University of Toronto
Major Modification Proposal:
New Field or Concentration Within an Existing Graduate Program

This template should be used to bring forward all proposals for new fields or concentrations in existing graduate programs for governance approval under the University of Toronto’s Quality Assurance Process.

A field or concentration within a graduate program refers to an area of specialization or focus that is related to the demonstrable and collective strengths of the program’s Faculty. Graduate programs are not required to have fields or concentrations in order to highlight an area of strength within a program.

The two terms are used interchangeably but one should be used consistently in the context of a specific program. In establishing fields or concentrations, select whichever term resonates most in your context.

<table>
<thead>
<tr>
<th>Program:</th>
<th>Master of Science in Applied Computing (MScAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing fields or concentrations:</td>
<td>Data Science</td>
</tr>
<tr>
<td>Proposed new field or concentration:</td>
<td>Applied Mathematics</td>
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<tr>
<td>specify what level program this will apply to; i.e., master’s, doctoral or both.</td>
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<tr>
<td>Unit (if applicable):</td>
<td>Computer Science and Mathematics</td>
</tr>
<tr>
<td>Faculty/academic division:</td>
<td>Arts &amp; Science</td>
</tr>
<tr>
<td>Dean’s Office contact:</td>
<td>Academic: Dwayne Benjamin, Vice-Dean Graduate Staff: Sharon Kelly, Research and Graduate Academic Planning Coordinator</td>
</tr>
</tbody>
</table>
We propose a new concentration, Applied Mathematics, within the current Master of Science in Applied Computing [MScAC]. The MScAC is offered through the Department of Computer Science. The proposed concentration is offered jointly by the Departments of Mathematics and Computer Science.

In 2017, a concentration in Data Science [DS] was introduced as a joint offering between the Departments of Computer Science and Department of Statistical Sciences. Interest from industry and students for the Data Science concentration has already exceeded the most optimistic projections. One effect of introducing the DS concentration was a jump in applications by students with strong mathematical training. We are also witnessing companies coming to the program with a range of problems requiring mathematical sophistication.

These efforts are critical to the research and training missions of both departments and in recognition of the increasing importance of the interface between these two disciplines. The opportunities for applying advanced numerical and modelling techniques to problems arising in a non-academic setting is immense. These efforts are also aligned with the University’s ambitions in Computational and Mathematical Science.

The past fifty years has seen a major shift towards quantitative techniques across social and economic sectors. The genomic revolution, quantum computing, development of sophisticated financial instruments, new advanced materials, and medical imaging amongst others are all premised on applying advanced mathematical techniques. This has driven
unexpected demand for linkages between mathematical scientists and industry, government, hospitals, etc. At the same time, students graduating with a deep understanding of these techniques are highly sought after by industry.

The proposed concentration in Applied Mathematics builds on the current MScAC infrastructure by bringing in expertise from Mathematics, to meet:

1. Current student needs for master’s level education in mathematical reasoning and modelling;
2. Industrial demand for mathematically competent interns;
3. Student demand for an internship experience utilizing mathematical modelling; and
4. U of T’s burgeoning research emphasis in Mathematical Science.

Both needs and demand are acutely evident within the current MScAC program, with some students in previous years’ cohorts cobbling together courses to try to create an ad-hoc Applied Mathematics concentration.

Effective Date

The first cohort eligible for enrolment in this concentration will be admitted September 1, 2019.

Academic Rationale

- Identification of existing fields or concentrations.
- Description of the field or concentration (its intellectual focus, etc.) and its relationship to existing fields or concentrations.
- Address how the proposed field or concentration relates to the current state of the discipline or area of study. Identify pedagogical and other issues giving rise to the creation of this program. Where appropriate, speak to changes in the area of study or student needs that may have given rise to this development.
- Appropriateness and consistency of the field or concentration name.
- Distinctiveness.
- Identify any distinctive or innovative aspects of the proposed field or concentration.
- To what extent is what is being proposed “the norm”? As appropriate, speak to similar offerings elsewhere at the University of Toronto or at other universities.
As a discipline, Applied Mathematics underlies the advances and insights of quantitative scientific domains. The techniques developed by applied mathematicians have proven to be invaluable for work in scientific computation, artificial intelligence, computer science, medical imaging (registration and segmentation, to name but two), data compression and inference (compressive sensing, and wavelets), quantum computing, modern financial instrument pricing and modelling, and a host of others too numerous to mention. A proper training in Applied Mathematics is necessary for competent researchers and practitioners in these disciplines.

An expert in Applied Mathematics has the training not only in mathematical reasoning and modelling but also practical experience in scientific or industrial collaboration. The proposed concentration in Applied Mathematics is unique to the University of Toronto and would be without peer in Canada due to the strength of expertise in the Departments of Computer Science and Mathematics, as well as the unrivalled wealth of potential collaborators across campus and within the Greater Toronto Area. As a new concentration in the current MScAC program, it is characterized by the involvement of another unit within the Faculty of Arts & Science that is responsible for a significant portion of the curriculum, as well as a reorientation in the current emphasis of the MScAC. The concentration bears the name of the related discipline Applied Mathematics. The concentration couples interest from students for training in more mathematical topics with the growing demand for increasingly more mathematically sophisticated roles in industry. This calls for a customized curricula and training that does not alter the general MScAC program.

Currently the Mathematics program does not offer a disciplinary focus in computer science. Ongoing dialogue between the Departments of Computer Science and Mathematics has renewed shared commitments within each program to the common uses and transferable skills the respective programs have excelled in providing their students. The structure and outcomes of the MScAC can readily accommodate a concentration in Applied Mathematics, and the curricular demand for training in both computer science and mathematics is best met through a computer science concentration offered in the mathematics program.

