MASTER OF SCIENCE MATHEMATICS AND STATISTICS SPECIALIZATION IN BIOINFORMATICS

Summary
- Degree offered: Master of Science (MSc)
- Registration status options: Full-time; Part-time
- Language of instruction: English
- Primary program: MSc in Mathematics and Statistics
- Collaborative specialization: Bioinformatics
- Program option (expected duration of the program):
  - with thesis (6 full-time terms; 24 consecutive months)
- Academic units: Faculty of Science, Department of Mathematics and Statistics, Ottawa-Carleton Institute of Mathematics and Statistics (OCIMS).

Program Description
Ottawa-Carleton Joint Program

The University of Ottawa offers a rich academic environment to study mathematics and statistics under the supervision of professors who have gained an international reputation for their research. Most major fields of research in mathematics and statistics are represented within the Department of mathematics and Statistics. Moreover, the Department is a participating unit in the master's level collaborative programs in bioinformatics and in biostatistics. Additional information about the Department and its programs is posted on the departmental website at www.mathstat.uottawa.ca.

Since 1984, the graduate programs in mathematics and statistics have been under the umbrella of the Ottawa-Carleton Institute of Mathematics and Statistics (OCIMS). The OCIMS consists of the School of Mathematics and Statistics at Carleton University and the Department of Mathematics and Statistics at the University of Ottawa. The two units have pooled together their resources to offer each year a large selection of graduate courses.

Collaborative Program Description

Bioinformatics is an emerging and increasingly important scientific discipline dedicated to the pursuit of fundamental questions about the structure, function and evolution of biological entities through the design and application of computational approaches. Fundamental research in these areas is expected to increase our understanding of human health and disease which translates into innovation in industry. Bioinformaticians today must be able to appreciate significant research in other fields and therefore require an understanding of the basic principles of other disciplines. To meet this challenge, Carleton University and the University of Ottawa offer a collaborative program leading to a master of science degree in the primary program with specialization in bioinformatics or, in the case of computer science, a master of computer science degree with specialization in bioinformatics.

Other Programs Offered Within the Same Discipline or in a Related Area
- Master of Science Mathematics and Statistics Concentration in Mathematics (MSc)
- Master of Science Mathematics and Statistics Concentration in Statistics (MSc)
- Master of Science Mathematics and Statistics Specialization in Biostatistics (MSc)
- Doctorate in Philosophy Mathematics and Statistics (PhD)

Fees and Funding
- Program fees:
  - The estimated amount for university fees associated with this program are available under the section Finance your studies. International students enrolled in a French-language program of study may be eligible for a differential tuition fee exemption.
  - To learn about possibilities for financing your graduate studies, consult the Awards and financial support section.

Notes
- Programs are governed by the general regulations in effect for graduate studies at both universities.
- In accordance with the University of Ottawa regulation, students have the right to complete their assignments, examinations, research papers, and theses in French or in English.
- Research activities can be conducted in English or French or both depending on the language used by the professor and the members of the research group.
Program Contact Information
Graduate Studies Office, Faculty of Science (https://science.uottawa.ca/en/faculty-services/graduate-studies)
30 Marie-Curie Street, Gendron Hall, Room 181
Ottawa, Ontario, Canada
K1N 6N5

Tel.: 613-562-5800 x3145
Email: gradsci@uOttawa.ca

Twitter | Faculty of Science (https://twitter.com/uOttawaScience?lang=en)
Facebook | Faculty of Science (https://www.facebook.com/uOttawaScience)

Admission Requirements
For the most accurate and up to date information on application deadlines, language tests and other admission requirements, please visit the specific requirements (http://www.uottawa.ca/graduate-studies/programs-admission/apply/specific-requirements) webpage.

To be eligible, candidates must:
• Have a bachelor's degree with a specialization or a major in mathematics and statistics (or equivalent) with a minimum average of 75% (B+).
  Note: International candidates must check the admission equivalencies (https://www.uottawa.ca/graduate-studies/international/study-uottawa/admission-equivalencies) for the diploma they received in their country of origin.
• Demonstrate a good academic performance in previous studies as shown by official transcripts, research reports, abstracts or any other documents demonstrating research skills.
• Meet the funding requirements.
  Note: International students must provide proof of financial support: i.e., a stipend provided by a supervisor as well as a combination of awards and/or trust funds.
• Pay the $100 (CDN non-refundable) application fee.
• Identify at least one professor who is willing to supervise your research and thesis.
• We recommend that you contact potential thesis supervisors as soon as possible.
• To register, you need to have been accepted by a thesis supervisor.
• The supervisor's name is required at the time of application.
• The choice of supervisor will determine the primary campus location of the student. It will also determine which university awards the degree.
• Be sponsored into the collaborative specialization by a faculty member of the collaborative program, normally the thesis supervisor, who must be appointed, cross-appointed or stand as an adjunct at the primary program.

Language Requirements
Applicants must be able to understand, write and fluently speak the language of instruction (French or English) in the program to which they are applying. Proof of linguistic proficiency may be required.

Applicants whose first language is neither French nor English must provide proof of proficiency in the language of instruction.

Language tests recognized by the University of Ottawa:
• TOEFL: 550 (paper-based) – 79-80 (internet-based); or
• IELTS: 6.5 Overall – 5.0 Individual (paper-based or internet-based); or
• An equivalent language test (http://www.uottawa.ca/graduate-studies/programs-admission/apply/required-documents).

Note: Candidates are responsible for any fees associated with the language tests.

Notes
• The admission requirements listed above are minimum requirements and do not guarantee admission to the program.
• Admissions are governed by the general regulations (http://www.uottawa.ca/graduate-studies/students/general-regulations) in effect for graduate studies and by the general regulations of the Ottawa-Carleton Institute of Mathematics and Statistics (OCIMS).
• Students must indicate in their initial application for admission to the master's program in mathematics and statistics that they wish to be accepted into the collaborative program in bioinformatics. Students must be admitted in one of the primary programs participating in the collaborative program.

Documents Required for Admission
In addition to the documents required (http://www.uottawa.ca/graduate-studies/programs-admission/apply/required-documents) for graduate and postdoctoral studies, candidates must submit the following documents:

• A resume
• A letter of intent or motivation or statement of purpose
  Letter outlining your professional goals and proposed research area.
• Two confidential letters of recommendation from professors who have known the applicant and are familiar with their work.
You are strongly encouraged to contact your referee(s) prior to submitting your application in order to confirm their email address and their availability to complete your letter of recommendation.

