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INTRODUCTION

The purpose of this handbook is to provide information about the graduate programs of the Department of Mathematics, University of Toronto. It includes detailed information about the department, its faculty members and students, a listing of core courses offered in 2017-2018, a summary of research activities, admissions requirements, application procedures, fees and financial assistance, and information about similar matters of concern to graduate students and prospective graduate students in mathematics.

This handbook is intended to complement the calendar of the university’s School of Graduate Studies, where full details on fees and general graduate studies regulations may be found.

For further information, please contact:

The Graduate Office
Department of Mathematics
University of Toronto
40 St George St, Room 6166
Toronto, Ontario, Canada M5S 2E4
Telephone: (416) 978-7894
Fax: (416) 978-4107
Email: gradinfo@math.toronto.edu
Website: http://www.math.utoronto.ca/cms/graduate-program/
1. DEPARTMENT OF MATHEMATICS

Mathematics has been taught at the University of Toronto since 1827. Since the first Canadian Ph.D. degree in mathematics was conferred to Samuel Beatty (under the supervision of John Charles Fields) in 1915, more than 400 Ph.D. degrees and 1,000 Master’s degrees have been awarded in this University. Many of our recent graduates are engaged in university teaching and a significant number of them hold administrative positions in universities or in the professional communities. Others are pursuing careers in industry (technological or financial), or in government.

The Department of Mathematics, University of Toronto is a distinguished faculty of more than sixty mathematicians. We have a large selection of graduate courses and seminars, and a diverse student body of domestic and international students, yet classes are small and the ratio of graduate students to faculty is low. We are in a unique position to take maximum advantage of the presence of the Fields Institute, which features special programs in pure and applied mathematics. Currently the department has 139 graduate students, of whom 27 are enrolled in the Master’s program, 104 in the Ph.D. program, 2 in non-degree programs, 2 international visiting research graduate students and 4 in the part-time Master’s program. Opportunities for graduate study and research are available in most of the main fields of pure and applied mathematics. These fields include real and complex analysis, ordinary and partial differential equations, harmonic analysis, nonlinear analysis, several complex variables, functional analysis, operator theory, C*-algebras, ergodic theory, group theory, analytic and algebraic number theory, Lie groups and Lie algebras, automorphic forms, commutative algebra, algebraic geometry, singularity theory, differential geometry, symplectic geometry, classical synthetic geometry, algebraic topology, set theory, set theoretic topology, mathematical physics, fluid mechanics, probability (in cooperation with the Department of Statistics), combinatorics, optimization, control theory, dynamical systems, computer algebra, cryptography, and mathematical finance.

We offer a research-oriented Ph.D., and Master’s program. Very strong students may be admitted directly to the Ph.D. program with a Bachelor’s degree; otherwise; it is normal to do a 1-year Master’s degree first. (Provisional admission to the Ph.D. program may be granted at the time of admission to the Master’s program.) The Master’s program may be extended to 16 months or 24 months for students who do not have a complete undergraduate preparation, or for industrial students engaged in a project.

There is a separate Master’s of Mathematical Finance Program not directly under the Department’s jurisdiction, but with which some of our faculty members are associated.

During their studies here, graduate students are encouraged to participate in the life of the close community of U of T mathematics. Almost all of them do some work in connection with undergraduate teaching, either as tutorial leaders, markers, or, especially in later years of their program, instructors. There is a Mathematics Graduate Student Association, which organizes social and academic events and makes students feel welcome.
GRADUATE FACULTY MEMBERS

AKCOGLU, M.A. (Professor Emeritus) Ph.D. 1963 (Brown)
- Ergodic theory, functional analysis, harmonic analysis
ALEXAKIS, Spyros (Professor) Ph.D. 2005 (Princeton)
- Geometric analysis and general relativity
ARETAKIS, S. (Assistant Professor) Ph.D. 2012 (University of Cambridge)
- Differential Geometry, Analysis of PDEs, General Relativity

ARTHUR, J. (University Professor, Mossman Chair) B.Sc. 1966 (Toronto), M.Sc. 1967 (Toronto), Ph.D. 1970 (Yale)
- Representations of Lie groups, automorphic forms

BARBEAU, E. (Professor Emeritus) B.Sc. 1960 (Toronto), M.A. 1961 (Toronto), Ph.D. 1964 (Newcastle)
- Functional analysis, optimization under constraint, history of analysis, number theory
- Theory of quantum invariants of knots, links and three manifolds
BIERSTONE, E. (Professor) B.Sc. 1969 (Toronto), Ph.D. 1973 (Brandeis)
- Singularity theory, analytic geometry, differential analysis
BINDER, I. (Associate Professor) Ph.D. 1997 (Caltech)
- Harmonic and complex analysis, conformal dynamics
BLAND, J. (Professor) Ph.D. 1982 (UCLA)
- Several complex variables, differential geometry
BLOOM, T. (Professor Emeritus) Ph.D. 1965 (Princeton)
- Several complex variables
BRAVERMAN, A. (Professor) Ph.D. 1998 (Tel Aviv)
- Representation theory, algebraic geometry
BUCHWEITZ, R.-O. (Professor) Ph.D. (Dr.rer.nat.) 1976 (Hannover), Doctorat d’Etat 1981 (Paris VII)
- Commutative algebra, algebraic geometry, singularities
BURKHARD, A. (Professor) Ph.D. (Georgia Tech) 1994
- Functional analysis
CHOI, M.-D. (Professor Emeritus) M.Sc. 1970 (Toronto), Ph.D. 1973 (Toronto)
- Operator theory, operator algebras, matrix theory
- Operators on Hilbert spaces, matrix theory and applications (including numerical analysis)
DE SIMOI, J. (Assistant Professor) Ph.D. 2009 (University of Maryland)
- Stochastic and ergodic properties of smooth and piecewise smooth dynamical systems
DERZKO, N. (Associate Professor Emeritus) B.Sc. 1970 (Toronto), Ph.D. 1965 (Caltech)
- Functional analysis, structure of differential operators, optimization and control theory with applications to economics
ELLERS, E. (Professor Emeritus) Dr rer. nat. 1959 (Hamburg)
- Classical groups
ELLIOIT, G. A. (Canada Research Chair and Professor) Ph.D. 1969 (Toronto)
- Operator algebras, K-theory, non-commutative geometry and topology
FAIFMAN, D. (Coxeter Assistant Professor) Ph.D. 2015 (Tel Aviv)
- Algebra, mathematical analysis, geometry
FORTIER BOURQUE, M. (Coxeter Assistant Professor) Ph.D. 2015 (Graduate Center of the City University of New York)
- Teichmüller theory, complex analysis, and hyperbolic geometry

FRIEDLANDER, J. (University Professor) B.Sc. 1965 (Toronto), Ph.D. 1972 (Penn State)
- Analytic number theory

- Spectral theory of Schrödinger operators and localization

GRAHAM, I. (Professor Emeritus) B.Sc. 1970 (Toronto), Ph.D. 1973 (Princeton)
- Several complex variables, one complex variable

GUALTIERI, M. (Professor) Ph.D. 2003 (Oxford)
- Differential geometry and mathematical physics

HALPERIN, S. (Professor Emeritus) B.Sc. 1965 (Toronto), M.Sc. 1966 (Toronto), Ph.D. 1970 (Cornell)
- Homotopy theory and loop space homology

HASLOFFER, R. (Assistant Professor) Ph.D. 2012 (ETH Zürich)
- Geometric analysis, differential geometry, partial differential equations

HERZIG, F. (Associate Professor) PhD 2006 (Harvard)
- Number theory, Galois representations, automorphic forms

IVRII, V. (Professor) Ph.D. 1973 (Novosibirsk)
- Partial differential equations

JEFFREY, L. (Professor) Ph.D. 1992 (Oxford)
- Symplectic geometry, geometric applications of quantum field theory

JERRARD, Robert (Professor) Ph.D. 1994 (Berkeley)
- Nonlinear partial differential equations, Ginzburg-Landau theory

JURDJEVIC, V. (Professor Emeritus) Ph.D. 1969 (Case Western)
- Systems of ordinary differential equations, control theory, global analysis

KAMNITZER, Joel (Professor) Ph.D. 2005 (Berkeley)
- Geometric and combinatorial representation theory

KAPOVITCH, V. (Professor) Ph.D. 1997 (University of Maryland)
- Global riemannian geometry

KARSHON, Y. (Professor) Ph.D. 1993 (Harvard)
- Equivariant symplectic geometry

KHANIN, K. (Professor) Ph.D. 1983 (Landau Institute, Moscow)
- Dynamical systems and statistical mechanics

KHESIN, B. (Professor) Ph.D. 1989 (Moscow State)
- Poisson geometry, integrable systems, topological hydrodynamics

KHOVANSKII, A. (Professor) Ph.D. 1973, Doctorat d’Etat 1987 (Steklov Institute, Moscow)
- Algebra, geometry, theory of singularities

KIM, Henry (Professor) Ph.D. 1992 (Chicago)
- Automorphic L-functions, Langlands’ program

KUDLA, S. (Canada Research Chair and Professor) Ph.D. 1971 (Harvard)
- Automorphic forms, Arithmetic geometry and Theta functions

LORIMIER, J.W. (Professor Emeritus) Ph.D. 1971 (McMaster)
- Rings and geometries, topological Klingenber planes, topological chain rings