Finally, the massive growth in complex data encountered by practitioners and researchers has been accompanied by an increasing demand for very specialized expertise lying at the interface of the computational and mathematical sciences. This need is acutely felt in machine learning and artificial intelligence applications, especially as models used require increasingly advanced mathematical knowledge by practitioners in order to be interpretable. The continuing integration of the two disciplines is certain to become more pronounced as advanced algorithms become more widely adopted. No professional in the quantitative sector can possibly hope to make a meaningful contribution in collaboration or research without a serious mathematical and computational skill-set. Conversely, computer scientists need far more in-depth mathematical training to fully understand the behaviour and impact of the tools and algorithms they discover. Our expectation is that the proposed concentration will serve to meet the above demand, further integrate the activity of the two partnering Departments, elevate the quality of training within both units particularly the M.Sc. within
Mathematics and the MScAC within CS, and align with the University’s ambitions in and commitments to Computational and Mathematical Sciences.

Need and Demand

- Provide a brief description of the need and demand for the proposed field or concentration focusing, as appropriate, on student interest, societal need, employment opportunities for prospective graduates, accreditation requirements, etc.

Large-scale, highly complex data has become a ubiquitous feature of practitioners in modern quantitative disciplines. Designing, interpreting and utilizing the sophisticated algorithms and mathematical models needed to manage complex data is a skill necessary to keep pace with the increasing opportunities for employment in many sectors; particularly in bioinformatics, advanced financial modelling, medical imaging, operational optimization, quantum computation, and large scale numerical scientific computing.

Student interest in Applied Mathematics has been the inevitable result of the increased demand for highly competent quantitative roles, and industrial demand for Applied Mathematicians is currently evident in the MScAC program. The following is a partial list of employers that have engaged our students in highly technical mathematical internships: Addictive Mobility, SmartFinance, Rakuten Kobo, NeuRecall, Geotab, Google, Ipsos, Wattpad, VerticalScope, Amazon, Scotiabank, PwC, and Facebook.

As sophisticated models and algorithms become increasingly adopted within a growing list of industrial and scientific communities, the need for qualified, mathematically trained personnel becomes even more acute. Our proposed concentration in Applied Mathematics will provide an ongoing supply of competitive applicants for a wide range of industrial and scientific opportunities.

Table 1: Graduate Enrolment Projections*

<table>
<thead>
<tr>
<th>Year in Program</th>
<th>Academic Year 2019-20</th>
<th>Academic Year 2020-21</th>
<th>Academic Year 2021-22</th>
<th>Academic Year 2022-23</th>
<th>Academic Year 2023-24*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total #</td>
<td># in Concentration</td>
<td>Total #</td>
<td># in Conc.</td>
<td>Total #</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>75</td>
<td>5</td>
<td>90</td>
<td>105</td>
</tr>
</tbody>
</table>

Developed by the Office of the Vice-Provost, Academic Programs

Template updated on March 7, 2017

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Major Modification Proposal: New Field or Concentration Within an Existing Graduate Program

<table>
<thead>
<tr>
<th></th>
<th>60</th>
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<tbody>
<tr>
<td>2</td>
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<td>60</td>
<td>5</td>
<td>75</td>
<td>5</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>115</td>
<td>5</td>
<td>135</td>
<td>10</td>
<td>165</td>
<td>15</td>
<td>195</td>
<td>20</td>
</tr>
</tbody>
</table>

*Steady state projected in 2023-24.

- Please adjust the table as necessary. Please show total registration in the program and indicate whether the addition of the new field or concentration will result in an overall increase in the total number of students or will be accommodated within the existing number of spaces. In either instance, please show the relative proportion of spaces in the proposed field or concentration.

- Below please provide any relevant information or comments on the enrolment projections above (e.g., relationship of field or concentration to existing field or concentration, etc.)

These projections are commensurate with known demand. For example, the financial technology (FinTech) sector in Toronto has seen a rapid increase in demand for mathematically trained data scientists and quantitative analysts in recent years. FinTech is far from the only source of demand for quantitative industry positions, it is simply the area of most significant recent growth. Over the last five years, more than half of MScAC internships involved quantitative, mathematically challenging projects.

Student demand for Mathematics, Applied Mathematics, Data Science, Machine Learning, and Artificial Intelligence courses and internships also continues to increase.

The enrolment in this concentration is already accounted for in FAS projections and represents a reallocation of projected enrolments from the MScAC general concentration here. Specifically, these enrolments will not come out of projections from the existing Data Science concentration with Department of Statistical Sciences, but rather from the undifferentiated program.

**Admission Requirements**

- Comment on the relationship of the admission requirements for the field or concentration to those of the parent program.

- If the same, describe the program admission requirements.

- If different, describe the field or concentration admission requirements; indicate how they are different from those of the parent program, and provide a rationale for the difference in

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relation to the focus and learning outcomes of the field or concentration; i.e., how are these admissions requirements suitable to help support the success of students.

- How will these be administered?

Students entering the Applied Mathematics Concentration of the MScAC program at the University of Toronto will register in the Department of Computer Science. The minimum admission requirements listed below are consistent with those criteria in Department of Mathematics MSc program, and are very similar to the Department of Computer Science’s MScAC program.

Minimum Admission Requirements

Applicants are admitted under the General Regulations of the School of Graduate Studies. Applicants must also satisfy the Department of Computer Science’s additional admission requirements stated below.

