax-Milgram theorem, the regularity of the weak solutions for elliptic, parabolic and hyperbolic PDEs will be studied, with particular consideration given to the standard examples of the respective classes: the Laplacian, the heat, and the wave equations. In the second part of the course, some of the main tools used to study weak solutions of nonlinear PDEs will be introduced. *Prerequisites: MATH 303 and MATH 309. Occasionally.*

MATH 311 Dynamical Systems 3.0; 3 cr.
The field of Dynamical systems involves the study of the long-term behavior of evolving systems, with wide applications to natural sciences, applied and pure Mathematics such as Partial Differential Equations, Topology and Geometry, Combinatorics and Diophantine Number Theory. This course will serve as an introduction to some of the most important topics of the field, including a treatment of hyperbolic dynamical systems and of the basics of ergodic theory. The last part of the course will deal with some of the modern developments of the subject, such as its applications to PDEs and to the study of homogeneous spaces. *Prerequisite: MATH 303 or consent of the instructor. Occasionally.*

MATH 312 Harmonic Analysis 3.0; 3 cr.
This is a graduate level course in harmonic analysis. After an introduction to complex measures, the course will present the theory of the (multi-dimensional) Fourier transform on the Schwartz space as well as on L^1 and L2 spaces. Further topics treated in course will include Oscillatory integrals and an introduction to geometric measure theory. Finally, applications to some deep results in the theory of distance sets will be discussed. *Prerequisite: MATH 303 or consent of the instructor. Occasionally.*

MATH 313 Several Complex Variables 3.0; 3 cr.
This is an introduction to the theory of holomorphic functions in several variables. The course will begin with a review of Complex Analysis in one variable, and then it will in- troduce holomorphic functions in several variables, starting with the aspects in common with the one dimensional setting (such as the Cauchy formula and power series expan- sion). Next, features which are peculiar to several variables will be discussed, including Hartogs' phenomenon and the notion of pseudoconvexity. The course will end with a treat- ment of some more modern topics. *Prerequisite: MATH 304 or consent of the instructor. Occasionally.*

MATH 314 Algebraic Topology I 3.0; 3 cr.
Homotopy, fundamental group, Seifert-van Kampen theorem, covering spaces, singular homology. *Prerequisites: MATH 214 and MATH 241, or graduate standing. Biennially.*

MATH 315 Algebraic Topology II 3.0; 3 cr.
Singular cohomology, Poincare duality, higher homotopy theory, fiber bundles. *Prerequisite: MATH 314. Occasionally.*

MATH 316 **Topics in Topology** **3.0; 3 cr.**

MATH 317 **Introduction to Algebraic Geometry** **3.0; 3 cr.**
The main purpose of the course is to provide an introduction to the principal notions of Algebraic Geometry, with a treatment flexible enough to allow for expansion in several directions, both towards the algebraic and the analytic side. After a brief review of commu- tative algebra, the course will introduce (affine and projective) algebraic sets, the Zariski topology, regular and rational maps, as well as notions of smoothness and dimension. A discussion of the main classical examples of algebraic sets and maps will be included in the development of the materials. *Prerequisite: MATH 341 or consent of the instructor. Occasionally.*

MATH 318 **Differential Geometry** **3.0; 3 cr.**
This course builds on MATH 306 and with examples drawn from Riemannian geometry. Students will be introduced to the theory of fiber bundles, Riemannian metrics, connections and curvature. The last part of the course will be devoted to some more advanced subjects, such as the theory of principal bundles or the study of spaces of constant curvature. The topics covered in the course are also essential to a modern treatment of mathematical and theoretical physics. *Prerequisite: MATH 306 or consent of the instructor. Occasionally.*

MATH 330 **Probability Theory** **3.0; 3 cr.**
This first course in Probability Theory will be devoted to the main properties of random variables (such as its moments and the notion of independence), with special emphasis put on classical results of convergence of sequence of random variables (for instance in L^p, in probability, and in law). The law of large numbers and the central limit theorem will be treated as well, and the last part of the course will deal with the theory of martingales. *Prerequisite: MATH 303. Occasionally.*