McCANN, R. (Professor) Ph.D. 1994 (Princeton)
- Mathematical physics, mathematical economics, inequalities, optimization, partial differential equations
McCOOL, J. (Professor Emeritus) Ph.D. 1966 (Glasgow)
- Infinite group theory

MEINRENKEN, E. (Professor) Ph.D. 1994 (Universität Freiburg)
- Symplectic geometry

MENDELSOHN, E. (Professor Emeritus) Ph.D. 1968 (McGill)
- Block designs, combinatorial structures

MILMAN, P. (Professor) Ph.D. 1975 (Tel Aviv)
- Singularity theory, analytic geometry, differential analysis

MURASUGI, K. (Professor Emeritus) D.Sc. 1960 (Tokyo)
- Knot theory

MURNAGHAN, F. (Professor) Ph.D. 1987 (Chicago)
- Harmonic analysis and representations of $p$-adic groups

- Number theory

NABUTOVSKY, A. (Professor) Ph.D. 1992 (Weizmann Institute of Science)
- Geometry and logic

NACHMAN, A. (Professor) Ph.D. 1980 (Princeton)
- Inverse problems, partial differential equations, medical imaging

PANCHENKO, D. (Professor) Ph.D. 2002 (University of New Mexico)
- Applied probability

PUGH, M. (Professor) Ph.D. 1993 (Chicago)
- Scientific computing, nonlinear PDEs, fluid dynamics, computational neuroscience

QUASTEL, J. (Professor) Ph.D. 1990 (Courant Institute)
- Probability, stochastic processes, partial differential equations

RAFI, Kasra (Associate Professor) Ph.D. 2001 (Stony Brook)
- Teichmüller space, geometric group theory, hyperbolic geometry

REPKA, J. (Professor) B.Sc. 1971 (Toronto), Ph.D. 1975 (Yale)
- Group representations, automorphic forms

ROSENTHAL, P. (Professor Emeritus) Ph.D. 1967 (Michigan)
- Operators on Hilbert spaces

ROSSMAN, B. (Assistant Professor) Ph.D. 2010 (MIT)
- Complexity theory and logic

ROTMAN, R. (Professor) Ph.D. 1998 (SUNY, Stony Brook)
- Riemannian geometry

SCHERK, J. (Associate Professor) D.Phil. 1978 (Oxford)
- Algebraic geometry

SECO, L. (Professor) Ph.D. 1989 (Princeton)
- Harmonic analysis, mathematical physics, mathematical finance

- Algebraic topology

SEN, D.K. (Professor Emeritus) Dr.es.Sc. 1958 (Paris)
- Relativity and gravitation, mathematical physics

SHANKAR, A. (Assistant Professor) Ph.D. 2012 (Princeton University)
- Number Theory
SHARPE, R. (Professor Emeritus) B.Sc. 1965 (Toronto), M.Sc. 1966 (Toronto), Ph.D. 1970 (Yale)
  • Differential geometry, topology of manifolds
SIGAL, I.M. (University Professor, Norman Stuart Robertson Chair in Applied Math) Ph.D. 1975 (Tel Aviv)
  • Mathematical physics
  • Fluid mechanics, particularly boundary layer theory
STINCHCOMBE, A. (Assistant Professor) Ph.D. 2013 (Courant Institute of Mathematical Sciences)
  • Mathematical biology, scientific computing
  • Partial differential equations, nonlinear analysis, numerical computations in fluid dynamics
TALL, F.D. (Professor Emeritus) Ph.D. 1969 (Wisconsin)
  • Set theory and its applications, set-theoretic topology
TANNY, S.M. (Associate Professor Emeritus) Ph.D. 1973 (M.I.T.)
  • Combinatorics, mathematical modeling in the social sciences
TIOZZO, G. (Assistant Professor) Ph.D. 2013 (Harvard)
  • Dynamical systems and ergodic theory
TODORCEVIC, S. (Canada Research Chair and Professor) Ph.D. 1979 (Belgrade)
  • Set theory and combinatorics
TSIMERMANN, J. (Assistant Professor) Ph.D. 2011 (Princeton University)
  • Analytic number theory, Abelian Varieties
VIRAG, B. (Canada Research Chair and Professor) Ph.D. 2000 (Berkeley)
  • Probability
VODA, M. (Assistant Professor, CLTA) Ph.D. 2011 (University of Toronto)
  • Spectral theory for Schrödinger operators.
WEISS, W. (Professor) M.Sc. 1972 (Toronto), Ph.D. 1975 (Toronto)
  • Set theory, set-theoretic topology
WU, H.-T. (Assistant Professor) Ph.D. 2011 (Princeton University)
  • Data analysis, big datasets and their medical applications
YAMPOLSKY, M. (Professor) Ph.D. 1997 (SUNY, Stony Brook)
  • Holomorphic and low-dimensional dynamical systems
ZHANG, Ke (Assistant Professor) PhD 2007 (Pennsylvania State University)
  • Dynamical systems: Hamiltonian dynamics, weak KAM theory, Arnold diffusion, smooth dynamics.
2. THE GRADUATE PROGRAM

The Department of Mathematics offers graduate programs leading to Master of Science (M.Sc.) and Doctor of Philosophy (Ph.D.) degrees in mathematics, in the fields of pure mathematics and applied mathematics. Students admitted to our M.Sc. program are admitted either as “terminal master’s” students or as “doctoral stream” students, the latter implying the intent of continuing on to our Ph.D. program. Students admitted to the doctoral-stream master’s program are fully funded for one year at the master’s level. Funding is limited to four years at the PhD level.

The M.Sc. Program

The M.Sc. program may be done on either a full- or part-time basis. Full-time students normally complete the program in one full year of study; three years in some cases. Part-time students may take up to six years to complete the program. The degree requirements are as follows:

1a. Completion of 6 half-courses (or the equivalent combination of half- and full-year courses). A current listing is available from the mathematics department website. The normal course load for full-time graduate students is 3 courses in the fall term and 3 in the spring term. Doctoral-stream students are required to take four half-course credits in core material.

1b. Completion of the Supervised Research Project (MAT 4000Y). This project is intended to give the student the experience of independent study in some area of advanced mathematics, under the supervision of a faculty member. The supervisor and the student, with the approval of the graduate coordinator decide the topic and program of study. The project is normally undertaken during the summer session, after the other course requirements have been completed, and has a workload roughly equivalent to that of a full-year course.

2. M.Sc. Thesis Option (less common than option 1). Students who take this option will be required to take and pass four half-courses and submit an acceptable thesis which should consist of a minimum of 20-pages of scholarly work. A presentation of the thesis results, in the form of a seminar, is required.

The Ph.D. Program

The Ph.D. program normally takes three or four years of full-time study beyond the Master’s level to complete. A Master’s degree is normally a prerequisite; however, exceptionally strong B.Sc. students may apply for direct admission to the Ph.D. program. Expected progress in the program is outlined in the following table:

<table>
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<tr>
<th>Year 1</th>
<th>Course work; Pass at least 3 comprehensive exams; Select a thesis advisor.</th>
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<tr>
<td>Year 2</td>
<td>Supervisory committee selected by graduate coordinator; First annual supervisory committee progress report due.</td>
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<tr>
<td>Year 3</td>
<td>Presentation of preliminary thesis results to supervisory committee; Achieve PhD candidacy.</td>
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</table>
1. **Coursework:** Completion of at least 6 half-courses (or the equivalent combination of half- and full-year courses). A current listing is available from the mathematics department website. Normally, 6 half-courses are taken in the first year of study (3 half-courses in the fall term and 3 in the spring term). It is strongly recommended that the student take some additional courses in other years.

2. **Comprehensive Examination:** The student is required to pass at least three comprehensive examinations in basic mathematics before beginning an area of specialization. The examinations in the five general areas (analysis (real and complex), algebra, topology, partial differential equations and probability) take place during a one-week period in early September. The passing grade on these examinations is A-/80%. Exemptions from individual exams will be given if the student has obtained a grade of A- or better in the corresponding core course(s). Syllabi for the pure mathematics comprehensive exams appear in Appendix A. Copies of mock examination questions and/or past written examination papers are accessible to all candidates at [http://www.math.utoronto.ca/cms/past-comprehensive-exams/](http://www.math.utoronto.ca/cms/past-comprehensive-exams/).

Students with interests in applied mathematics should refer to Appendix B for possible alternate comprehensive exams.

All exams are to be taken within 13 months of entering the Ph.D. program unless the Examination Committee grants permission in writing for a deferral. Ph.D. candidacy must be achieved by the end of the 3rd year.

3. **Supervisory Committee:** The purpose of the Supervisory Committee (SC) is to monitor the student’s progress at least on an annual basis, keeping the following in mind.

No supervisor is perfect! The SC may be able to offer further mathematical and further career advice beyond what the supervisor alone may offer. This is relevant both at the start of studies, when mathematical advice is most in need, and towards the end of studies, when career advice is needed.

No student is perfect! The SC should note if a student is falling behind and should propose ways for the student to catch up, if necessary.

While most student-supervisor relationships are cordial and productive, occasional misunderstandings, miscommunications and cases of false expectations do occur. The SC should note if a student-supervisor relationship is heading wrong and make sure that steps are taken to fix the problems.