Admission to the MScAC program is on a competitive basis. For an applicant to be considered in the Applied Mathematics concentration, they must have:

- An appropriate Bachelor’s degree from a recognized university in a related area such as applied mathematics, mathematics, physics, computational mathematics, statistics, computer science, or any discipline where there is a significant quantitative and/or mathematical component. The completed bachelor’s degree must include significant exposure to advanced mathematics, statistics, and computer science, including coursework in advanced and multivariate calculus (preferably analysis), linear algebra, probability and statistics, programming languages, and general computational methods.

- A minimum average grade of B+ or equivalent over the final two years of undergraduate studies.

- Applicants whose primary language is not English and who have graduated from a university where the primary language of instruction is not English must achieve a Test of English as a Foreign Language (TOEFL) score of at least 580 on the paper-based test and 4 on the Test of Written English (TWE); 93/120 on the Internet-based test and 22/30 on the writing and speaking sections.

- Three letters of reference from faculty and/or employers with preference for at least one such letter from a faculty member in Mathematics or Applied Mathematics.

- A statement of purpose (limited to 500 words) explaining their interest in applied mathematics and objectives for the program.

- Applicants must indicate a preference for a concentration in Applied Mathematics in their application. Admission is competitive, and students who are admitted into...
the MScAc program are not automatically admitted to this concentration upon request.

As noted in the minimum admission requirements, admission to the Applied Mathematics Concentration is competitive. Achievement of the minimum standards does not guarantee admission into the program. Those accepted will normally have achieved a standing considerably higher than the minimum B+ standing or have demonstrated exceptional ability through appropriate workplace experience.

Program Requirements

- Describe the requirements of the field or concentration. Please comment on the relationship of the requirements of the field or concentration to those for the program in general and any other fields or concentrations.

- Provide, as an appendix, proposed calendar copy (with all changes tracked) including the specific program requirements, required courses, electives and prerequisites.

- Provide as an appendix, where appropriate:
The program requirements for the proposed Applied Mathematics concentration will be:

Completion of 3.0 full course equivalents including:

- 1.0 FCE chosen from the MAT1000-level or higher. This may include those courses cross-listed as APM400 – level.
- 1.0 FCE chosen from the Computer Science (CSC course designator) graduate course listings.
- 1.0 FCEs required courses in technical communications (CSC 2701H) and technical entrepreneurship (CSC 2702H)
- Students must also complete an eight-month industrial research internship. The internship CSC 2703H (3.5 FCEs) is coordinated by the computer science department, and evaluated on a pass/fail basis by the department where the student receives academic supervision.
- Students in the AM concentration may choose a supervisor from either the Department of Mathematics or the Department of Computer Science. It is also possible for a joint supervision of faculty members from both departments.

The Applied Mathematics concentration program requirements follow the structure of the existing MScAC program. The existing program and new concentration are designed as a 16-month (4 session, F/W/S/F) full-time program comprised of 4 half courses (2.0 FCEs) that will be completed in 8-months (2 sessions), 2 required courses in technical communications and entrepreneurship (1.0 FCE) and an 8-month (2 session) industrial internship (3.5 FCE).

Students in the new Applied Mathematic concentration, like those in the general MScAC program, follow a course of study that is fully integrated; course projects and assignments will be designed to integrate the material learned from a variety of the courses and to utilize it in a practical context. Excellent communication and presentation skills will be emphasized in both the oral and written components of the projects and assignments. The program contains an 8-month internship component from May – December. The students will enter the internship immediately after coursework is completed at the end of the Winter term.

The required course work can be completed during the regular academic year. The course load of two half courses per session is identical to that of the current MScAC program in the Department of Computer Science.

In addition to the 4 half courses taken during the first 2 sessions, two specialized half courses (in Technical Communication and in Technical Entrepreneurship) are required. One of these courses is taken during the first eight months of the student’s term, while the other is taken during the eight-month internship period.

Whereas the Province’s Quality Assurance Framework requires that students complete a minimum of 2/3 courses at the graduate level, the University of Toronto requires graduate
students to complete all of their course requirements from amongst graduate level courses. This proposed Applied Mathematics Concentration complies with this requirement.

The Applied Mathematics concentration does not require the creation of any new courses at the graduate level. Students enrolled in the Applied Mathematics concentration will select existing courses from the two departments, Mathematics and Computer Science, and receive approval of their choices from each graduate unit and/or the director of the program.

Among the total 2.0 FCEs, one FCE will come from the MAT 1000-level or higher. The other 1.0 FCE will be selected from the CSC graduate course listings.

Within the MScAC program, support for establishing and maintaining industrial partners for internships is key to attracting students. The required internship provides a critical experiential learning component for industrial research, and helps students improve their communication skills. Students will not only gain practical experience in knowledge and technology transfer, but will also have access to well-trained professional support staff in their host company to realize their vision and make further connections in industry.

Our current relationship with Mitacs indicates that internships under the proposed concentration should qualify for partial funding under the Mitacs Accelerate program, which would offset $10,000 of the employer’s cost (the current average total compensation per student is $61,000 over eight months). The proposed AM concentration would make interns even more attractive and make this opportunity consistent with the current MScAC program.

For academic supervision, students in the AM concentration may choose a supervisor from either Department of Mathematics or Department of Computer Science faculty. It is also possible for a joint supervision of faculty members from both departments. The selection of an appropriate academic supervisor is facilitated by the program director once the student has accepted a qualifying internship placement.

All students in the MScAC, including students in the new concentration, receive individualized advising by MScAC personnel to ensure that they select courses that a) meet the program requirements, including any requirements specific to the concentration; b) have sufficient academic preparation for each course; and c) support their professional goals.

Students currently completing the general requirements for the MScAC as of September 2019 will be allowed to opt-in to the new concentration if they are eligible.