- Transcripts from all universities attended:
  - You must submit official transcripts from all the universities you have attended.
  - This applies to all courses and programs at any university you attended, including regular programs (completed or not), exchanges, letters of permission, online or correspondence courses, courses taken as a special student or visiting student, etc.
  - If the transcript and degree certificate are not in English or French, a certified translation (signed and stamped/sealed) must be submitted.

Note: Documents that are not required for admission will not be consulted, conserved or returned to the student. These documents will be destroyed according to our administrative procedures.

**Information about how to apply to this program is available under the Apply Now** (http://www.uottawa.ca/graduate-studies/programs-admission/apply/#apply-now) section.

Students should complete and submit their online application with supporting documentation (if applicable) by the deadline indicated above. The supporting documentation should be sent by e-mail attachment, regular mail, or in person.

### Program Requirements

#### Master’s with Collaborative Specialization

At least 50% of the units must be from the student’s home university.

The Department may require students to take additional courses, depending on their backgrounds.

Students must meet the following requirements for the master’s with collaborative specialization:

**Compulsory Courses (MAT):**

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<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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<tbody>
<tr>
<td>MAT 5105</td>
<td>Discrete Applied Mathematics I: Gra. Theory</td>
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<tr>
<td>MAT 5107</td>
<td>Discrete Applied Mathematics II: Combinatorial Enumeration</td>
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<tr>
<td>MAT 5121</td>
<td>Introduction to Hilbert Space</td>
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<td>MAT 5125</td>
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<td>MAT 5126</td>
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<td>MAT 5127</td>
<td>Complex Analysis</td>
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<td>MAT 5131</td>
<td>Ordinary Differential Equations I</td>
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<td>MAT 5134</td>
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<td>Groups Representations and Applications</td>
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<td>MAT 5151</td>
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<tr>
<td>BNF 5106</td>
<td>Bioinformatics</td>
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<tr>
<td>BNF 6100</td>
<td>MSc Seminar</td>
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**Thesis:**

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<tbody>
<tr>
<td>MAT 7999</td>
<td>Masters Thesis</td>
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**Note(s):**

1. See below for the list of courses in mathematics.
2. The seminar course in bioinformatics involves a written report, the presentation of a seminar, and regular attendance at departmental seminars.
3. Presentation and defence of a research thesis on a topic in bioinformatics based on original research carried out under the supervision of a faculty member participating in the bioinformatics collaborative program.
4. Students are responsible for ensuring they have met all of the thesis requirements (http://www.uottawa.ca/graduate-studies/students/theses).

### List of Courses by Field

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<tr>
<td>MAT 5325</td>
<td>Topics in Information and Systems Science</td>
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<tr>
<td>MAT 5326</td>
<td>Topics in Analysis</td>
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<td>MAT 5330</td>
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<td>MAT 5331</td>
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<tr>
<td>MAT 5341</td>
<td>Quantum Computing</td>
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<tr>
<td>MAT 5343</td>
<td>Mathematical Aspects of Wavelets and Digital Signal Processing</td>
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<tr>
<td>MAT 5361</td>
<td>Topics in Mathematical Logic</td>
<td>3</td>
</tr>
<tr>
<td>MAT 5180</td>
<td>Numerical Analysis for Differential Equations</td>
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### Mathematics and Statistics Courses

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<tr>
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<td>MAT 5311</td>
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<td>MAT 5312</td>
<td>Topics in Stochastic Processes</td>
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<td>MAT 5313</td>
<td>Stochastic Analysis</td>
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<tr>
<td>MAT 5314</td>
<td>Network Performance</td>
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</tr>
<tr>
<td>MAT 5315</td>
<td>Mathematical Statistics</td>
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<td>MAT 5316</td>
<td>Advanced Statistical Inference</td>
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<tr>
<td>MAT 5317</td>
<td>Multivariate Normal Theory</td>
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<tr>
<td>MAT 5318</td>
<td>Seminar in Biostatistics</td>
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### Fast-Track from Master’s to PhD

Students enrolled in the master’s program in mathematics and statistics at the University of Ottawa may be eligible to fast-track directly into the doctoral program without writing a master’s thesis. For additional information, please consult the “Admission Requirements” section of the PhD program.

### Minimum Requirements

The passing grade in all courses is B.

Students who fail two courses (equivalent to 6 units), or whose progress is deemed unsatisfactory are required to withdraw.

### Research

#### Research Fields & Facilities

Located in the heart of Canada’s capital, a few steps away from Parliament Hill, the University of Ottawa is among Canada’s top 10 research universities.

uOttawa focuses research strengths and efforts in four Strategic Areas of Development in Research (SADRs):

- Canada and the World
- Health
- e-Society
- Molecular and Environmental Sciences

With cutting-edge research, our graduate students, researchers and educators strongly influence national and international priorities.

#### Research at the Faculty of Science

The Faculty of Science has become a true centre of excellence in research through its world-class professors as well as its programs and infrastructure in Biology, Chemistry, Earth Sciences, Mathematics and Statistics, and Physics.

The research accomplished by its 140 internationally recognized professors, its approximately 400 graduate students and its dozens of postdoctoral researchers and visiting scientists has positioned the Faculty of Science as one of the most research intensive science faculties in Canada. Our professors have received many international and national awards including three NSERC Gerhard Herzberg Gold Medal winners and numerous Fellows of the Royal Society of Canada.

The Faculty of Science, through its strategic use of infrastructure programs, hosts world-class Core Facilities and is at the leading edge for the study of Catalysis, Experimental and Computational Chemistry, Environmental Toxins, Nuclear Magnetic Resonance, Isotope Analysis, Molecular Biology and Genomics, X-Ray Spectrometry/Diffractometry, Geochemistry, Mass Spectrometry, Physiology and Genetics of Aquatic Organisms, and Photonics. The Faculty is also associated with the Fields Institute for research in mathematical science and the Centre de recherche mathématiques (CRM) at the Université de Montréal, providing a unique setting for mathematical research.

For more information, refer to the list of faculty members and their research fields on [Uniweb](https://www.uniweb.ca).
IMPORTANT: Candidates and students looking for professors to supervise their thesis or research project can also consult the website of the faculty or department (https://www.uottawa.ca/graduate-studies/students/academic-unit-contact-information) of their program of choice. Uniweb does not list all professors authorized to supervise research projects at the University of Ottawa.