Ph.D. students must select a supervisor by the beginning of their second year in the Ph.D. program. In accordance with School of Graduate Studies’ regulations, a supervisory committee (SC) will be established for each Ph.D. student who has chosen a research area.
and a supervisor. This committee consists of three faculty members including the supervisor. The SC is expected to meet with the student at least annually, including on the last year of studies. Since some of the role of the SC is private and confidential, it is not appropriate to substitute these meetings with public lectures. The SC will file an annual written report with the graduate office.

Further information about general graduate supervision is available at [http://www.sgs.utoronto.ca/Documents/Supervision+Guidelines.pdf](http://www.sgs.utoronto.ca/Documents/Supervision+Guidelines.pdf)

4. **Thesis**: The main requirement of the degree is an acceptable thesis. This will embody an individual contribution to original research of a standard that warrants publication in the research literature. It must be written under the supervision of one or more members of the department. The student presents the thesis results in three stages.

   (i) **Thesis Content Seminar.** This is an opportunity for the student to present his/her thesis results to department members. The presentation frequently takes place within one of the regular departmental research seminars.

   (ii) **Departmental Oral Examination.** The student gives a 20-minute summary of the thesis and must defend it before a departmental examination committee. Copies of the thesis should be available two weeks before the departmental oral examination. The committee may approve the thesis without reservations, or approve the thesis on condition that revision be made, or require the student to take another departmental oral examination.

   (iii) **Final Oral Examination.** Eight weeks after the successful completion of the departmental oral, the student proceeds to the final oral examination conducted by the School of Graduate Studies. The thesis is sent to an external reader who submits a report two weeks prior to the examination; this report is circulated to members of the examination committee and to the student. The examination committee consists of four to six faculty members; it is recommended that the external reader attend the examination. The student gives a 20-minute summary of the thesis, which is followed by a question period.

As an alternative to the above examination procedure, it will sometimes be possible, on the PhD candidate's initiative and with the agreement of the candidate's academic advisor, to substitute a 50 minute presentation for the 20 minute presentation in the departmental oral examination and the final oral examination. The math department will attempt to accommodate such requests though technical and administrative considerations (space and scheduling issues, communication issues when some committee members are not physically present, compliance issues with SGS rules, etc.) may prevent this alternative. It is recommended that such requests will be made at least 4 weeks in advance of the departmental examination. It is recommended that the 50 minutes option for the final oral examination not be considered when the external examiner is participating by teleconference.

5. Students are expected to become extensively involved in departmental life (seminars, colloquia and related activities).
3. Administration of the Graduate Program

A central administration authority called the School of Graduate Studies establishes the basic policies and procedures governing all graduate study at the University of Toronto. Detailed information about the School is obtained in its calendar, distributed to new graduate students during registration week.

The Department of Mathematics has its own graduate administrative body—the graduate committee—composed of 8-12 faculty members appointed by the chair of the department, and five graduate students elected by the Mathematics Graduate Students Association. One of the faculty members is the graduate coordinator, who is responsible for the day-to-day operation of the program. The graduate committee meets frequently throughout the year to consider matters such as admissions, scholarships, course offerings, and departmental policies pertaining to graduate students. Student members are not permitted to attend meetings at which the agenda concerns confidential matters relating to other students. Information regarding appeals of academic decisions is given in the Grading Procedures section of the Calendar of the School of Graduate Studies. Students may also consult the Graduate Coordinator (or the student member of the departmental Graduate Appeals Committee) regarding information about such appeals.

General Outline of the 2017-2018 Academic Year

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<th>Registration</th>
<th>July 18 – September 8, 2017</th>
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<td>Fall Term</td>
<td>Classes begin Monday, September 11, 2017</td>
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<tr>
<td>Spring Term</td>
<td>Classes begin Monday, January 8, 2018</td>
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Official Holidays (University Closed):

| Labour Day     | Monday, September 4, 2017 |
| Thanksgiving Day | Monday, October 9, 2017 |
| Christmas/New Year | Thursday, December 21, 2017 – Tuesday, January 2, 2018 |
| Family Day     | Monday, February 19, 2018 |
| Good Friday    | Friday, March 30, 2018 |
| Victoria Day   | Monday, May 21, 2018 |
| Canada Day     | Monday July 2, 2018 |
| Civic Holiday  | Monday, August 6, 2018 |
4. GRADUATE COURSES

The following is a list and description of the core courses offered to graduate students in the 2017-2018 academic year. These are the basic beginning graduate courses. They are designed to help the student broaden and strengthen his/her general background in mathematics prior to specializing towards a thesis. A student with a strong background in the area of any of the core courses should not take that particular course. A complete listing of all graduate courses on offer in a given year is available from the mathematics department website. These include cross-listed graduate courses and topics courses. In addition, graduate students may take several intermediate (300-level) undergraduate courses (listed in the Faculty of Arts and Science Calendar) if their background is felt to be weak in some area; no graduate course credit is given for these courses.

There are three other means by which graduate students may obtain course credit, apart from completing the formal courses listed on the following pages. In each of these cases, prior approval of the graduate coordinator is required.

1. Students may take a suitable graduate course offered by another department. Two-thirds of the course requirements for each degree should be in the Mathematics Department.
2. It is sometimes possible to obtain course credit for appropriately extensive participation in a research seminar (see Research Activities section).
3. It is also possible to obtain a course credit by working on an individual reading course under the supervision of one of the faculty members, provided the material covered is not available in one of the formal courses or research seminars. (Note: this is distinct from the MAT 4000Y Supervised Research Project required of M.Sc. students.)

Most courses meet for three hours each week, either in three one-hour sessions or two longer sessions. For some courses, particularly those cross-listed with undergraduate courses, the times and locations of classes will be set in advance of the start of term. For other courses, the times and locations of classes will be established at organizational meetings during the first week of term, so that a time convenient for all participants may be arranged. During registration week, students should consult the math department website for class and organization meeting times and locations: https://www.math.toronto.edu/cms/2017-2018-tentative-graduate-courses-timetable/.

CORE COURSES

MAT 1000HF (MAT 457H1F)
REAL ANALYSIS I
J. De Simoi

Measure Theory: Lebesque measure and integration, convergence theorems, Fubini's theorem, Lebesgue differentiation theorem, abstract measures, Caratheodory extension theorem, Radon-Nikodym theorem.


Textbook:
References:
Elias Stein and Rami Shakarchi, Measure Theory, Integration, and Hilbert Spaces
Elliott H. Lieb and Michael Loss, Analysis, AMS Graduate Texts in Mathematics, 14 (either edition)
H. L. Royden, Real Analysis, Macmillan, 1998
A. N. Kolmogorov and S. V. Fomin: Introductory Real Analysis, 1975

MAT 1001HS (MAT 458H1S)
REAL ANALYSIS II
J. Arthur

Fourier analysis: Fourier series and transform, convergence results, Fourier inversion theorem, $L$-theory, estimates, convolutions.


Textbook:

References:
E. Lorch, Spectral Theory.

MAT 1002HS (MAT 454H1S)
COMPLEX ANALYSIS
E. Bierstone

2. Harmonic functions. Poisson’s integral formula and Dirichlet’s problem
3. Conformal mapping, Riemann mapping theorem.
4. Analytic continuation, Monodromy Theorem, Riemann surfaces.
5. Modular functions and the Picard Theorems.
6. Other topics are possible, like product theorems, elliptic functions, and non-isolated removability theorems.

Recommended prerequisites: A first course in complex analysis and a course in real analysis. Measure theory is not required.

Main References:
L. Ahlfors: Complex Analysis, 3rd Edition
Stein and Shakarchi: Complex Analysis

Additional References:
T. Gamelin, Complex Analysis
W. Rudin, Real and Complex Analysis, 2nd or 3rd edition
D. Sarason, Complex Function Theory
MAT 1060HF
PARTIAL DIFFERENTIAL EQUATIONS I
C. Sulem

This is a basic introduction to partial differential equations as they arise in physics, geometry and optimization. It is meant to be accessible to beginners with little or no prior knowledge of the field. It is also meant to introduce beautiful ideas and techniques, which are part of most analysts’ basic bag of tools. A key theme will be the development of techniques for studying non-smooth solutions to these equations.

Textbook:

References:
R. McOwen, Partial Differential Equations, (2nd ed),

MAT 1061HS
S. Alexakis

This course will consider a range of mostly nonlinear partial differential equations, including elliptic and parabolic PDE, as well as hyperbolic and other nonlinear wave equations. In order to study these equations, we will develop a variety of methods, including variational techniques, and fixed point theorems. One important theme will be the relationship between variational questions, such as critical Sobolev exponents, and issues related to nonlinear evolution equations, such as finite-time blowup of solutions and/or long-time asymptotics.

The prerequisites for the course include familiarity with Sobolev and other function spaces, and in particular with fundamental embedding and compactness theorems.

Other topics in PDE will also be discussed.

Textbook:

References:
R. McOwen, Partial Differential Equations, (2nd ed),
MAT 1100HF
ALGEBRA I
A. Braverman


Group Theory: Isomorphism theorems, group actions, Jordan-Hölder theorem, Sylow theorems, direct and semidirect products, finitely generated abelian groups, simple groups, symmetric groups, linear groups, nilpotent and solvable groups, generators and relations.