Please see Appendix A for the proposed calendar entry. Please see Appendix B for a list of suggested course numbers and titles. Note that these are existing courses offered by the participating departments, and specifically that none of these courses were created as a result of this proposed concentration.
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Degree-Level Expectations (DLEs), Program Learning Outcomes and Program Structure

- Clearly outline the learning outcomes as they relate to the proposed field or concentration, underlining where these are similar to or different from those for existing fields or concentrations. Indicate the means by which students will satisfy the relevant DLEs.
- Demonstrate the clarity and appropriateness of the program’s requirements and associated learning outcomes in addressing the institution’s DLEs

Table 1: Master’s DLEs

<table>
<thead>
<tr>
<th>MASTER’S DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents (OCAV) DLEs)</th>
<th>MASTER’S PROGRAM LEARNING OBJECTIVES AND OUTCOMES</th>
<th>HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXPECTATIONS: This Applied Mathematics (AM) concentration in the Master of Science in Applied Computing is awarded to students who have demonstrated:</td>
<td></td>
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</tr>
<tr>
<td>1. Depth and Breadth of Knowledge</td>
<td>Depth and breadth of knowledge is understood in the MScAC program as the ability to explore, manipulate, and visualize large-scale complex massive data. This is reflected in students who are able to: Use advanced problem solving skills utilizing appropriate computational tools. Perform deep quantitative analysis of a given problem across a variety of domains. Use abstract reasoning and demonstrable critical and logical thinking.</td>
<td>The program design of the Applied Mathematics concentration will support students to: assimilate new mathematical concepts and apply these to related disciplines such as in the physical and biological sciences; form, assimilate and distill complex mathematical models into informed decisions; and have the ability to solve problems utilizing a cross-section of mathematical and computational tools including: AI, algebra, analysis, combinatorics, data analytics, probability and statistics, systems, numerical analysis, and visualization. The program design and requirement elements that ensure these outcomes for depth and breadth of knowledge are from a T-shaped breadth and depth requirement that requires students undertake 1.5 FCE in three different methodological areas with an additional 0.5 FCS in one of those three breadth areas. These breadth areas include: Analysis and computation in discrete models</td>
</tr>
<tr>
<td>MASTER’S DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents (OCAV) DLEs)</td>
<td>MASTER’S PROGRAM LEARNING OBJECTIVES AND OUTCOMES</td>
<td>HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES</td>
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<tr>
<td>2. Research and Scholarship</td>
<td>Research and Scholarship is defined in the MScAC as the ability to abstract information. This is reflected in students who are able to: Apply quantitative techniques to produce effective designs and solutions to a given problem. Identify, analyze, and synthesize scholarly literature relevant to the problem at hand. Formulate hypotheses, and test these against given data. Create, review, validate, and refine quantitative models to validate hypothesis.</td>
<td>In achieving these learning outcomes, students in the Applied Mathematics concentration will be able to 1) define and describe a variety of mathematical models and their applications, 2) formulate mathematical models, spanning existing techniques and algorithms, which are tailored to new problems and applications. These learning outcomes are achieved through a number of advanced research-level graduate courses from which students may choose. In particular, 1.0 FCE are chosen from the MAT1000-level or higher and 1.0 FCE chosen from the Computer Science (CSC course designator) graduate course listings. Relevant courses could include: MAT1060- Partial Differential Equations I MAT1061 – Partial Differential Equations II MAT1302/APM461 – Combinatorial Methods MAT1304/CSC2429 – Topics in Combinatorics: Circuit Complexity MAT1508/APM446 – Techniques of Applied Mathematics: Applied Nonlinear Equations MAT1509 – Mathematical and Computational Linguistics MAT1525 – Topics in Inverse Problems and Image Analysis MAT1750 – Computational Mathematics: Numerical Methods</td>
</tr>
<tr>
<td>A conceptual understanding and methodological competence that</td>
<td></td>
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<tr>
<td>i) Enables a working comprehension of how established techniques of research and inquiry are used to create and interpret knowledge in the discipline;</td>
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<tr>
<td>ii) Enables a critical evaluation of current research and advanced research and scholarship in the discipline or area of professional competence; and</td>
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<tr>
<td>iii) Enables a treatment of complex issues and judgments based on established principles and techniques; and, on the basis of that competence, has shown at least one of the following: i) The development and support of a sustained argument in written form; or ii) Originality</td>
<td></td>
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</table>
### 3. Level of Application of Knowledge

Competence in the research process by applying an existing body of knowledge in the critical analysis of a new question or of a specific problem or issue in a new setting.

<table>
<thead>
<tr>
<th>Application of knowledge in the MScAC is defined as the ability for systematic inquiry involving the practical application of quantitative techniques in a professional setting (company site, hospital, etc) during an applied research internship. This is reflected in students who are able to: Demonstrate competence in utilizing existing bodies of knowledge in the critical analysis of a new question or of a specific problem or issue in a new setting.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students in the Applied Mathematics concentration will demonstrate expertise in mathematical and computational modelling and mathematical reasoning, critically and comprehensively assess problems arising from a variety of application contexts, and provide quantitative solutions to a new question or a specific problem in a new setting, with mathematical, computational and/or statistical thinking and reasoning. The application of research knowledge is assured through an industrial research internship. These internships are carefully chosen to ensure students are presented with...</td>
</tr>
</tbody>
</table>
### MASTER’S DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents (OCAV) DLEs)

#### MASTER’S PROGRAM LEARNING OBJECTIVES AND OUTCOMES

- **Problem or issue in a new setting.**
  - Deploy advanced theories, knowledge, methodologies, and techniques for a specific, often stated, business or client-driven challenge.
  - Showcase an ability to take unstructured problems and deploy empirical methodologies.