Courses

Not all of the listed courses are given each year. The course is offered in the language in which it is described.

Course codes in parentheses are for Carleton University. A 3-unit course at the University of Ottawa is equivalent to a 0.5-unit course at Carleton University.

MAT 5105 Discrete Applied Mathematics I: Gra. Theory (3 units)
Paths and cycles, trees, connectivity, Euler tours and Hamilton cycles, edge colouring, independent sets and cliques, vertex colouring, planar graphs, directed graphs. Selected topics from one or more of the following areas: algebraic graph theory, topological theory, random graphs. This course is equivalent to MATH 5818 at Carleton University.
Course Component: Lecture

MAT 5106 Combinatorial Optimization (3 units)
Network flow theory and related material. Topics will include shortest paths, minimum spanning trees, maximum flows, minimum cost flows. Optimal matching in bipartite graphs. This course is equivalent to MATH 5808 at Carleton University.
Course Component: Lecture

MAT 5107 Discrete Applied Mathematics II: Combinatorial Enumeration (3 units)
Ordinary and exponential generating functions; product formulas; permutations; partitions; rooted trees; cycle index; WZ method. Lagrange Inversions; singularity analysis of generating functions and asymptotics. Selected topics from one or more of the following areas: random graphs, random combinatorial structures, hypergeometric functions. This course is equivalent to MATH 5819 at Carleton University.
Course Component: Lecture

MAT 5121 Introduction to Hilbert Space (3 units)
This course is equivalent to MATH 5009 at Carleton University.
Course Component: Lecture

MAT 5122 Banach Algebras (3 units)
This course is equivalent to MATH 5003 at Carleton University.
Course Component: Lecture

MAT 5125 Real Analysis I (3 units)
General measure and integral, Lebesgue measure and integration on R, Fubini's theorem, Lebesgue-Radon-Nikodym theorem, absolute continuity and differentiation, Lp-Spaces. Selected topics such as Daniell-Stone theory. This course is equivalent to MATH 5007 at Carleton University.
Course Component: Lecture
Prerequisite: MAT 5125 (MATH 5007).

MAT 5126 Real Analysis II (3 units)
Banach and Hilbert spaces, bounded linear operators, dual spaces. Topics selected from: weak- and weak-topologies, Alaoglu’s theorem, compact operators, differential calculus in Banach spaces, Riesz representation theorems. This course is equivalent to MATH 5008 at Carleton University.
Course Component: Lecture
Prerequisite: MAT 5125 (MATH 5007).

MAT 5127 Complex Analysis (3 units)
This course is equivalent to MATH 5005 at Carleton University.
Course Component: Lecture

MAT 5131 Ordinary Differential Equations I (3 units)
This course is equivalent to MATH 5405 at Carleton University.
Course Component: Lecture

MAT 5133 Partial Differential Equations I (3 units)
First-order equations, characteristics method, classification of second-order equations, separation of variables, Green’s functions. Lp and Sobolev spaces, distributions, variational formulation and weak solutions, Lax-Milgram theorem, Galerkin approximation. Parabolic PDes. Wave equations, hyperbolic systems, nonlinear PDes, reaction diffusion equations, infinite-dimensional dynamical systems, regularity. This course is equivalent to MATH 5406 at Carleton University.
Course Component: Lecture

MAT 5134 Topics in Differential Equations (3 units)
This course is equivalent to MATH 5407 at Carleton University.
Course Component: Lecture

MAT 5141 Algebra I (3 units)
Groups, Sylow subgroups, finitely generated abelian groups. Rings, field of fractions, principal ideal domains, modules. Polynomial algebra, Euclidean algorithm, unique factorization. This course is equivalent to MATH 5107 at Carleton University.
Course Component: Lecture

MAT 5142 Algebra II (3 units)
Field theory, algebraic and transcendental extensions, finite fields, Galois groups. Modules over principal ideal domains, decomposition of a linear transformation, Jordan normal form. This course is equivalent to MATH 5109 at Carleton University.
Course Component: Lecture
Prerequisite: MAT 5141 (MATH 5107).

MAT 5143 Lie Algebras (3 units)
This course is equivalent to MATH 5104 at Carleton University.
Course Component: Lecture

MAT 5144 Commutative Algebra (3 units)
Prime spectrum of a commutative ring (as a topological space); localization of rings and modules; tensor product of modules and algebras; Hilbert’s Nullstellensatz and consequences for finitely generated algebras; Krull dimension of a ring; integral dependence, going-up, going-down; Noether Normalization Lemma and dimension theory for finitely generated algebras over a field; noetherian rings and Hilbert Basis Theorem; introduction to affine algebraic varieties and their morphisms. This course is equivalent to MATH 5001 at Carleton University.
Course Component: Lecture

MAT 5145 Group Theory (3 units)
This course is equivalent to MATH 5106 at Carleton University.
Course Component: Lecture

MAT 5146 Rings and Modules (3 units)
This course is equivalent to MATH 5103 at Carleton University.
Course Component: Lecture

MAT 5147 Homological Algebra and Category Theory (3 units)
This course is equivalent to MATH 5108 at Carleton University.
Course Component: Lecture

MAT 5148 Groups Representations and Applications (3 units)
This course is equivalent to MATH 5102 at Carleton University.
Course Component: Lecture
MAT 5149 Algebraic Geometry (3 units)
Brief overview of commutative algebra, Hilbert’s Nullstellensatz, algebraic sets, and Zariski topology. Affine and projective varieties over algebraically closed fields. Regular functions and rational maps. Additional topics chosen from: the relation of varieties over complex numbers to complex analytic manifolds, genus, divisors, line bundles, Riemann-Roch Theorem, Bézout’s Theorem. This course is equivalent to MATH 5002 at Carleton University.

Course Component: Lecture

MAT 5150 Topics in Geometry (3 units)
This course is equivalent to MATH 5201 at Carleton University.

Course Component: Lecture

MAT 5151 Topology I (3 units)
Topological spaces, product and identification topologies, countability and separation axioms, compactness, connectedness, homotopy, fundamental group, net and filter convergence. This course is equivalent to MATH 5205 at Carleton University.

Course Component: Lecture

Prerequisites: MAT 3143 and MAT 5151 (MATH 3100 and MATH 5205).