Ring Theory: Rings, ideals, Euclidean domains, principal ideal domains, and unique factorization domains.

Modules: Modules and algebras over a ring, tensor products, modules over a principal ideal domain.

Recommended prerequisites are a full year undergraduate course in Linear Algebra and one term of an introductory undergraduate course in higher algebra, covering, at least, basic group theory. While this material will be reviewed in the course, it will be done at "high speed", assuming that you have already some familiarity with the basics. You will be very well prepared indeed, if you have no difficulties reading and understanding the book, listed here under "Other References", M. Artin: Algebra that the author wrote for his undergraduate algebra courses at MIT.

Textbooks:
Dummit and Foote: Abstract Algebra, 2nd Edition

Other References:
Jacobson: Basic Algebra, Volumes I and II.
Cohn: Basic Algebra
M. Artin: Algebra.

MAT 1101HS
ALGEBRA II
F. Murnaghan

Fields: Algebraic and transcendental extensions, normal and separable extensions, fundamental theorem of Galois theory, solution of equations by radicals.

Commutative Rings: Noetherian rings, Hilbert basis theorem, invariant theory, Hilbert Nullstellensatz, primary decomposition, affine algebraic varieties. Structure of semisimple algebras, application to representation theory of finite groups.

Textbooks:
Dummit and Foote: Abstract Algebra, 3rd Edition

Other References:
Jacobson: Basic Algebra, Volumes I and II.
Cohn: Basic Algebra
M. Artin: Algebra.
MAT 1300HF
TOPOLOGY I
M. Gualtieri

Local differential geometry: the differential, the inverse function theorem, smooth manifolds, the
tangent space, immersions and submersions, regular points, transversality, Sard’s theorem, the
Whitney embedding theorem, smooth approximation, tubular neighborhoods, the Brouwer fixed
point theorem.

Differential forms: exterior algebra, forms, pullbacks, integration, Stokes’ theorem, div grad curl
and all, Lagrange’s equation and Maxwell’s equations, homotopies and Poincare’s lemma, linking
numbers.

Prerequisites: linear algebra; vector calculus; point set topology

Textbook:
John M. Lee: Introduction to Smooth Manifolds

MAT 1301HS
TOPOLOGY II
A. Nabutovsky

Fundamental groups: paths and homotopies, the fundamental group, coverings and the fundamental
group of the circle, Van-Kampen’s theorem, the general theory of covering spaces.

Homology: simplices and boundaries, prisms and homotopies, abstract nonsense and diagram
chasing, axiomatics, degrees, CW and cellular homology, subdivision and excision, the generalized
Jordan curve theorem, salad bowls and Borsuk-Ulam, cohomology and de-Rham’s theorem, products.

Textbook:
Allen Hatcher, Algebraic Topology

Recommended Textbooks:
Munkres, Topology
Munkres, Algebraic Topology

MAT1600HF
MATHEMATICAL PROBABILITY
D. Panchenko

The class will cover classical limit theorems for sums of independent random variables, such as
the Law of Large Numbers and Central Limit Theorem, conditional distributions and martingales,
metrics on probability measures.

Textbook:

Recommended prerequisite:
Real Analysis I.
MAT1601HS
MATHEMATICAL PROBABILITY
D. Panchenko

The class will cover some of the following topics: Brownian motion and examples of functional central limit theorems, Gaussian processes, Poisson processes, Markov chains, exchangeability.

Textbook:

Recommended prerequisites:
Real Analysis I and Probability I.

2017-18 TOPICS COURSES AND CROSS-LISTED UNDERGRADUATE/GRADUATE COURSES

A listing is available from the graduate website: https://www.math.toronto.edu/cms/2017-2018-tentative-graduate-courses-descriptions/

INDIVIDUAL READING COURSES

Students requiring individual course numbers:

MAT 1900Y/1901H/1902H
READING IN PURE MATHEMATICS
Numbers assigned for students wishing individual instruction in an area of pure mathematics.

MAT 1950Y/1951H/1952H
READING IN APPLIED MATHEMATICS
Numbers assigned for students wishing individual instruction in an area of applied mathematics.

COURSE IN TEACHING TECHNIQUES

The following course is offered to help train students to become effective lecturers. It is not for degree credit and is not to be offered every year.

MAT 1499HS (not offered in 2017-18 session)
TEACHING LARGE MATHEMATICS CLASSES
J. Repka

The goals of the course include techniques for teaching large classes, sensitivity to possible problems, and developing an ability to criticize one’s own teaching and correct problems.

Assignments will include such things as preparing sample classes, tests, assignments, course outlines, designs for new courses, instructions for teaching assistants, identifying and dealing with various types of problems, dealing with administrative requirements, etc.

The course will also include teaching a few classes in a large course under the supervision of the instructor. A video camera will be available to enable students to tape their teaching for later (private) assessment.
COURSES FOR GRADUATE STUDENTS FROM OTHER DEPARTMENTS

(Math graduate students cannot take the following courses for graduate credit.)

MAT 2000Y  READINGS  IN THEORETICAL MATHEMATICS
MAT 2001H  READINGS  IN THEORETICAL MATHEMATICS I
MAT 2002H  READINGS  IN THEORETICAL MATHEMATICS II

(These courses are used as reading courses for engineering and science students in need of instruction in special topics in theoretical mathematics. These course numbers can also be used as dual numbers for some third and fourth year undergraduate mathematics courses if the instructor agrees to adapt the courses to the special needs of graduate students. A listing of such courses is available in the 2014-2015 Faculty of Arts and Science Calendar. Students taking these courses should get an enrolment form from the graduate studies office of the Mathematics Department. Permission from the instructor is required.)

PROFESSIONAL DEVELOPMENT PROGRAMS OFFERED BY SGS

English Language and Writing Support (ELWS)
The English Language and Writing Support program, at the School of Graduate Studies, offers individual consultations, single-session workshops, and free non-credit courses for both native and non-native speakers of English. Information and registration:
http://www.sgs.utoronto.ca/currentstudents/Pages/English-Language-and-Writing-Support.aspx

Graduate Professional Skills Program (GPS)
The Graduate Professional Skills program (GPS) is a new initiative from the School of Graduate Studies to help doctoral-stream graduate students become fully prepared for their future. It focuses on skills beyond those conventionally learned within a disciplinary program, skills that may be critical to success in the wide range of careers that graduates enter, both within and outside academe. GPS can help you to communicate effectively, plan and manage your time, be entrepreneurial, understand and apply ethical practices, and work effectively in teams and as leaders. The GPS consists of a range of optional “offerings” with a time commitment roughly equivalent to 60 hours of work. Its successful completion will be recognized by a transcript notation. For more information: http://www.sgs.utoronto.ca/currentstudents/Pages/Professional-Development.aspx

MITACS
Mitacs (www.mitacs.ca) is a national research organization offering unique research and training programs to graduate students and postdoctoral fellows (PDFs) in Canada. For more information: http://www.sgs.utoronto.ca/currentstudents/Pages/International-Student-Awards.aspx
5. RESEARCH ACTIVITIES

The Department of Mathematics offers numerous research activities, in which graduate students are encouraged to participate. Research seminars are organized informally at the beginning of each year by one or more faculty members and/or students, and are offered to faculty and graduate students on a weekly basis throughout the year. The level and specific content of these seminars varies from year to year, depending upon current faculty and student interest, and upon the availability and interests of invited guest lecturers. The following research seminars were offered in the past year:

- Algebra and Geometry Seminar
- Analysis and Applied Math Seminar
- Dynamics Seminar
- Fields Analysis Working Group Seminar
- Fields Colloquium/Seminar in Applied Math
- Ganita Seminar
- Geometric Representation Theory Seminar
- Geometry and Topology Seminar
- Graduate Student Seminar
- Homological Methods Seminar
- Inverse Problems and Image Analysis Seminar
- Number Theory/Representation Theory Seminar
- Operator Theory Seminar
- Probability, Geometry and Groups Learning Seminar
- Probability Study Group
- Student Number Theory Seminar
- Symplectic Seminar
- Teichmüller Theory and Dynamics Learning Seminar
- Toronto Probability Seminar
- Toronto Set Theory Seminar
- Trace Formula Working Seminar
- Women in Mathematics
- Working Group in Hamiltonian Systems Seminar

A full list of events in the department can be found in this link:
https://seminars.math.toronto.edu/seminars/list/events.py/process?start

In addition to the weekly seminars, there are numerous special seminars throughout the year, a series of colloquia, and an active program of visiting lecturers:

- Departmental Colloquium
- Blyth Lecture Series

Graduate students are also encouraged to attend lectures and seminars offered by other departments.
6. ADMISSION REQUIREMENTS AND APPLICATION PROCEDURES

Due to the large numbers of applications received in the Department of Mathematics each year, serious consideration will only be given to applicants with strong backgrounds in theoretical mathematics and with first class academic standing.

Application materials and admission requirements are available from the Department of Mathematics website: http://www.math.utoronto.ca/cms/potential-students-grad/

Please read all instructions carefully and note the deadlines. In addition, the Department of Mathematics requires three letters of reference. The letters must be from three people familiar with your mathematical work, giving their assessment of your potential for graduate study and research in mathematics.