- **Professional Capacity/Autonomy**
  - The qualities and transferable skills necessary for employment requiring i) The exercise of initiative and of personal responsibility and accountability; and ii) Decision-making in complex situations;
  - The intellectual independence required for continuing professional development;
  - The ethical behaviour consistent with academic integrity and the use of appropriate guidelines and procedures for responsible conduct of research; and

#### HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES

- **Professional Capacity/Autonomy** in the MScAC program is defined as the qualities and transferable skills necessary for employment requiring: the exercise of initiative and of personal responsibility and accountability; decision-making in complex situations; the intellectual independence required for continuing professional development; the ethical behaviour consistent with academic integrity and the use of appropriate guidelines and procedures for responsible conduct of research; and the ability to appreciate the broader implications of applying knowledge to particular contexts.

  This is reflected in students who are able to:
  - Prepare written reports and deliver oral presentations to expert (quantitative teams) and
  - Internship research outcomes are assessed on the ability of the student to apply advanced knowledge of mathematical modelling to the real-world problem in the industrial setting.

- **Industrial Research Internship:**
  - The exploration of new or specific problems is coupled with the students’ quantitative skills and statistical rationale, with the aim of solving practical issues in an environment of complex and/or massive datasets.

  In addition, as outlined in section 6, there is a special course on technical entrepreneurship and business; CSC2702 – Technical Entrepreneurship. This is a required course.

  Students attend regularly scheduled meetings with both their academic and industrial supervisors and, at the industry site, with a broader team.

  Student present their research findings to both their supervisors in a research report that is assessed for their ability to apply knowledge in a new and creative manner, for their intellectual independence, and their ability to abstract their own work into a broader setting.
<table>
<thead>
<tr>
<th>MASTER’S DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice Presidents (OCAV) DLEs)</th>
<th>MASTER’S PROGRAM LEARNING OBJECTIVES AND OUTCOMES</th>
<th>HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>d. The ability to appreciate the broader implications of applying knowledge to particular contexts.</td>
<td>non-expert audiences (upper management) Provide a holistic perspective on advanced problem solving utilizing quantitative techniques in industry problem solving in a real-world setting.</td>
<td></td>
</tr>
</tbody>
</table>

5. Level of Communications Skills
The ability to communicate ideas, issues and conclusions clearly.

Students in the MScAC program must showcase their ability to communicate ideas, issues and conclusions clearly.

This is reflected in students who are able to:
- Construct a credible argument and present it in appropriate formats
- Construct detailed research reports and executive summaries
- Deliver professional presentations to expert (quantitative teams) and non-expert audiences (upper management)

The program design and requirement elements that ensure these student outcomes are:

- The required written report on the internship experience, which is designed for students to connect their course work with their industrial experience.
- Students make oral presentation in front of faculty, industry experts and other students in the program. They must discuss and critically assess their success at applying their academic knowledge to specific problems they encountered in their internship.
- In addition, as outlined in section 6, there is a special course on technical communications skills; CSC2701 – Communication for Computer Scientists. This is a required course.
Assessment of Teaching and Learning

Please describe the methods of evaluation for the various program requirements as they relate to the proposed field or concentration.

Describe how the methods for assessing student achievement are appropriate and effective relative to established program learning outcomes and DLEs (in other words, how will faculty be able to determine whether students have learned and can do what we expect them to by the end of the program).

How will the program document and demonstrate the level of performance of students consistent with the University’s DLEs?

Student performance in the program will be assessed through a variety of methods including reports, presentations, assignments, case studies, and exams. Students will receive letter grades for their performance in all courses except that CR/NCR is given for their written and oral reports on industrial internship.

<table>
<thead>
<tr>
<th>Teaching and Learning Outcomes</th>
<th>Assignments</th>
<th>Projects</th>
<th>Exam</th>
<th>Presentations</th>
<th>Internships</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Depth and Breadth of Knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excel in the chosen mathematics graduate course offerings</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display expertise in mathematical methods and constructing mathematical models</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Display competence in describing numerical data in a quantitative, mathematical manner</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Provide justification for reasonableness of results of computational models based on underlying principles</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Critically assess a problem that is complex and has alternative design approaches</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Identify key debates that result from conflicting practitioner/scientists/business views</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>2. Scholarship</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formulate and implement a mathematical model in a project</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make mathematically sound, informed judgments on complex issues using complex data</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Articulate those strategies and judgments</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Application of Knowledge

| Assess a complex problem from the viewpoints of practitioners/scientists/business | ✓ | ✓ | ✓ | ✓ |
| Use probability and/or mathematical analysis in formulating strategies | ✓ | ✓ | ✓ | ✓ |

4. Professional Capacity

| Complete the degree requirements in a timely manner | ✓ | ✓ | ✓ | ✓ | ✓ |
| Demonstrate project management skills | ✓ | ✓ | ✓ | ✓ |
| Adjust communications to address different audiences | ✓ | ✓ | ✓ | ✓ |

5. Communication Skills

| Explain the technical, mathematical arguments underlying major algorithms and/or software in chosen domain | ✓ | ✓ | ✓ |
| Communicate mathematically complex ideas effectively to diverse audiences | ✓ | ✓ | ✓ | ✓ |
| Prepare reports and presentations that outline the problem, option and solutions | ✓ | ✓ | ✓ | ✓ |

**Consultation**

Describe the expected impact of what is being proposed on the nature and quality of the unit’s/division’s program of study and any impact on other units/divisions.

Describe any consultation with the Deans of Faculties/divisions that will be implicated or affected by the creation of the proposed field or concentration.