MAT 5152 Topology II (3 units)
Covering spaces, homology via the Eilenberg-Steenrod axioms, applications, construction of a homology functor. This course is equivalent to MATH 5206 at Carleton University.

Course Component: Lecture

MAT 5155 Differentiable Manifolds (3 units)
This course is equivalent to MATH 5208 at Carleton University.

Course Component: Lecture

MAT 5158 Lie Groups (3 units)
This course is equivalent to MATH 6104 at Carleton University.

Course Component: Lecture

MAT 5160 Mathematical Cryptography (3 units)
Analysis of cryptographic methods used in authentication and data protection, with particular attention to the underlying mathematics, e.g. Algebraic Geometry, Number Theory, and Finite Fields. Advanced topics on Public-Key Cryptography: RSA and integer factorization, Diffie-Hellman, discrete logarithms, elliptic curves. Topics in current research. This course is equivalent to MATH 5300 at Carleton University.

Course Component: Lecture

Prerequisite: undergraduate honours algebra, including group theory and finite fields.

MAT 5161 Mathematical Logic (3 units)
A basic graduate course in mathematical logic. Propositional and Predicate logic, Proof theory, Gentzen’s Cut-Elimination, Completeness, Compactness, Henkin models, model theory, arithmetic and undecidability. Special Topics (time permitting) depending on interests of instructor and audience. This course is equivalent to MATH 5301 at Carleton University.

Course Component: Lecture

Prerequisite: Honours undergraduate algebra, analysis and topology (or permission of the instructor).

MAT 5162 Mathematical Foundations of Computer Science (3 units)
Foundations of functional languages, lambda calculi (typed, polymorphically typed, untyped), Curry-Howard Isomorphism, proofs-as-programs, normalization and rewriting theory, operational semantics, type assignment, introduction to denotational semantics of programs, fixed-point programming. Topics chosen from: denotational semantics for lambda calculi, models of programming languages, complexity theory and logic of computation, models of concurrent and distributed systems, etc. This course is equivalent to MATH 6807 at Carleton University.

Course Component: Lecture

Prerequisite: Honours undergraduate algebra and either topology or analysis. Some acquaintance with Logic useful.

MAT 5163 Analytic Number Theory (3 units)
This course is equivalent to MATH 5305 at Carleton University.

Course Component: Lecture

MAT 5164 Algebraic Number Theory (3 units)
This course is equivalent to MATH 5306 at Carleton University.

Course Component: Lecture

MAT 5165 Theory of Automata (3 units)
This course is equivalent to MATH 5605 at Carleton University.

Course Component: Lecture

MAT 5166 Formal Language and Syntax Analysis (3 units)
This course is equivalent to MATH/COMP 5807 at Carleton University.

Course Component: Lecture

MAT 5167 Functional Analysis (3 units)
This course is equivalent to MATH 5207 at Carleton University.

Course Component: Lecture

MAT 5168 Homology Theory (3 units)
This course is equivalent to MATH 5202 at Carleton University.

Course Component: Lecture

MAT 5169 Foundations of Geometry (3 units)
This course is equivalent to MATH 5207 at Carleton University.

Course Component: Lecture

MAT 5170 Probability Theory I (3 units)
Probability spaces, random variables, expected values as integrals, joint distributions, independence and product measures, cumulative distribution functions and extensions of probability measures, Borel-Cantelli lemmas, convergence concepts, independent identically distributed sequences of random variables. This course is equivalent to STAT 5708 at Carleton University.

Course Component: Lecture

Prerequisites: MAT 3125 and MAT 3172 (MATH 3001, MATH 3002 and MATH 3500).

MAT 5171 Probability Theory II (3 units)
Laws of large numbers, characteristic functions, central limit theorem, conditional probabilities and expectation, basic properties and convergence theorems for martingales, introduction to Brownian motion. This course is equivalent to MATH 5709 at Carleton University.

Course Component: Lecture

Prerequisite: MAT 5170 (STAT 5708).

MAT 5172 Topics in Stochastic Processes (3 units)
This course is equivalent to STAT 5508 at Carleton University.

Course Component: Lecture

MAT 5173 Stochastic Analysis (3 units)
Brownian motion, continuous martingales and stochastic integration. This course is equivalent to STAT 5604 at Carleton University.

Course Component: Lecture
MAT 5174 Network Performance (3 units)
The course will focus on advanced techniques in performance evaluation of large complex networks. Topics may include classical queueing theory and simulation analysis; models of packet networks; loss and delay systems; blocking probabilities. This course is equivalent to STAT 5704 at Carleton University.

Course Component: Lecture
Prerequisite: Some familiarity with probability and stochastic processes and queueing, or permission of the instructor.

MAT 5175 Robust Statistical Inference (3 units)
This course is equivalent to STAT 5506 at Carleton University.

Course Component: Lecture

MAT 5176 Advanced Statistical Inference (3 units)
Pure significance tests; uniformly most powerful unbiased and invariant tests; asymptotic comparison of tests; confidence intervals; large sample theory of likelihood ratio and chi-square tests; likelihood inference; Bayesian inference. Topics such as empirical Bayes inference, fiducial and structural inference, resampling methods. This course is equivalent to STAT 5507 at Carleton University.

Course Component: Lecture

MAT 5177 Multivariate Normal Theory (3 units)
This course is equivalent to STAT 5500 at Carleton University.

Course Component: Lecture

MAT 5178 Topics in Applied Mathematics (3 units)
This course is equivalent to MATH 5403 at Carleton University.

Course Component: Lecture

MAT 5190 Mathematical Statistics I (3 units)
Statistical decision theory; likelihood functions; sufficiency; factorization theorem; exponential families; UMVU estimators; Fisher's information; Cramer-Rao lower bound; maximum likelihood and moment estimation; invariant and robust point estimation; asymptotic properties; Bayesian point estimation. This course is equivalent to STAT 5600 at Carleton University.

Course Component: Lecture
Prerequisites: MAT 3172 and MAT 3375.

MAT 5191 Mathematical Statistics II (3 units)
Confidence intervals and pivots; Bayesian intervals; optimal tests and Neyman-Pearson theory; likelihood ratio and score tests; significance tests; goodness-of-fit tests; large sample theory and applications to maximum likelihood and robust estimation. This course is equivalent to STAT 5501 at Carleton University.

Course Component: Lecture
Prerequisite: MAT 5190.