It is essential that all incoming graduate students have a good command of English. Facility in the English language must be demonstrated by all applicants educated outside Canada whose primary language is not English. This requirement is a condition of admission and should be met before application. Here are three ways to satisfy this requirement: (1) Test of English as a Foreign Language (TOEFL): (a) internet-based test (iBT), minimum score of 22/30 for both the Writing and Speaking sections, with an overall minimum TOEFL score of 93/120, or (b) paper-based test, minimum score 580, with TWE (Test of Written English), minimum score 5.0; (2) a score of at least 85 on the Michigan English Language Assessment Batter (MELAB); (3) a score of at least 7.0 on the International English Language Testing Service (IELTS). Applicants are required to satisfy this requirement by December 20, so that scores are available at the time applications are considered.

Suggested prerequisites:

We recognize that our students come from many different places and with a significant range of differing backgrounds. Hence there is no fixed and rigid list of prerequisites, and applicants are considered and often admitted even if their formal previous mathematical education is very different from the informal list of prerequisites below. In general, we’d like to see some sort of overall mathematical maturity and experience, and we appreciate (though we do not require) evidence of in-depth concentration in one mathematical discipline or another.

Yet here’s a non-binding list of courses that are recommended to applicants from within the University of Toronto in order to be seriously considered for the doctoral stream master’s program. Students coming from other institutions will have to make the appropriate substitutions:

2nd year Advanced ODE’s, e.g. MAT 267H


3rd year Real Analysis, e.g. MAT 357H

3rd year Complex Analysis, e.g. MAT 354H

Approximate syllabus: Complex numbers, the complex plane and Riemann sphere, Möbius transformations, elementary functions and their mapping properties, conformal mapping, holomorphic functions, Cauchy’s theorem and integral formula. Taylor and Laurent series, maximum modulus principle, Schwarz’s lemma, residue theorem and residue calculus.

3rd year Algebra, e.g. MAT 347Y

Approximate syllabus: Groups, subgroups, quotient groups, Sylow theorems, Jordan-Hölder theorem, finitely generated abelian groups, solvable groups. Rings, ideals, Chinese remainder theorem; Euclidean domains and principal ideal domains: unique factorization. Noetherian rings, Hilbert basis theorem. Finitely generated modules. Field extensions, algebraic closure, straight-edge and compass constructions. Galois theory, including insolvability of the quintic.

3rd year Topology, e.g. MAT 327H


In addition to that we also value some ability in computer programming and some background in physics (though neither is required).

Likewise here’s a non-binding list of courses that are recommended to applicants from within the University of Toronto in order to be seriously considered for the terminal master’s program. Students coming from other institutions will have to make the appropriate substitutions:

Linear Algebra, e.g. MAT 224


Groups and Symmetries, e.g. MAT 301


Complex Variables, e.g. MAT 334

Approximate syllabus: Theory of functions of one complex variable, analytic and meromorphic functions. Cauchy’s theorem, residue calculus, conformal mappings, introduction to analytic continuation and harmonic functions.

Real Analysis, e.g. MAT 337

7. POLICY ON FINANCIAL SUPPORT, FEES AND FINANCIAL ASSISTANCE

Department of Mathematics Policy on Financial Support of Graduate Students

**Ph.D. Students:** At the time of admission to the Ph.D. program, students will normally be guaranteed support for a period of four years (five years in the case of students admitted directly from a Bachelor’s program), except that students who complete their degree requirements earlier will not be supported past the end of the academic year in which they finish. This guarantee will be made up of a mix of fellowships (including external awards such as NSERC, OGS), teaching assistantships and other sources of funding, at the discretion of the Department; and is subject to satisfactory academic progress, the maintenance of good standing, and in the case of teaching assistantships, satisfactory performance in that role, as judged by the Department. Absent this, support may be reduced, suspended, or discontinued.

In exceptional circumstances some funding may be provided to students in a subsequent year, but the Department expects that students will normally have completed their degree requirements within the four-year period.

**M.Sc. Students:** Students who are granted provisional admission to the Ph.D. program at the time of admission will receive financial support, for one year only.

All full-time students in the first or second year of a Master’s program are eligible for teaching assistant work (subject to availability and satisfactory performance).

**Fees**

Listed below are the fees for the 2016-17 academic session, including incidental fees and the health insurance premium for visa students. The university has not yet published a listing of fees for 2017-18. For detailed information, visit [http://www.fees.utoronto.ca/](http://www.fees.utoronto.ca/)

**Domestic Fees**

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Doctoral &amp; Doctoral Stream - St. George Campus</th>
</tr>
</thead>
<tbody>
<tr>
<td>PhD, MusD, SJD, MA, MASC, MSc, MSzF, MusM (Music Ed)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2016-2017 FALL-WINTER SESSION</th>
<th>Program Fees</th>
<th>Incidental, System Access &amp; Ancillary Fees (Note 1)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time: Fall-Winter</td>
<td>$7,030.00</td>
<td>$1,461.69</td>
<td>$8,491.69</td>
</tr>
<tr>
<td>Full-time: Fall or Winter</td>
<td>$3,515.00</td>
<td>$755.85</td>
<td>$4,270.85</td>
</tr>
<tr>
<td>Part-time: Fall-Winter</td>
<td>$2,109.00</td>
<td>$747.80</td>
<td>$2,856.80</td>
</tr>
<tr>
<td>Part-time: Fall or Winter</td>
<td>$1,054.50</td>
<td>$398.90</td>
<td>$1,453.40</td>
</tr>
</tbody>
</table>

**Table A: Program Fee - Degree Students**

1) There may be additional ancillary fees levied for enrolment in specific courses or for individual circumstances. Check your invoice on ACORN/ROSI.

<table>
<thead>
<tr>
<th>Table B: Course Fee - Non-Degree, Special Students</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>2016-17 FALL-WINTER SESSION</th>
<th>Initial Course Load</th>
<th>Course Fees</th>
<th>Incidental, System Access &amp; Ancillary Fees (Note 1)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>$1,054.50</td>
<td>$747.80</td>
<td>$1,802.30</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>$2,109.00</td>
<td>$747.80</td>
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<td></td>
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International Fees

<table>
<thead>
<tr>
<th>2016-2017 FALL-WINTER SESSION</th>
<th>Program Fees</th>
<th>Incidental, System Access &amp; Ancillary Fees (Note 1)</th>
<th>University Health Insurance Plan (UHIP) Fees (Note 2)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time: Fall-Winter</td>
<td>$20,530.00</td>
<td>$1,461.69</td>
<td>$612.00</td>
<td>$22,603.69</td>
</tr>
<tr>
<td>Full-time: Fall or Winter</td>
<td>$10,265.00</td>
<td>$755.85</td>
<td>$612.00</td>
<td>$11,632.85</td>
</tr>
<tr>
<td>Part-time: Fall-Winter</td>
<td>$6,159.00</td>
<td>$747.80</td>
<td>$612.00</td>
<td>$7,518.80</td>
</tr>
<tr>
<td>Part-time: Fall or Winter</td>
<td>$3,079.50</td>
<td>$398.90</td>
<td>$612.00</td>
<td>$4,090.40</td>
</tr>
</tbody>
</table>

1) There may be additional ancillary fees levied for enrolment in specific courses or for individual circumstances. Check your invoice on ACORN/ROSI.
2) Information about UHIP can be viewed at [http://www.studentlife.utoronto.ca/cie/uhip](http://www.studentlife.utoronto.ca/cie/uhip).

<table>
<thead>
<tr>
<th>Initial Course Load</th>
<th>Course Fees</th>
<th>Incidental, System Access &amp; Ancillary Fees (Note 1)</th>
<th>University Health Insurance Plan (UHIP) Fees (Note 2)</th>
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<td>$4,439.30</td>
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1) There may be additional ancillary fees levied for enrolment in specific courses or for individual circumstances. Check your invoice on ACORN/ROSI.
2) Information about UHIP can be viewed at [http://www.studentlife.utoronto.ca/cie/uhip](http://www.studentlife.utoronto.ca/cie/uhip).

Financial Assistance

Below is a list of those types of financial assistance most commonly awarded to mathematics graduate students in 2016-17. This information should also be applicable for students who wish to apply for the 2017-18 academic year; the deadlines for applications will be altered slightly in accordance with the 2017-18 calendar. Some awards are available from external funding agencies; others come from within the University.

Less common scholarships, offered by smaller or foreign funding agencies, are also available; information about these may be found at: [http://www.sgs.utoronto.ca/currentstudents/Pages/Financing-Your-Graduate-Education.aspx](http://www.sgs.utoronto.ca/currentstudents/Pages/Financing-Your-Graduate-Education.aspx). Announcements are made to students.

**Vanier Canada Graduate Scholarships (Vanier CGS) Program**

**Value: $50,000 per annum for a maximum of 3 years**

*Eligibility:* A student must be nominated by a Canadian university. Vanier Scholarships must be held by the student at the university that nominated them. The scholarships are not transferable: they may not be taken to another university. Applicants do not have to be registered as doctoral students at the time of application, but must be registered as doctoral students at a Canadian university when they take up the Vanier Scholarship. Canadian citizens, landed immigrants (permanent residents), and international students are all eligible for Vanier Scholarships. Students who have held or are currently holding Tri-Agency scholarship funding for their doctoral program are not eligible to apply.