MATH 338 **Introduction to Stochastic Processes** **3.0; 3 cr.**
This course gives an overview of stochastic processes. Topics will include discrete- and continuous-time Markov chains with discrete and continuous state space; basic martingale theory and Brownian motion. If time permits, integration with respect to Brownian motion will be covered to provide students with a first idea of stochastic integration. *Annually.*

MATH 340 **Groups and Geometry** **3.0; 3 cr.**
The goal of this course is to familiarize the students with the connection between the al- gebraic structure of groups and their actions on geometric objects, in the spirit of Felix Klein's Erlangen program. The course will illustrate how groups can be used to understand geometry and topology and, conversely, how one can study abstract groups by using geometric techniques and ultimately by treating groups themselves as geometric objects. *Prerequisite: graduate standing or consent of the instructor. Occasionally.*

MATH 341 **Modules and Rings** **3.0; 3 cr.**
Fundamental concepts of modules and rings, projective and injective modules, modules over a PID, Artinian and Noetherian modules and rings, semi-simplicity, and tensor products. *Prerequisite: MATH 241 or graduate standing. Annually.*

MATH 342 Modules and Rings II 3.0; 3 cr.
A course covering more advanced topics in modules and rings. *Prerequisite: MATH 341. Occasionally.*

MATH 343 Field Theory 3.0; 3 cr.
Prerequisite: MATH 242. Occasionally.

MATH 344 Commutative Algebra 3.0; 3 cr.
Prerequisites: MATH 242 and MATH 341. Occasionally.

MATH 345 Topics in Algebra 3.0; 3 cr.
Occasionally.

MATH 346 Algebraic Number Theory 3.0; 3 cr.
The subject of this course can be understood in two ways, as algebra applied to number theory, but also as the study of algebraic numbers, that is the roots of polynomials with integer coefficients. These numbers occur naturally when one attempts to solve Diophantine equations. Alongside a review of the relevant algebra (such as field theory and ideal factorization), the course will introduce and discuss algebraic integers, the class group and units. The last part of the course will revolve around more advanced topics such as for instance the Dedekind zeta function. *Prerequisite: MATH 341 or consent of the instructor. Occasionally.*

MATH 347 Elliptic Curves and Modular Forms 3.0; 3 cr.
This course focuses on two interrelated notions: first, elliptic curves and their arithmetic aspects, and second, modular curves, which are spaces classifying elliptic curves, and modular forms, which are objects living on these modular curves. The course culminates with the statement of the modularity theorem, which expresses a second relation between modular curves and modular forms. P*rerequisites: MATH 227 or 304, MATH 261, MATH 341 or MATH 220, MATH 306 or 223,* MATH 220; or consent of the instructor. *Occasionally.*

MATH 348 Monte Carlo Methods 3.0; 3 cr.
Common techniques and basic principles of Monte Carlo simulations, including an overview of random number generation, rejection methods, importance sampling and variance reduction techniques, Monte Carlo integration, Markov chain Monte Carlo (Metropolis-Hastings and Gibbs sampler and some variants, e.g., cluster algorithms and multilevel samplers, as time allows). *Annually.*

MATH 350 Discrete Models for Differential Equations 3.1; 3 cr.
A detailed study of methods and tools used in deriving discrete algebraic systems of equations for ordinary and partial differential equations: finite difference and finite element discretization procedures; generation and decomposition of sparse matrices, finite-precision arithmetic, ill-conditioning and pre-conditioning, scalar, vector, and parallelized versions of the algorithms. The course includes tutorial immersion sessions in which students become acquainted with state-of-the-art scientific software tools on standard computational platforms.*Prerequisites: Linear algebra and the equivalent of MATH/CMPS 251 (which can be taken concurrently) or consent of instructor. Same as CMPS 350. Annually.*

MATH 351 **Optimization and Nonlinear Problems** **3.1; 3 cr.**
A study of practical methods for formulating and solving numerical optimization problems that arise in science, engineering and business applications. Newton's method for nonlinear equations and unconstrained optimization. Simplex and interior-point methods for linear programming. Equality and inequality-constrained optimization. sequential quadratic programming. Emphasis is on algorithmic description and analysis. The course includes an implementation component where students develop software and use state-of-the-art numerical libraries. *Prerequisite: Graduate standing. Same as CMPS 351. Occasionally.*