MAT 5192 Sampling Theory and Methods (3 units)
Unequal probability sampling with and without replacement; unified theory of standard errors; prediction approach; ratio and regression estimation; stratification and optimal designs; multistage cluster sampling; double sampling; domains of study; post-stratification; non-response; measurement errors. Related topics. This course is equivalent to STAT 5502 at Carleton University.

Course Component: Lecture

MAT 5193 Linear Models (3 units)
Theory of non-full-rank linear models: estimable functions, best linear unbiased estimators, hypothesis testing, confidence regions; multiway classification; analysis of covariance; variance component models: maximum likelihood estimation, MINQUE, ANOVA methods. Miscellaneous topics. This course is equivalent to STAT 5503 at Carleton University.

Course Component: Lecture
Prerequisite: MAT 4175 (MATH 4500) or MAT 5190 (STAT 5600).

MAT 5194 Stochastic Processes and Times Series Analysis (3 units)
This course is equivalent to STAT 5504 at Carleton University.

Course Component: Lecture

MAT 5195 Design of Experiments (3 units)
Overview of linear model theory; orthogonality; randomized block and split plot designs; Latin square designs; randomization theory; incomplete block designs; factorial experiments; confounding and fractional replication; response surface methodology. Miscellaneous topics. This course is equivalent to STAT 5505 at Carleton University.

Course Component: Lecture
Prerequisites: MAT 3375 and MAT 3376 or MAT 5190 (STAT 3505 and STAT 4500 or STAT 5600).

MAT 5196 Multivariate Analysis (3 units)
This course is equivalent to STAT 5509 at Carleton University.

Course Component: Lecture

MAT 5197 Stochastic Optimization (3 units)
Topics chosen from stochastic dynamic programming, Markov decision processes, search theory, optimal stopping. This course is equivalent to STAT 5601 at Carleton University.

Course Component: Lecture
Prerequisite: STAT 3506 or MAT 4371.
MAT 5198 Stochastic Models (3 units)
Markov systems, stochastic networks, queuing networks, spatial
processes, approximation methods in stochastic processes and
queueing theory. Applications to the modeling and analysis of computer-
communications systems and other distributed networks. This course is
equivalent to MATH 5701 at Carleton University.
Course Component: Lecture

MAT 5301 Topics in Combinatorial Mathematics (3 units)
This course is equivalent to MATH 5609 at Carleton University.
Course Component: Lecture

MAT 5303 Linear Optimization (3 units)
This course is equivalent to MATH 5801 at Carleton University.
Course Component: Lecture

MAT 5304 Nonlinear Optimization (3 units)
This course is equivalent to MATH 5803 at Carleton University.
Course Component: Lecture

MAT 5307 Topics in Operations Research (3 units)
This course is equivalent to MATH 5804 at Carleton University.
Course Component: Lecture

MAT 5308 Topics in Algorithm Design (3 units)
This course is equivalent to MATH 5805 at Carleton University.
Course Component: Lecture

MAT 5309 Harmonic Analysis on Groups (3 units)
This course is equivalent to MATH 6002 at Carleton University.
Course Component: Lecture

MAT 5312 Topics in Topology (3 units)
This course is equivalent to MATH 6003 at Carleton University.
Course Component: Lecture

MAT 5314 Topics in Probability and Statistics (3 units)
This course is equivalent to MATH 6007 at Carleton University.
Course Component: Lecture

MAT 5315 Advanced Design of Surveys (3 units)
Course Component: Lecture

MAT 5317 Analysis of Categorical Data (3 units)
Analysis of one-way and two-way tables of nominal date; multi-
dimensional contingency tables, log-linear models; tests of symmetry, marginal homogeneity in square tables; incomplete tables; tables with ordered categories; fixed margins, logistic models with binary response; measures of association and agreement; biological applications. This course is equivalent to STAT 5602 at Carleton University.
Course Component: Lecture

MAT 5318 Reliability and Survival Analysis (3 units)
This course is equivalent to STAT 5603 at Carleton University.
Course Component: Lecture

MAT 5319 Topics in Probability and Statistics (3 units)
This course is equivalent to MATH 6507 at Carleton University.
Course Component: Lecture

MAT 5324 Games Theory (3 units)
This course is equivalent to MATH 5607 at Carleton University.
Course Component: Lecture

MAT 5325 Topics in Information and Systems Science (3 units)
This course is equivalent to MATH 5802 at Carleton University.
Course Component: Lecture

MAT 5326 Topics in Analysis (3 units)
This course is equivalent to MATH 6008 at Carleton University.
Course Component: Lecture

MAT 5327 Topics in Algebra (3 units)
This course is equivalent to MATH 6101 at Carleton University.
Course Component: Lecture

MAT 5328 Topics in Analysis (3 units)
This course is equivalent to MATH 6008 at Carleton University.
Course Component: Lecture

MAT 5329 Topics in Analysis (3 units)
This course is equivalent to MATH 6009 at Carleton University.
Course Component: Lecture

MAT 5330 Topics in Algebra (3 units)
This course is equivalent to MATH 6102 at Carleton University.
Course Component: Lecture

MAT 5331 Topics in Algebra (3 units)
This course is equivalent to MATH 6103 at Carleton University.
Course Component: Lecture

MAT 5341 Quantum Computing (3 units)
Space of quantum bits, entanglement. Observables in quantum mechanics. Density matrix and Schmidt decomposition. Quantum cryptography. Classical and quantum logic gates. Quantum Fourier transform. Shor’s quantum algorithm for factorization of integers. This course is equivalent to MATH 5821 at Carleton University.
Course Component: Lecture

MAT 5343 Mathematical Aspects of Wavelets and Digital Signal Processing (3 units)
Lossless compression methods. Discrete Fourier transform and Fourier-based compression methods. JPEG and MPEG. Wavelet analysis. Digital filters and discrete wavelet transform. Daubechies wavelets. Wavelet compression. This course is equivalent to MATH 5822 at Carleton University.
Course Component: Lecture
Prerequisites: Linear algebra and Fourier series

MAT 5361 Topics in Mathematical Logic (3 units)
This course is equivalent to MATH 6806 at Carleton University.
Course Component: Lecture