The proposed applied mathematics concentration is the result of a lengthy collaboration between the Departments of Computer Science and Mathematics. Beyond this, there have been many discussions with the Fields Institute, and in particular, the Centre for Quantitative Analysis and Modelling (CQAM) about identifying and improving the existing opportunities for collaborative exchanges between programs. These have also included identifying the opportunities for training and novel applications of the respective disciplines to quantitative projects arising in industrial and scientific enterprises in the Greater Toronto Area and beyond. There have also been discussions about identifying and extending applied mathematics intensive courses and activities offered in our programs and at Fields. Other significant consultations have taken place with the Department of Statistical Sciences. The expectation is
that these consultations will be extended to each unit within the FAS [Social Sciences and Humanities].

**Resources**

Describe any resource implications of the change(s) including, but not limited to, faculty complement, space, libraries and enrolment/admissions.

Please specify where this may impact significant enrolment agreements with the Faculty/Provost’s Office.

Indicate if the major modification will affect any existing agreements with other institutions, or will require the creation of a new agreement to facilitate the major modification (e.g., Memorandum of Understanding, Memorandum of Agreement, etc.). Please consult with the Provost’s Office (vp.academicprograms@utoronto.ca) regarding any implications to existing or new agreements.

As the program grows, there will be resource implications on various fronts. In terms of faculty complement, we anticipate growing faculty complement by several FTEs in the Applied Mathematics area (see below). Space continues to be an issue for MScAC but the incremental space needs for this concentration are minimal. Administrative staffing will be handled by the MScAC program, and will be funded through revenues from the concentration itself, so no new central funds will be required. This is intended to be a self-sustaining concentration, within the existing MScAC program, with a formal agreement between Computer Science and Mathematics. As discussed earlier in the Need and Demand section, the capacity in the field for internship supervision is equivalent to the demand for the internships themselves. These internships are proposed by those individuals in the field that are uniquely qualified to provide supervision of the students. As discussed previously, this is precisely the demand that is currently unmet.

**Faculty Complement**

Brief statement to provide evidence of the participation of a sufficient number and quality of faculty who will actively participate in the delivery of the program.

Comment on the expertise of the faculty who will actively support or participate in the field or concentration and discuss the role of any adjunct or contractual faculty.

Comment on the impact of the field or concentration on the parent program, focusing on the extent of the diversion of faculty from existing graduate courses and/or supervision.
Comment on the provision of supervision of experiential learning opportunities, as appropriate.
If relevant, describe the plan to provide additional faculty resources to support the program.

The concentration will require faculty expertise in various areas of applied mathematics. This includes areas in which Department of Mathematics has committed faculty with domain-specific expertise such as optimization, combinatorics, classical and quantum computation, numerical methods, differential equations, and inverse problems (particularly in the medical domain). Committed Mathematics Faculty members are eager to help train and supervise students in these areas. In the coming years, given the departments’ and university’s significant focus on the mathematical and computational sciences, we expect to be hiring additional faculty in related areas, which will sync with the expected growth rate of the proposed concentration.

Table 4: Detailed Listing of Committed Faculty

<table>
<thead>
<tr>
<th>Faculty name and rank</th>
<th>Home unit</th>
<th>Area(s) of Specialization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almut Burchard, Professor and Associate Chair (Graduate)</td>
<td>Mathematics</td>
<td>Analysis, Optimization</td>
</tr>
<tr>
<td>Robert Haslhofer, Assistant Professor</td>
<td>Mathematics</td>
<td>Geometric analysis, Partial Differential Equations, Stochastic Analysis</td>
</tr>
<tr>
<td>Victor Ivrii, Professor</td>
<td>Mathematics</td>
<td>Partial Differential Equations, Analysis</td>
</tr>
<tr>
<td>Jeremy Quastel, Professor and Chair</td>
<td>Mathematics &amp; Statistical Sciences</td>
<td>Probability, Stochastic Processes, Partial Differential Equations</td>
</tr>
<tr>
<td>Radford Neal, Professor</td>
<td>Computer Science &amp; Statistical Sciences</td>
<td>Machine Learning, MCMC, Neural Networks</td>
</tr>
<tr>
<td>Kumar Murty, Professor</td>
<td>Mathematics</td>
<td>Number Theory, Cryptography</td>
</tr>
<tr>
<td>Faculty name and rank</td>
<td>Home unit</td>
<td>Area(s) of Specialization</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>------------------------------------</td>
<td>----------------------------------------------------------------</td>
</tr>
<tr>
<td>Robert Jerrard, Professor</td>
<td>Mathematics</td>
<td>Nonlinear partial differential equations, Calculus of Variations</td>
</tr>
<tr>
<td>Jeffrey Rosenthal, Professor</td>
<td>Statistical Sciences</td>
<td>MCMC, Stochastic Processes</td>
</tr>
<tr>
<td>Nicholas Hoell, Assistant Professor, Teaching Stream</td>
<td>Mathematics</td>
<td>Inverse Problems, Mathematical Imaging, Differential Equations</td>
</tr>
<tr>
<td>Benjamin Rossman, Assistant Professor</td>
<td>Mathematics &amp; Computer Science</td>
<td>Computational Complexity</td>
</tr>
<tr>
<td>Luis Seco, Professor</td>
<td>Mathematics</td>
<td>Mathematical Finance, Harmonic Analysis</td>
</tr>
<tr>
<td>Jeremie Lefebvre, Assistant Professor</td>
<td>Mathematics</td>
<td>Computational Neuroscience, Nonlinear Dynamics</td>
</tr>
<tr>
<td>Adam Stinchcombe, Assistant Professor</td>
<td>Mathematics</td>
<td>Mathematical Biology, Scientific Computing</td>
</tr>
<tr>
<td>Catherine Sulem, Professor</td>
<td>Mathematics</td>
<td>Partial Differential Equations, Nonlinear Analysis, Numerical Computation</td>
</tr>
<tr>
<td>Henry Yuen, Assistant Professor</td>
<td>Mathematic &amp; Computer Science</td>
<td>Quantum Computing, Cryptography</td>
</tr>
<tr>
<td>Ruslan Salakhutdinov, Assistant Professor</td>
<td>Computer Science &amp; Statistical Sciences</td>
<td>Statistical Machine Learning, Deep Learning</td>
</tr>
<tr>
<td>Matilde Marcolli, Professor</td>
<td>Mathematics</td>
<td>Mathematical and Theoretical Physics, Computational Linguistics</td>
</tr>
<tr>
<td>Robert McCann, Professor</td>
<td>Mathematics</td>
<td>Mathematical Physics, Optimization, Mathematical Economics, Partial Differential Equations</td>
</tr>
<tr>
<td>Faculty name and rank</td>
<td>Home unit</td>
<td>Area(s) of Specialization</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Adrian Nachman, Professor</td>
<td>Mathematics, Electrical and Computer Engineering</td>
<td>Inverse Problems, Partial Differential Equations, Medical Imaging</td>
</tr>
<tr>
<td>Dmitry Panchenko, Professor</td>
<td>Mathematics</td>
<td>Applied Probability</td>
</tr>
<tr>
<td>Mary Pugh, Professor</td>
<td>Mathematics</td>
<td>Scientific Computing, Nonlinear Partial Differential Equations, Computational Neuroscience, Fluid Dynamics</td>
</tr>
<tr>
<td>Allan Borodin, University Professor</td>
<td>Computer Science</td>
<td>Mathematical foundations of Computer Science</td>
</tr>
<tr>
<td>Matt Medland, Assistant Professor, Teaching Stream &amp; Director, Professional Programs &amp; External Relations</td>
<td>Computer Science</td>
<td>Computer Science Education, Software Engineering</td>
</tr>
<tr>
<td>Richard Zemel, Professor</td>
<td>Computer Science</td>
<td>Machine learning methods, with a specific focus on unsupervised learning, and probabilistic models of neural representations</td>
</tr>
<tr>
<td>Ravin Balakrishnan, Professor &amp; Chair</td>
<td>Computer Science</td>
<td>Human-computer interaction (HCI) with special focus on methods for interacting with and visualizing large amounts of data</td>
</tr>
<tr>
<td>Anna Goldenberg, Assistant Professor</td>
<td>Computer Science</td>
<td>Machine learning methods to decipher human disease heterogeneity</td>
</tr>
</tbody>
</table>