MATH 352 **Computational Linear Algebra with Applications** **3.0; 3 cr.**
This course mostly focuses on problems that involve sparse matrix computations. It underlies the fundamental methods for efficiently solving (sequentially and in parallel) sparse systems of linear equations using direct methods with fill-in phenomena, together with iterative methods such as Krylov subspace methods, with several types of preconditioning. It also treats comprehensively the numerical eigenvalue problems and their applications such as computation of the PageRank Vector for Google matrices. *Prerequisite: MATH 350. Occasionally.*

MATH 353 **Computational Methods for Time-Dependent Systems** **3.0; 3 cr.**
This course covers numerical methods for time-dependent linear and nonlinear partial differential equations starting with hyperbolic conservation law models such as wave propagation in gases and fluids. Topics include the method of characteristics, difference methods, CFL conditions, weak solutions and finite volume methods for hyperbolic systems. Computation of solutions of other types of time-dependent partial differential equations will also be considered. Implementation is illustrated through computational models using MATLAB to solve problems arising in fluid dynamics and wave propagation. *Prerequisite: MATH 350. Occasionally.*

MATH 358 **Introduction to Symbolic Computing** **3.0; 3 cr.**
Introductory topics in computer algebra and algorithmic number theory that include fast multiplication of polynomials and integers, fast Fourier transforms, primality testing and integers factorization. Applications to cryptography and pseudo-random number generation. Linear algebra and polynomial factorization over finite fields. Applications to error-correcting codes. Introduction to Grōbner bases. *Prerequisite: Good background in programming, linear algebra, discrete mathematics or consent of instructor. Same as CMPS 358. Occasionally.*

MATH 360 **Special Topics in Computational Science** **3.0; 3 cr.**
A course on selected topics in computational science that changes according to the interests of visiting faculty, instructors and students. Selected topics cover state-of-the-art tools and applications in computational science. *Prerequisite: Consent of instructor. Same as CMPS 359. May be repeated for credit. Occasionally.*

MATH 395A **Comprehensive Exam** **0 cr.**
Prerequisite: Consent of advisor.

MATH 399 **Thesis** **6 cr.**

Statistics

The graduate program in statistics is currently frozen.

STAT 331 Advanced Probability Theory 3.0; 3 cr.
Characteristic functions, types of convergence, limiting properties of distribution and characteristic functions, limit theorems, and multivariate functions. *Prerequisites: MATH 227, STAT 238 and MATH 303. Annually.*

STAT 332 Advanced Mathematical Statistics 3.0; 3 cr.
Distribution theory, decision theory, and advanced topics in estimation and inference. *Prerequisites: STAT 235 and STAT 238. Annually.*

STAT 333 Multivariate Analysis 3.0; 3 cr.
Multivariate distributions, correlation coefficients, classification and discrimination, Hotelling's T2, tests of hypotheses for multivariate distributions and canonical variables. *Prerequisite: STAT 238. Annually.*

STAT 334 Advanced Topics in Statistics 3.0; 3 cr.
Annually.

STAT 335 Special Topics from Probability and Statistics 3.0; 3 cr.
May be repeated for credit. Annually.

STAT 338 Introduction to Stochastic Processes 3.0; 3 cr.
This course gives an overview of stochastic processes. Topics will include discrete- and continuous-time Markov chains with discrete and continuous state space; basic martingale theory and Brownian motion. If time permits, integration with respect to Brownian motion will be covered to provide students with a first idea of stochastic integration. *Annually*

STAT 348 Monte Carlo Methods 3.0; 3 cr.
Common techniques and basic principles of Monte Carlo simulations, including an overview of random number generation, rejection methods, importance sampling and variance reduction techniques, Monte Carlo integration, Markov chain Monte Carlo (Metropolis-Hastings and Gibbs sampler and some variants, e.g., cluster algorithms and multilevel samplers, as time allows). *Annually.*

STAT 395A Comprehensive Exam 0 cr.
Prerequisite: Consent of advisor.

STAT 399 Thesis 6 cr.