MAT 5375 Mathematical Statistics (3 units)
Limit theorems; sampling distributions; parametric estimation; concepts of sufficiency and efficiency; Neyman-Pearson paradigm, likelihood ratio tests; parametric and non-parametric methods for two-sample comparisons; notions of experimental design, categorical data analysis, the general linear model, decision theory and Bayesian inference. This course is equivalent to STAT 5610 at Carleton University.
Course Component: Lecture

MAT 5505 Mathématiques discrètes appliquées I: Théorie des graphes (3 crédits)
Chemins et cycles, arbres, connexité, parcours eulériens et cycles hamiltoniens, coloration des arêtes, ensembles indépendants et cliques, coloration des sommets, graphes planaires, graphes orientés. Sujets choisis parmi les thèmes suivants : théorie algébrique des graphes, théorie topologique des graphes, graphes aléatoires. Ce cours est équivalent à MATH 5818 à la Carleton University.
Volet : Cours magistral
MAT 5506 Optimisation combinatoire (3 crédits)
Theorie des flots et thèmes voisins. On traitera parmi d'autres les sujets suivants : chemins minimaux, arbores générateurs de coût minimal, flots de coût maximal, flots de coût minimal. Couplage optimal dans les graphes bipartis. Ce cours est équivalent à MATH 5808 à la Carleton University.
Volet : Cours magistral

MAT 5507 Mathématiques discrètes appliquées II : Énumération combinatoire (3 crédits)
Fonctions génératrices ordinaires et exponentielles; formules de produit; permutations; partitions; arborescences; indice de cycle; méthode WZ. Inversion de Lagrange; analyse des singularités des fonctions génératrices et leur comportement asymptotique. Sujets choisis parmi les thèmes suivants : graphes aléatoires, structures combinatoires aléatoires, fonctions hypergéométriques. Ce cours est équivalent à MATH 5819 à la Carleton University.
Volet : Cours magistral

MAT 5521 Introduction aux espaces hilbertiens (3 crédits)
Ce cours est équivalent à MATH 5009 à la Carleton University.
Volet : Cours magistral

MAT 5522 Algèbres de banach (3 crédits)
Ce cours est équivalent à MATH 5003 à la Carleton University.
Volet : Cours magistral

MAT 5525 Analyse réelle I (3 crédits)
Mesure et intégration, mesure de Lebesgue et intégration sur R, théorème de Fubini, théorème de Lebesgue-Radon-Nikodym, continuité absolue et dérivation, espaces Lp. Chapitres choisis comme par exemple la théorie de Stone-Daniell. Ce cours est équivalent à MATH 5007 à la Carleton University.
Volet : Cours magistral
Préalables : MAT 3525 (MATH 3001 and MATH 3002).

MAT 5526 Analyse réelle II (3 crédits)
Espaces de Banach et de Hilbert, opérateurs linéaires bornés, espaces duals. Chapitres choisis parmi les suivants : topologies faibles, théorème d'Aaoglu, opérateurs compacts, calcul différentiel dans les espaces de Banach, théorèmes de représentation de Riesz. Ce cours est équivalent à MATH 5008 à la Carleton University.
Volet : Cours magistral
Prerequisite for MAT 5526

MAT 5527 Analyse complexe (3 crédits)
Ce cours est équivalent à MATH 5005 à la Carleton University.
Volet : Cours magistral

MAT 5531 Équations différentielles ordinaires I (3 crédits)
Ce cours est équivalent à MATH 5405 à la Carleton University.
Volet : Cours magistral

MAT 5533 Équations aux dérivées partielles I (3 crédits)
Ce cours est équivalent à MATH 5406 à la Carleton University.
Volet : Cours magistral
Prerequisite: An intermediate level course on Ordinary Differential Equations such as MAT 3130 Dynamical Systems or equivalent, or the permission of the School or Department.

MAT 5534 Équations différentielles : Chapitres choisis (3 crédits)
Ce cours est équivalent à MATH 5407 à la Carleton University.
Volet : Cours magistral

MAT 5541 Algèbre I (3 crédits)
Groupes, sous-groupes de Sylow, groupes abéliens de type fini. Anneaux, corps des fractions, anneaux principaux, modules. Algèbre de polynômes, algorithme d'Eulide, unicité de la décomposition. Ce cours est équivalent à MATH 5107 à la Carleton University.
Volet : Cours magistral
Prerequisites: MAT 3141 and MAT 3143.

MAT 5542 Algèbre II (3 crédits)
Théorie des corps, extensions algébriques et transcendantes, corps finis, groupes de Galois. Modules sur un anneau principal, décomposition d'une application linéaire, forme normale de Jordan. Ce cours est équivalent à MATH 5109 à la Carleton University.
Volet : Cours magistral
Prerequisite: MAT 5141 (MATH 5107).

MAT 5543 Algèbre de lie (3 crédits)
Ce cours est équivalent à MATH 5104 à la Carleton University.
Volet : Cours magistral

MAT 5544 Algèbre commutative (3 crédits)
Spectre premier d'un anneau commutatif (comme espace topologique); localisation des anneaux et des modules; produit tensoriel des modules et algèbres; théorème des zéros de Hilbert et conséquences pour les algèbres de type fini sur un corps; dimension de Krull d'un anneau; dépendance intégrale, théorèmes de « going-up » et « going-down »; lemme de normalisation de Noether et théorème de la dimension dans les algèbres de type fini sur un corps; anneaux noethériens et théorème « de la base » de Hilbert; introduction aux variétés algébriques affines et à leurs morphismes.
Volet : Cours magistral

MAT 5545 Théorie des groupes (3 crédits)
Ce cours est équivalent à MATH 5106 à la Carleton University.
Volet : Cours magistral

MAT 5546 Anneaux et modules (3 crédits)
Ce cours est équivalent à MATH 5103 à la Carleton University.
Volet : Cours magistral

MAT 5547 Algèbre homologique et théorie des catégories (3 crédits)
Ce cours est équivalent à MATH 5108 à la Carleton University.
Volet : Cours magistral

MAT 5548 Représentation de groupes et applications (3 crédits)
Volet : Cours magistral

MAT 5549 Géométrie algébrique (3 crédits)
Quelques notions d'algèbre commutative, théorème des zéros de Hilbert, ensembles algébriques, topologie de Zariski. Variétés affines et projectives sur un corps algébriquement clos. Fonctions régulières et applications rationnelles. Sujets choisis parmi : la relation entre les variétés algébriques complexes et les variétés analytiques complexes; genres; diviseurs; fibrés en droites; Théorèmes de Riemann-Roch et de Bézout.
Volet : Cours magistral
Prerequisite: MAT 3143

MAT 5551 Topologie I (3 crédits)
Spates topologiques; topologie produit et topologie quotient; axiomes de dénombrabilité et axiomes de séparation; espaces compacts, connexes; homotopie, groupe fondamental; convergence des filtres et des suites généralisées. Ce cours est équivalent à MATH 5205 à la Carleton University.
Volet : Cours magistral
Prerequisite: MAT 3153 (MATH 3001).
MAT 5552 Topologie II (3 crédits)  
Revêtements, homologie (axiomes d’Eilenberg-Steenrod), applications, construction d’une théorie de l’homologie. Ce cours est équivalent à MATH 5206 à la Carleton University.  
**Volet : Cours magistral**  
Préalables: MAT 3143 and MAT 5151 (MATH 3100 and MATH 5205).