**Application:** [http://www.vanier.gc.ca/](http://www.vanier.gc.ca/)

**Deadline:** early September. Consult department for deadline.
Natural Sciences and Engineering Research Council (NSERC) Postgraduate Scholarships and Canada Graduate Scholarships

Value: approx. $17,300-$35,000 for a twelve month period
Eligibility: Canadian citizens, permanent residents; first class academic standing; full-time attendance
Application: apply through the university you are currently attending; application available at www.nserc.ca
Deadline: early October. Consult department for deadline

Ontario Graduate Scholarships (OGS)
Value: approx. $5,000 per term for two or three terms
Eligibility: no citizenship restrictions; first class academic standing; full-time attendance at an Ontario university
Application: apply through the department you wish to attend (http://www.sgs.utoronto.ca/currentstudents/Pages/Ontario-Graduate-Scholarship.aspx).
Deadline: Consult department for deadline.

Queen Elizabeth II Graduate Scholarship in Science and Technology (QEII-GSST)
Value: approx. $15,000 for a twelve month period
Eligibility: Canadian citizens, permanent residents; first class academic standing; full-time attendance
Application: OGS application (see above).
Deadline: Consult department for deadline.

University of Toronto Fellowships
Value: minimum $1,000
Eligibility: no citizenship restrictions; at least an A- average; full-time attendance at the University of Toronto
Application: graduate school applicants will be considered automatically
Deadline: early December

Connaught International Scholarship for Doctoral Students (entrance scholarship)
Value: The effective value awarded to each student will be $35,000.00 total (including tuition). Scholarships will continue in the same form throughout the normal period in the funded cohort, provided progress.
Application: A graduate school application. Graduate units decide nominations in the winter semester.
Deadline: To be considered, international doctoral applicants must submit a graduate school application by early December

Ontario Trillium Scholarship (OTS) for Doctoral Students (entrance scholarship)
The Ontario Trillium Scholarship (OTS) is designed to attract international PhD students to the University of Toronto.
Value: Each OTS will be worth $40,000 per annum (including tuition), and is renewable for four years, provided progress.
Application: A graduate school application. Graduate units decide nominations in the winter semester.
Deadline: To be considered, international doctoral applicants must submit a graduate school application by early December
Research Assistantships

Value: a limited amount of funds is available for academically worthy students

Eligibility: no citizenship restrictions; full-time attendance; high academic standing

Application: graduate school applicants will be considered automatically
Deadline: early December

Teaching Assistantships

Value: $44.62 per hour; Eligibility: full-time students who are accepted by the Mathematics Department (subject to satisfactory performance); may be held in conjunction with other awards

Application: forms available online. Deadline: early June

Doctoral Thesis Completion Award (DCA)

The Department of Mathematics receives funding from the university to help support students beyond the funded cohort: Doctoral Thesis Completion Award. The policy of the mathematics department is to spend its DCA funds aiming to bring the total amount of after-fees funding (including both external and other internal sources) for all fifth-year students who are in good academic standing (including a satisfactory supervisory committee report) to be as close to uniform within that group as feasible, and in as much as possible, close to the level of support funded-cohort students are receiving. Shall there be any DCA funds remaining after that, these funds will be distributed on a similar basis among sixth year students.

Arts and Science Conference Travel Grant

An important part of the research process is the presentation of one’s work at scholarly conferences. The purpose of this program is to provide additional funds to enable graduate students in the Faculty of Arts and Science to travel to conferences where they will present their work.

Value: varies to a maximum of $1,000

Eligibility: no citizenship restrictions; award holders must be doctoral students in the funded cohort.

Graduate students may hold only one Travel Grant during their time in the department.

Eligible Expenses: Conference registration and abstract submission costs, travel and living expenses.

Application: Applications available from the Math Graduate Office; deadline October 1.

Selection Criteria: Past academic performance, need to attend conference for professional development, quality of abstract. Preference will be given to students near the end of their degrees.

School of Graduate Studies Conference Grant

The School of Graduate Studies Conference Grant program is intended to encourage students in doctoral-stream programs to actively present their research at a regional, national or international conference or equivalent academic event early in their program.

Value: The value will be based on the event’s registration-fee (at the student-rate) as well as a pre-determined amount based on the location of the event.

Eligibility: no citizenship restrictions; award holders must be doctoral-stream students; registered full-time at the time of application and at the time of conference attendance; in good standing; an active participant. Applicants need not have received confirmation of their participation in the conference at the time of application.

Application: For more information and deadlines:
http://www.sgs.utoronto.ca/currentstudents/Pages/SGS-Conference-Grant.aspx

Selection Criteria: Preference will be given to applicants who are in the early stage of their academic program, have not previously attended a conference during their current program and/or who have
not previously received an SGS Conference Grant. The SGS Conference Grant is not intended to be the principal source of funding. Applicants are expected to seek funding from other sources, and must list other resources that will or may be used to support their conference attendance.

8. OTHER INFORMATION

The Department of Mathematics is located in the heart of the University of Toronto, which in turn is located in the heart of downtown Toronto. Students therefore have access to a wide range of facilities and services. A list appears below.

Facilities and Services

Library Facilities

The University of Toronto Library system is the 4th largest academic research library in North America. It contains over 4 million print volumes as well as a vast assortment of electronic resources. The Mathematical Sciences Library (MSL) is in the same building as the Mathematics Department. The majority of mathematics journals held by the University of Toronto are housed in the MSL, with some being held in the Gerstein Science Information Centre. The MSL’s collection also contains over 20,000 books. The MSL website includes an interface with the UofT catalogue that includes the collections of all the libraries on the St. George, Mississauga, and Scarborough campuses and includes links to online books, journals and abstract and indexing databases including MathSciNet. The MSL offers a wireless environment with study spaces for research. Each graduate student in mathematics receives a photocopying allowance. The Gerstein Science Information Centre also has a comprehensive collection of mathematics books up to 1998.

St. George T-Card Office
Koeffler Student Service Centre
214 College Street, Room 102
(Tel) 416-946-8047 │ tcard.office@utoronto.ca │ http://tcard.utoronto.ca/

- University of Toronto TCard is a photo ID smartcard which provides identification for academic purposes, student activities and services, facility access and a Library Card.

Mathematics Library
40 St. George Street, Room 6141
Toronto, Ontario M5S 3G3
(Tel) 416-978-8624 │ (Fax) 416-978-4107
mathlib@math.toronto.edu
http://www.library.utoronto.ca/math/

- Hours: M-F, 9 – 5; Summer hours: M-F, 9 – 4:30

Gerstein Science Information Centre
7 - 9 King’s College Circle
Toronto, Ontario M5S 1A5
Phone: 416-978-2280
Fax: 416-971-2848
ask.gerstein@utoronto.ca
http://www.library.utoronto.ca/gerstein
Computer Facilities

All faculty and graduate students can request accounts on the main departmental server and the departmental compute server. The main server, coxeter, is a six-core IBM x3630 M3 server with 32GB of RAM, and the compute server, sphere, is a twelve-core IBM x3630 M3 server with 64GB of RAM, both running Red Hat Enterprise Linux 6. These accounts give access to electronic mail facilities which are also remotely accessible via encrypted IMAP/Submission or webmail, to the internet including the ability to put a webpage on the departmental webserver, to many mathematical software packages (for example, Matlab, Mathematica, pari/gp, octave), to scientific and other graphics programs (most of the symbolic manipulators, gimp), to software compilers (supporting, for example, fortran77, fortran95, C, C++, java), to a rich mathematical software library, to mathematical typesetting programs (TeX, LaTeX), etc.

See http://www.math.toronto.edu/intro.html for a very brief introduction to the computing resources in the department. There is a public Computer Room (BA6200) in addition to machines in individual offices. University-managed wireless connectivity (the SSID is UofT) is available for most people in the department; you will need your UTORid for this. Please see http://www.math.utoronto.ca/cms/wireless-networking/ for more information.

Application forms for computer accounts on our systems are available from the Departmental Office (BA6290) and the Mathematics Graduate Office.

Housing

The university operates five graduate student residences-apartment complexes on or near the campus, ranging from unfurnished family apartments to the more conventional bed-and-board residences. In addition, the University Housing Service provides a listing of privately owned rooms, apartments and houses available for students to rent.

Students should keep in mind that accommodation could be expensive and limited, particularly in downtown Toronto. It is therefore advisable to make inquiries well in advance and to arrive in Toronto a few days prior to the start of term. Students can expect to pay anywhere between $500 to $1,000 per month on accommodation and from $300 to $500 per month on food, travel and household necessities.

University Housing Service
214 College Street, 1st Floor
Toronto, Ontario M5T 2Z9
(Tel) 416-978-8045 │ (Fax) 416-978-1616
housing.services@utoronto.ca
http://www.housing.utoronto.ca

Health Services

The University of Toronto Health Service offers medical services and referrals to private physicians for University of Toronto students. Most of these services are free of charge if you are covered under Ontario Health Coverage (OHIP), or the University Health Insurance Plan (UHIP) for visa students. OHIP application forms and information are available from the University Health Services. UHIP coverage for visa students is compulsory and is arranged during registration at the Centre for International Experience
Health & Wellness Centre
214 College Street, 2nd Floor
Toronto, Ontario M5T 2Z9
(Tel) 416-978-8030 | (Fax) 416-978-2089
Email: healthask@mail.studentlife.utoronto.ca
http://www.healthservice.utoronto.ca/
- Medical assistance for University of Toronto students
- Application forms for Ontario Health Coverage

Centre for International Experience
Cumberland House, 33 St. George Street
(Tel) 416-978-2564 | (Fax) 416-978-4090
http://cie.utoronto.ca/
- University Health Insurance Plan (UHIP) registration at Cumberland House

Students with Disabilities
Services and facilities for students with disabilities are available at the University of Toronto. The University of Toronto’s Accessibility Services facilitates the inclusion of students with hidden or obvious disabilities and health conditions into university life. Services are provided to students with a documented disability, be it physical, sensory, a learning disability or a mental health condition, temporary or long-term.