**Space/Infrastructure**

Address any unique space/infrastructure requirements including information technology, laboratory space and equipment, etc.
Students in the concentration will be provided office space in the Bahen Centre, alongside the current MScAC students. IT support is provided by a 0.25 FTE IT staff member in the Department of Computer Science. There is no lab space or specialized equipment requirement for the program.

**UTQAP Process**

The UTQAP pathway is summarized in the table below.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Approval</th>
</tr>
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<tbody>
<tr>
<td>Development/consultation within unit</td>
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<tr>
<td>Consultation with Dean’s Office (and VPAP)</td>
<td>Fall 2018</td>
</tr>
<tr>
<td>September 16, 2018</td>
<td>Graduate unit approval as appropriate</td>
</tr>
<tr>
<td></td>
<td>Faculty/divisional council</td>
</tr>
<tr>
<td>Submission to Provost’s Office</td>
<td></td>
</tr>
<tr>
<td>Report to AP&amp;P</td>
<td></td>
</tr>
<tr>
<td>Report to Ontario Quality Council</td>
<td></td>
</tr>
</tbody>
</table>
Appendix A: Calendar Entry

Computer Science
Computer Science: Introduction

Faculty Affiliation
Arts and Science

Degree Programs
Applied Computing

<table>
<thead>
<tr>
<th>MScAC</th>
<th>Concentrations:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data Science</td>
</tr>
<tr>
<td></td>
<td>Applied Mathematics</td>
</tr>
</tbody>
</table>

Computer Science
MSc
PhD

Collaborative Specializations
The following collaborative specializations are available to students in participating degree programs as listed below:

1. Genome Biology and Bioinformatics
   Computer Science, PhD
2. Knowledge Media Design
   Computer Science, MSc, PhD
3. Neuroscience
   Computer Science, MSc, PhD

Overview
Graduate faculty in the Department of Computer Science are interested in a wide range of subjects related to computing, including programming languages and methodology, software engineering, operating systems, compilers, distributed computation, networks, numerical analysis and scientific computing, financial computation, data structures, algorithm design and analysis, computational complexity, cryptography, combinatorics, graph theory, artificial intelligence, neural networks, knowledge representation, computational linguistics, computer
vision, robotics, database systems, graphics, animation, interactive computing, and human-computer interaction.

For further details, consult the graduate student handbook prepared by the department and available online.

**Contact and Address**

Web: [www.cs.toronto.edu](http://www.cs.toronto.edu)
Email: gradadmissions@cs.toronto.edu
Telephone: (416) 978-8762
Fax: (416) 946-1932

Department of Computer Science Graduate Office
University of Toronto
Room 4242, Bahen Centre for Information Technology
40 St. George Street
Toronto, Ontario M5S 2E4
Canada

**Computer Science: Applied Computing MScAC**

*Master of Science in Applied Computing*

The MScAC program is offered as a general program (no concentration) or as a Data Science concentration. The Data Science concentration is offered jointly by the Department of Computer Science and the Department of Statistical Sciences.