MAT 5555 Variétés différentielles (3 crédits)  
Ce cours est équivalent à MATH 5208 à la Carleton University.  
**Volet : Cours magistral**

MAT 5558 Groupes de Lie I (3 crédits)  
Ce cours est équivalent à MATH 6104 à la Carleton University.  
**Volet : Cours magistral**

MAT 5565 Théorie des automates I (3 crédits)  
Ce cours est équivalent à MATH 5605 à la Carleton University.  
**Volet : Cours magistral**

MAT 5567 Langages formels et analyse syntaxique (3 crédits)  
Ce cours est équivalent à MATH/COMP 5807 à la Carleton University.  
**Volet : Cours magistral**

MAT 5568 Homologie (3 crédits)  
Ce cours est équivalent à MATH 5202 à la Carleton University.  
**Volet : Cours magistral**

MAT 5570 Théorie des probabilités I (3 crédits)  
Espaces probabilisés, variables aléatoires, l’espérance mathématique définie comme une intégrale, lois conjointes, indépendance et mesure produit, répartitions et extensions de mesures de probabilité, lemmes de Borel-Cantelli, notions de convergence, suites de variables aléatoires indépendantes et équidistribuées. Ce cours est équivalent à STAT 5708 à la Carleton University.  
**Volet : Cours magistral**  
Préalables: MAT 3125 and MAT 3172 (MATH 3001, MATH 3002 and MATH 3500).

MAT 5571 Théorie des probabilités II (3 crédits)  
Lois des grands nombres, fonctions caractéristiques, théorème-limite central, probabilité et espérance conditionnelles, propriétés élémentaires et théorèmes de convergence des martingales, introduction au mouvement brownien. Ce cours est équivalent à MATH 5709 à la Carleton University.  
**Volet : Cours magistral**  
Préalable: MAT 5170 (STAT 5708).

MAT 5572 Processus stochastique : Chapitres choisis (3 crédits)  
Ce cours est équivalent à STAT 5508 à la Carleton University.  
**Volet : Cours magistral**

MAT 5576 Inférence statistique (3 crédits)  
Tests de signification pure; tests uniformément les plus puissants sans biais et sans variance; comparaison asymptotique des tests; intervalles de confiance; théorie des grands échantillons et tests du carré chi; inférence de la vraisemblance; inférence de Bayes; inférence empirique de Bayes; induction fiduciaire et structurale; méthodes de répétition de l’échantillonnage. Ce cours est équivalent à STAT 5507 à la Carleton University.  
**Volet : Cours magistral**  
Préalables : MAT 4170 ou l’équivalent, et MAT 5191.

MAT 5577 Analyse multivariée normale (3 crédits)  
Ce cours est équivalent à STAT 5500 à la Carleton University.  
**Volet : Cours magistral**

MAT 5580 Analyse numérique I pour les équations différentielles (3 crédits)  
Arithmétique des nombres à virgule flottante; solution numérique des équations différentielles ordinaires; méthode des différences finies pour les équations aux dérivées partielles; stabilité, consistance et convergence: analyse de von Neumann, condition de Courant-Friedrichs-Lewy, théorème de Lax; méthode des éléments finis: problèmes aux limites et équations aux dérivées partielles elliptiques; méthodes Spectrale et Pseudo-Spectrale.  
**Volet : Cours magistral**

MAT 5591 Inférence statistique (3 crédits)  
Ce cours est équivalent à STAT 5501 à la Carleton University.  
**Volet : Cours magistral**  
Préalable: MAT 5190.

MAT 5593 Modèles linéaires (3 crédits)  
Théorie des modèles linéaires des rangs non-exhaustifs : fonctions estimables, meilleurs estimateurs linéaires sans biais, vérification des hypothèses, régions de confiance; classification multidimensionnelle; analyse de la covariance; modèles de composantes de variance; méthode du maximum de vraisemblance; méthode MINQUE, ANOVA; sujets divers. Ce cours est équivalent à STAT 5503 à la Carleton University.  
**Volet : Cours magistral**

MAT 5595 Plan d’expériences (3 crédits)  
Aperçu de la théorie du modèle linéaire; orthogonalité; blocs complets avec randomisation totale; plans split plot; plans de carré latin; théorie du caractère aléatoire; plans de blocs incomplets; expériences factorielles; la théorie de la randomisation; les effets confondus et la replication fractionnelle; méthodologie de la surface de réponse; sujets divers.  
**Volet : Cours magistral**

MAT 5596 Analyse multivariée (3 crédits)  
Cours visant à donner à l’étudiant la possibilité d’entreprendre de la recherche mathématique dans le contexte d’un projet en collaboration avec un organisme parrain des secteurs public ou privé. Inclut des séminaires sur des sujets pertinents au projet de l’étudiant. Note finale de S (satisfaisant) ou NS (non satisfaisant) décidée par le professeur responsable du cours en consultation avec le superviseur du stage, fondée sur le contenu mathématique et sur la présentation orale et écrite des résultats. Ce cours est équivalent à STAT 5509 à la Carleton University.  
**Volet : Cours magistral**  
Préalable: Permission de l’Institut.

MAT 5597 Optimisation stochastique (3 crédits)  
Ce cours est équivalent à STAT 5601 à la Carleton University.  
**Volet : Cours magistral**  
Préalable: STAT 3506 or MAT 4371.