Accessibility Services
455 Spadina Ave., 4th Floor, Suite 400 (Just north of College Street) Toronto, Ontario, M5S 2G8
Voice: 416-978-8060
Fax: 416-978-8246
TTY: 416-978-1902
Email: accessibility.services@utoronto.ca
http://www.accessibility.utoronto.ca

International Students
The Centre for International Experience (CIE) offers many services to international students, including an orientation program in late August - early September, individual counselling whenever appropriate, and an English language program. In addition, the CIE contacts all foreign students once they have been accepted into the graduate program, to provide information and advice concerning immigration procedures (visa and student authorization forms), employment restrictions and authorization while in Canada, and other relevant matters.

Centre for International Experience
Cumberland House, 33 St. George Street, and Koffler Student Centre, Room 201, 214 College Street
(Tel) 416-978-2564 | (Fax) 416-978-4090
http://cie.utoronto.ca/
- Serves international students coming to U of T and domestic students looking to go abroad
- University Health Insurance Plan (UHIP) registration at Cumberland House
**Athletics & Recreation**

A wide range of athletic facilities are available within the university, including an arena and stadium, playing fields, swimming pools, squash, tennis, badminton, volleyball and basketball courts, running tracks, archery and golf ranges, fencing salons, exercise and wrestling rooms, dance studios, saunas, lockers and a sports store. Instruction courses, exercise classes and fitness testing are regularly offered, and there is an extensive intramural program with several levels of competition in more than 30 sports.

Other recreational activities and facilities are also available within the university, such as theatre, music, pubs, dances, art exhibitions, a wide range of clubs, debates lectures and seminars, reading rooms, cafeterias and chapels.

University of Toronto students also enjoy easy access (walking distance or only a few minutes by subway) to symphony concerts, theatres, ballet, operas, movies, restaurants and shopping.

**The Athletic Centre**
55 Harbord Street
Toronto, Ontario M5S 2W6
(Tel) 416-978-3437  |  (Fax) 416-978-6978
[www.athletics.utoronto.ca](http://www.athletics.utoronto.ca)

- Multi-use health and fitness facility
- Members of the Athletic Centre also enjoy access to the state-of-the-art facilities at the new [Varsity Centre](http://www.utoronto.ca), located at 299 Bloor Street West.
- All U of T students are automatically members of the Athletic Centre and Varsity Centre.

**Hart House**
7 Hart House Circle
Toronto, Ontario M5S 3H3
416-978-2452
inquiries@harthouse.ca
[http://www.harthouse.ca](http://www.harthouse.ca)

- University of Toronto centre for arts, culture and recreation

**Graduate Student Associations**

Every graduate student at the University of Toronto is automatically a member of the Graduate Student Union (GSU). Graduate students in the Department of Mathematics are also members of the Mathematical Graduate Students Association (MGSA). Between them, these associations sponsor many events every year, including parties, pubs, dances, outings and more serious endeavours such as seminars and lectures.

**Mathematics Graduate Student Union**
Department of Mathematics
40 St. George Street, Room 6290
[mgsa@math.utoronto.ca](mailto:mgsa@math.utoronto.ca)
The Graduate Students’ Union represents over 17,000 students studying in over 80 departments. It advocates for increased student representation, funding, and provided services such as health insurance, confidential advice, and a voice for the graduate student body on the various committees of the University.

Other Contacts and Sources of Information

Mathematics Graduate Office
Department of Mathematics
University of Toronto
40 St. George St., Room 6166
Toronto, Ontario M5S 2E4
(Tel) 416-978-7894 | (Fax) 416-978-4107
gradinfo@math.toronto.edu
http://www.math.utoronto.ca/cms/graduate-program/
- All matters relating to graduate studies in mathematics at the University of Toronto
- Office Hours: M-F, 9-4

School of Graduate Studies
University of Toronto
63 St. George Street
Toronto, Ontario
416-978-5369
416-978-4367 (Fax)
graduate information@utoronto.ca
http://www.sgs.utoronto.ca
- General information concerning graduate studies at the University of Toronto
- Services include confirmation of registration letters, confirmation of degree letters, legal status changes, legal name changes
- Office Hours: M-F, 10-4

Fees Department
Office of the Comptroller
University of Toronto
215 Huron Street, 3rd Floor
Toronto, Ontario M5S 1A1
416-978-2142
416-978-2610 (Fax)
fees@finance.utoronto.ca
www.fees.utoronto.ca

- Enquiries concerning fees
- Payment of fees

**Sexual Harassment Office**
University of Toronto
215 Huron – 6th floor, suite 603
416-978-3908
http://sho.utoronto.ca/

- Students are covered by the Sexual Harassment Policy while on university premises or carrying on a university-related activity. Complaints and requests for information are confidential.

**Human Resources Development Canada (HRDC)**
25 St. Clair Avenue East, 1st Floor or City Hall, 100 Queen Street West, 1st Floor
1-800-206-7218

- To obtain a Social Insurance Number (in person only). Office hours: Monday-Friday, 08:30-16:00
  Supporting documentation must be original, e.g. student authorization and an offer of employment letter
- Takes an average of 4 weeks to process
Algebra
1. Linear algebra. Students will be expected to have a good grounding in linear algebra, vector spaces, dual spaces, direct sum, linear transformations and matrices, determinants, eigenvectors, minimal polynomials, Jordan canonical form, Cayley-Hamilton theorem, symmetric, alternating and Hermitian forms, polar decomposition.
2. Group Theory. Isomorphism theorems, group actions, Jordan-Hölder theorem, Sylow theorems, direct and semidirect products, finitely generated abelian groups, simple groups, symmetric groups, linear groups, nilpotent and solvable groups, generators and relations.
4. Modules. Modules and algebras over a ring, tensor products, modules over a principal ideal domain, applications to linear algebra, structure of semisimple algebras, application to representation theory of finite groups.
5. Fields. Algebraic and transcendental extensions, normal and separable extensions, fundamental theorem of Galois theory, solution of equations by radicals.

No reference is provided for the linear algebra material.
References for the other material:
Dummit & Foote: *Abstract Algebra*, Chapters 1-14 (pp. 17-568).
Alperin & Bell: *Groups and Representations*, Chapter 2 (pp. 39-62), 5, 6 (pp. 107-178).

Complex Analysis
3. Conformal mapping, Riemann mapping theorem.

Note: The material in Ahlfors can largely be replaced by Chapters 10, 11, 12.1-12.6, and 14 of Rudin. But Ahlfors is the official syllabus for this material. The second edition of Ahlfors can be used if it is noted that Section 5.5 in the third edition is Section 5.4 in the second edition.)

Real Analysis
References:
1. Background: Royden, Chapters 1 and 2; Folland (Prologue).
2. Basic Measure Theory: Royden, Chapters 3 and 4, for the classical case on the real line (which contains all the basic ideas and essential difficulties), then Chapter 11, Sections 1-4, for the general abstract case; Folland, Chapters 1 and 2.
3. Differentiation: Royden, Chapter 5, for the classical case, then Chapter 11, Sections 5 and 6 for the general case; Folland, Chapter 3 (For differentiation on $\mathbb{R}^n$ one can restrict the attention to the one dimensional case, which contains all the basic ideas and essential difficulties.)
4. Basic Functional Analysis: Royden, Chapter 10, Sections 1,2,3,4,8; Folland, Chapter 5, Sections
1. Local differential geometry: the differential, the inverse function theorem, smooth manifolds, the tangent space, immersions and submersions, regular points, transversality, Sard’s theorem, the Whitney embedding theorem, smooth approximation, tubular neighborhoods, the Brouwer fixed point theorem.

2. Differential forms: exterior algebra, forms, pullbacks, d, integration, Stokes’ theorem, div grad curl and all, Lagrange’s equation and Maxwell’s equations, homotopies and Poincare’s lemma, linking numbers.

3. Fundamental groups: paths and homotopies, the fundamental group, coverings and the fundamental group of the circle, Van-Kampen’s theorem, the general theory of covering spaces.

4. Homology: simplices and boundaries, prisms and homotopies, abstract nonsense and diagram chasing, axiomatics, degrees, CW and cellular homology, subdivision and excision, the generalized Jordan curve theorem, salad bowls and Borsuk-Ulam, cohomology and de-Rham’s theorem, products.

Second-Order: gradient flows, linearization around special solutions, vanishing viscosity limit of Burger’s equation.

6) Calculus of variations: direct methods, convexity, weak-* continuity and compactness, first and second variations, Euler-Lagrange equation, Lagrange multipliers, constraints

References:
V. I. Arnold: Ordinary differential equations 1992
G.B. Folland: Introduction to partial differential equations 1995
W. Hurewicz: Lectures on ordinary differential equations 1990

APPENDIX B: APPLIED MATH COMPREHENSIVE EXAMINATION

A student planning to specialize in applied mathematics must pass three comprehensive exams, at least two of which are a general written exam (algebra, analysis (real and complex), topology, or partial differential equations (PDE I and PDE II), Probability).

Other exams may be offered upon request.

APPENDIX C: PH.D. DEGREES CONFERRED FROM 2013-2017

2013
AMIR-KHOSRAVI, Zavosh (Arithmetic Geometry) Moduli of Abelian Schemes and Serre’s Tensor Construction
ANGHEL, Catalina (Number Theory) The self-power map and its image modulo a prime
BARTOSOVA, Dana (Set Theory) Topological dynamics in the language of near ultrafilters and automorphism groups of $\omega$-homogeneous structures
CHEN, Shibing (Analysis of PDE) Convex solutions to the power-of-mean curvature flow, conformally invariant inequalities and regularity results in some applications of optimal transportation
DOTTERER, Dominic (Metric Geometry) The (co)isoperimetric problem in (random) polyhedra
LAPTYEVA, Nataliya (Number Theory) A Variant of Lehmer’s Conjecture in the CM Case
LI, Travis (Differential Geometry) Constructions of Lie Groupoids
MOURTADA, Mariam (Number Theory) The distribution of values of logarithmic derivatives of real $L$-functions
PYM, Brent (Algebraic Geometry) Poisson structures and Lie algebroids in complex geometry
SMITH, Kathleen (Symplectic Geometry and Topology) Connectivity and Convexity Properties of the Momentum Map for Group Actions on Hilbert Manifolds
WALLS, Patrick (Number Theory) The Theta Correspondence and Periods of Automorphic Forms

2014
BRODSKY, Ari (Set Theory) A Theory of Stationary Trees and the Balanced Baumgartner-Hajnal-Todorcevic Theorem for Trees
BURKO, Robert (Number Theory) Computing the Zeta Function of Two Classes of Singular Curves
CAVIEDES CASTRO, Alexander (Symplectic Geometry) Upper bounds for the Gromov width of coadjoint orbits of compact Lie groups
CHAMBERS, Gregory (Metric and Riemannian Geometry) Optimal homotopies of curves on surfaces
DONNELLY, Ryan (Stochastic Control and High Frequency Trading) Effects of Ambiguity Aversion on High Frequency Trading
FISHER, Jonathan (Symplectic and algebraic geometry, group actions) The Topology and Geometry of Hyperkähler Quotients
HART, Eric (Probability) Hölder Continuity of the Integrated Density of States in the One-Dimensional Anderson Model
HANNIGAN-DALEY, Bradley (Algebraic Geometry) Hypertoric varieties and wall-crossing
MAYOST, Daniel (Differential Geometry) Applications of the signed distance function to surface geometry
MORGAN, Stephen (Representation Theory) Quantum Hamiltonian reduction of W-algebras and category $\mathcal{O}$
ROBINSON, Patrick (Poisson Geometry) The Classification of Dirac Homogeneous Spaces
VENA, Lluis (Combinatorics) The removal property for linear configurations in compact abelian groups
WATSON, Nicola (Operator Algebras) On the Structure of Nuclear C*-algebras with Real Rank Zero
XU, Bin (Number Theory) Endoscopic Classification of Representations of GSp(2n) and GSO(2n)

2015

ANGELOPOULOS, Ioannis (Partial Differential Equations) Nonlinear waves on extremal black hole spacetimes
CHOW, Aaron (Number Theory) Applications of Fourier coefficients of modular forms
CHTERENTAL, Oleg (Virtual Braids) Virtual Braids and Virtual Curve Diagrams
DAHL, Alexander (Analytic Number Theory) Subconvexity for a double Dirichlet series and non-vanishing of L-functions
EAGLE, Christopher (Set Theory) Topological Aspects of Real-Valued Logic
FENG, Jackson (Probability) Rescaled Directed Random Polymer in Random Environment in Dimension 1 + 2
GEORGE, William (Number Theory) Lifting Problems, Cross-fiberedness, and Diffusive Properties on Elliptic Surfaces
GUDIM, Mikhail (Homological algebra) Equivariant Modules
HANSON, Brandon (Analytic Number Theory, Combinatorics) Character Sum Estimates in Finite Fields and Applications
LIOKUMOVICH, Yevgeniy (Riemannian geometry) Sweepouts of Riemannian surfaces
PAVLOV, Alexander (Homological algebra, algebraic geometry) Betti Tables of Maximal Cohen-Macaulay Modules over the Cones of Elliptic Normal Curves
PAWLIUK, Micheal (Set Theory) Amenability and Unique Ergodicity of the Automorphism Groups of all Countable Homogeneous Directed Graphs
RAHMAN, Mustazee (Probability) Sub-optimality of local algorithms on sparse random graphs
ROWE, Daniel (Geometric Representation Theory) Lusztig Slices in the Affine Grassmannian and Nilpotent Matrices
SOUKUP, Daniel (Set Theory) Colouring problems of Erdős and Rado on infinite graphs

2016

BAZETT, Trefor (Equivariant K-theory) The equivariant K-theory of commuting 2-tuples in SU(2)
CROOKS, Peter (Lie Theory and Equivariant Geometry) The Equivariant Geometry of Nilpotent Orbits and Associated Varieties
ESKANDARI, Payman (Number theory) Algebraic Cycles, Fundamental Group of a Punctured Curve, and Applications in Arithmetic
FOURNODAVLOS, Grigorios (Geometric Analysis) Stability of singularities in geometric evolutionary PDE
GLYNN-ADEY, Parker (Quantitative geometry) Width, Ricci Curvature, and Bisecting Surfaces
HALACHEVA, Iva (Knot Theory, Representation Theory) Alexander-type invariants of tangles, Skew Howe duality for crystals and the cactus group
HOLDEN, Tyler (Geometry) Convexity and Cohomology of the Based Loop Group
KOTOWSKI, Marcin (Probability) Random Schroedinger operators with connections to spectral properties of groups and directed polymers
KOTOWSKI, Michal (Probability) Return probabilities on groups and large deviations for permuton processes
LISHAK, Boris (Quantitative geometry) Balanced Presentations of the Trivial Group and 4-dimensional Geometry
LIVINSKYI, Ivan (Number Theory) On the integrals of the Kudla-Millson theta series
MOUSAVIDEHSHIKH, Ali (Homological algebra) Constructing endomorphism rings of large finite global dimension
STEWART, Andrew (Probability, Random Walks on Groups) On the scaling limit of the range of a random walk bridge on regular trees
THOMSON, Kyle (PDEs) Dynamics of Superconducting Interfaces
THIBAULT, Louis-Philippe (Representation Theory of Algebras)
VAUGHAN, Jennifer (Geometric quantization) Quantumorphisms and Quantized Energy Levels for Metaplectic-c Quantization
VOLTZ, Jeremy (Probability Theory) Two results on Asymptotic Behaviour of Random Walks in Random Environment
WEEKES, Alexander (Representation theory) Highest weights for truncated shifted Yangians

2017

BALEHOWSKY, Tracey, (Geometric inverse problems) Recovering a Riemannian Metric from Knowledge of the Areas of Properly-Embedded, Area-Minimizing Surfaces
KLYS, Jack (Number Theory) Statistics of class groups and related topics
LANE, Jeremy (Symplectic geometry) On the topology of collective integrable systems
LOIZIDES, Yiannis (Symplectic geometry) Norm-square localization for Hamiltonian LG-spaces
LUK, Kevin (Algebraic geometry) Logarithmic algebroids and line bundles and gerbes
LUTLEY, James (Diagonal maps between RFD algebras) The Structure of Diagonally Constructed ASH Algebras
MRACEK, James (Symplectic geometry) Applications of algebraic microlocal analysis in symplectic geometry and representation theory
REISS, David (PDEs) Global Well-Posedness and Scattering Of Besov Data For the Energy-Critical Nonlinear Schrödinger Equation by
SCHACHTER, Benjamin (Optimal transportation, calculus of variations, PDEs) An Eulerian Approach to Optimal Transport with Applications to the Otto Calculus
SMITH, Jerrod (Representation theory of p-adic groups) Construction of relative discrete series representations for p-adic GLn
YANG, Jonguk (Complex dynamics and renormalization) Applications of Renormalization to Irrationally Indifferent Complex Dynamics
ZAMAN, Asif (Analytic number theory) Analytic estimates for the Chebotarev Density Theorem and their applications
The Fields Institute for Research in Mathematical Sciences was created in November 1991 with major funding from the Province of Ontario, the Natural Sciences and Engineering Research Council of Canada, and McMaster University, the University of Toronto, and the University of Waterloo. In September 1996 it moved from its temporary location in Waterloo to its permanent site, a new building located at 222 College Street in Toronto, next to the University of Toronto Bookstore. In addition to the three principal sponsoring universities about twenty universities across Canada are affiliated with it.

The mandate of the Fields Institute specifically includes the training of graduate students and this function is given a higher profile than at other similar mathematics research institutes. All major programs run at the institution contain graduate courses which students at any university affiliated with the institute may take for credit and the organizers of major programs are expected to set aside some money to make it possible for graduate students to participate in their program.