MAT 5598 Modèles stochastiques (3 crédits)  
Ce cours est équivalent à MATH 5701 à la Carleton University.  
**Volet : Cours magistral**

MAT 5709 Analyse harmonique sur les groupes (3 crédits)  
Ce cours est équivalent à MATH 6002 à la Carleton University.  
**Volet : Cours magistral**

MAT 5712 Topologie : Chapitres choisis (3 crédits)  
Ce cours est équivalent à STAT 5501 à la Carleton University.  
**Volet : Cours magistral**

MAT 5713 Topics in Probability and Statistics (3 crédits)  
Ce cours est équivalent à MATH 6507 à la Carleton University.  
**Volet : Cours magistral**
Ce cours est équivalent à MATH 5901 à la Carleton University.

Volet / Course Component:

MAT 5990 Séminaire / Seminar (3 crédits / 3 units)
Ce cours est équivalent à MATH 5900 à la Carleton University. / Project-oriented course affording students the opportunity to undertake research in applied mathematics as a cooperative project with governmental or industrial sponsors. Project work and seminars on related topics. Grade S (Satisfactory) or NS (Not satisfactory) to be assigned based upon the mathematical content as well as upon the oral and written presentation of results, and to be determined by the professor in charge of the course in consultation with the internship supervisor.

Volet / Course Component: Cours magistral / Lecture

MAT 5991 Travaux dirigés / Directed Studies (3 crédits / 3 units)
Ce cours est équivalent à MATH 6901 à la Carleton University. / Project in mathematics and statistics supervised by a professor approved by the director of graduate studies and leading to the writing of an in-depth report (approx. 30-40 pages). Graded S (Satisfactory) or NS (Not satisfactory) by the supervisor and by another professor appointed by the director of graduate studies in mathematics and statistics.

Volet / Course Component: Recherche / Research

MAT 5992 Seminar in Biostatistics (3 crédits / 3 units)
Students work in teams on the analysis of experimental data or experimental plans. The participation of experimenters in these teams is encouraged. Student teams present their results in the seminar, and prepare a brief written report on their work.

Volet / Course Component: Cours magistral / Lecture

MAT 5996 Stage de recherche / Research Internship (3 crédits / 3 units)
Cours visant à donner à l’étudiant la possibilité d’entreprendre de la recherche mathématique dans le contexte d’un projet en collaboration avec un organisme parrain des secteurs public ou privé. Inclut des séminaires sur des sujets pertinents au projet de l’étudiant. Note finale S (satisfaisant) ou NS (non satisfaisant), à décider par le professeur responsable du cours en consultation avec le superviseur du stage, fondée sur le contenu mathématique et sur la présentation orale et écrite des résultats. / Project-oriented course affording students the opportunity to undertake research in applied mathematics as a cooperative project with governmental or industrial sponsors. Project work and seminars on related topics. Grade S (Satisfactory) or NS (Not satisfactory) to be assigned based upon the mathematical content as well as upon the oral and written presentation of results, and to be determined by the professor in charge of the course in consultation with the internship supervisor.

Volet / Course Component: Cours magistral / Lecture

MAT 6990 Séminaire / Seminar (3 crédits / 3 units)
Ce cours est équivalent à MATH 6900 à la Carleton University. / This course is equivalent to MATH 6900 at Carleton University.

Volet / Course Component: Cours magistral / Lecture

MAT 6991 Travaux dirigés / Directed Studies (3 crédits / 3 units)
Ce cours est équivalent à MATH 6901 à la Carleton University. / This course is equivalent to MATH 6901 at Carleton University.

Volet / Course Component: Recherche / Research

MAT 6997 Projet en mathématiques et statistique / Project in Mathematics and Statistics (6 crédits / 6 units)
Projet en mathématiques et statistique dirigé par un professeur approuvé par le directeur des études supérieures et donnant lieu à la rédaction d’un rapport approfondi (30-40 pages approx). Note S (satisfaisant) ou NS (non satisfaisant) par le directeur du projet et un autre professeur nommé par le directeur des études supérieures en mathématiques et statistique. Le projet est normalement complété en une session. Ce cours est équivalent à MATH 5910 à la Carleton University. / Project in mathematics and statistics supervised by a professor approved by the director of graduate studies and leading to the writing of an in-depth report (approx. 30-40 pages). Graded S (Satisfactory) or NS (Not satisfactory) by the supervisor and by another professor appointed by the director of graduate studies in mathematics and statistics. The project will normally be completed in one session. This course is equivalent to MATH 5910 at Carleton University.

Volet / Course Component: Recherche / Research

MAT 7999 Thèse maîtrise / Masters Thesis
Ce cours est équivalent à MATH 5909 à la Carleton University. / This course is equivalent to MATH 5909 at Carleton University.

Volet / Course Component: Recherche / Research

MAT 9998 Examen général / Comprehensive Examination
Volet / Course Component: Recherche / Research

MAT 9999 Thèse doctorat / Ph.D. Thesis
Ce cours est équivalent à MATH 6909 à la Carleton University. / This course is equivalent to MATH 6909 at Carleton University.

Volet / Course Component: Recherche / Research
BNF 5106 Bioinformatics (3 units)
Major concepts and methods of bioinformatics. Topics may include, but are not limited to: genetics, statistics & probability theory, alignments, phylogenetics, genomics, data mining, protein structure, cell simulation and computing.
Course Component: Lecture

BNF 5107 Applied Bioinformatics (3 units)
Computational knowledge discovery in and the dynamic nature of cellular networks. Includes, but is not limited to, knowledge representation, large scale data integration, data mining and computational systems biology.
This course is equivalent to BIOL 5516 at Carleton University.
Course Component: Lecture

BNF 5506 Bioinformatique (3 crédits)
Concepts et méthodes en bioinformatique. Les sujets abordés peuvent inclure, entre autres, la génétique, les statistiques et les théories des probabilités, les alignements, la phylogénétique, la génomique et la structure de protéines.
Volet : Cours magistral

BNF 6100 MSc Seminar (3 units)
Current topics in bioinformatics presented by program professors and invited speakers. Oral presentation and written report required. Graded S (Satisfactory) / NS (Not satisfactory).
Course Component: Lecture

BNF 6500 Séminaire de maîtrise (3 crédits)
Sujets courants en bioinformatique présentés par des professeurs membres du programme et des conférenciers invités. Présentation orale et rapport écrit requis. Noté S (satisfaisant) ou NS (non satisfaisant).
Volet : Cours magistral