**MScAC General Program (No Concentration)**

**Minimum Admission Requirements**

- Applicants are admitted under the General Regulations of the School of Graduate Studies. Applicants must also satisfy the Department of Computer Science's additional admission requirements stated below.
- An appropriate bachelor's degree in computer science.
- A minimum average grade of B+ over the final two years of undergraduate studies.
- Applicants whose primary language is not English and who have graduated from a university where the primary language of instruction is not English must achieve a Test of English as a Foreign Language (TOEFL) score of at least 580 on the paper-based test and 4 on the Test of
Major Modification Proposal: New Field or Concentration Within an Existing Graduate Program

Written English (TWE); 93/120 on the Internet-based test and 22/30 on the writing and speaking sections.

- Three letters of support from faculty and/or employers.
- A statement of purpose.

**Program Requirements**

- Coursework. Completion of 3.0 full-course equivalents (FCEs) including:
  - FCE in required courses: technical communications (CSC 2701H) and technical entrepreneurship (CSC 2702H).
  - An eight-month industrial **internship**, CSC 2703H (3.5 FCEs). The internship is coordinated by the department, and evaluated on a pass/fail basis.
- There is no thesis requirement.

**Program Length**

4 sessions full-time (typical registration sequence: F/W/S/F)

**Time Limit**

3 years full-time

**MScAC Program (Data Science Concentration)**

**Minimum Admission Requirements**

- Applicants are admitted under the General Regulations of the School of Graduate Studies. Applicants must also satisfy the Department of Computer Science's additional admission requirements stated below.
- An appropriate bachelor’s degree from a recognized university in a related area such as statistics, computer science, mathematics, or any discipline where there is a significant quantitative component. The completed bachelor’s degree must include significant exposure to statistics, computer science, and mathematics, including coursework in advanced calculus, linear algebra, probability and statistics, programming languages, and computational methods.
- A minimum average grade of B+ over the final two years of undergraduate studies.
- Applicants whose primary language is not English and who have graduated from a university where the primary language of instruction is not English must achieve a Test of English as a Foreign Language (TOEFL) score of at least 580 on the paper-based test and 4 on the Test of Written English (TWE); 93/120 on the Internet-based test and 22/30 on the writing and speaking sections.

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Template updated on March 7, 2017
• Three letters of support from faculty and/or employers.
• A statement of purpose, ideally explaining their interest in applied mathematical topics in computational science
• Applicants must indicate a preference for a concentration in Data Science in their application. Admission is competitive, and students who are admitted to the MScAC program are not automatically admitted to this concentration upon request.

Program Requirements

• Coursework. Completion of 3.0 full-course equivalents (FCEs) including:
  • FCE chosen from the STA 2000-level courses or higher. This may include a maximum of 0.5 FCE chosen from the STA 4500-level of six-week modular courses (0.25 FCE each).
  • FCE chosen from the Computer Science (CSC course designator) graduate course listings.
  • FCE in required courses: Technical Communications (CSC 2701H) and Technical Entrepreneurship (CSC 2702H).
• Course selections should be made in consultation with the Program Director.
• An eight-month industrial internship, CSC 2703H (3.5 FCEs). The internship is coordinated by the department, and evaluated on a pass/fail basis.

MScAC Program (Applied Mathematics Concentration)

Minimum Admission Requirements

• Applicants are admitted under the General Regulations of the School of Graduate Studies. Applicants must also satisfy the Department of Computer Science’s additional admission requirements stated below.
• An appropriate Bachelor’s degree from a recognized university in a related area such as applied mathematics, mathematics, physics, computational mathematics, statistics, computer science, or any discipline where there is a significant quantitative and/or mathematical component. The completed bachelor’s degree must include significant exposure to advanced mathematics, statistics, and computer science, including coursework in advanced and multivariate calculus (preferably analysis), linear algebra, probability and statistics, programming languages, and general computational methods.
• A minimum average grade of B+ or equivalent over the final two years of undergraduate studies.
• Applicants whose primary language is not English and who have graduated from a university where the primary language of instruction is not English must achieve a Test of English as a
Foreign Language (TOEFL) score of at least 580 on the paper-based test and 4 on the Test of Written English (TWE); 93/120 on the Internet-based test and 22/30 on the writing and speaking sections.

- Three letters of reference from faculty and/or employers with preference for at least one such letter from a faculty member in Mathematics or Applied Mathematics.
- A statement of purpose (limited to 500 words) explaining their interest in applied mathematics and objectives for the program.
- Applicants must indicate a preference for a concentration in Applied Mathematics in their application. Admission is competitive, and students who are admitted into the MScAc program are not automatically admitted to this concentration upon request.

**Program Requirements**

- **Coursework.** Completion of **3.0 full-course equivalents (FCEs)** including:
  - **1.0 FCE** chosen from the MAT1000-level or higher. This may include courses cross-listed as APM400-level.
  - **1.0 FCE** chosen from the Computer Science (CSC course designator) graduate course listings.
  - **1.0 FCEs** required courses in Technical Communications (CSC 2701H, 0.5 FCE) and Technical Entrepreneurship (CSC 2702H, 0.5 FCE)

- Course selections should be made in consultation with the Program Director.

- Students enrolled in the Applied Mathematics Concentration must also complete an eight-month industrial internship. The internship CSC 2703H (3.5 FCEs) is coordinated by the department, and evaluated on a pass/fail basis.

**Program Length**

4 sessions full-time (typical registration sequence: F/W/S/F)

**Time Limit**

3 years full-time
Appendix B: List of Courses associated with the new concentration

All students in the MScAC, including students in the new concentration, receive individualized advising to ensure that they select courses that a) meet the program requirements, including any requirements specific to the concentration; b) have sufficient academic preparation for each course; and c) support their professional goals.

Students pursuing the new concentration in data science may select graduate-level courses from the participating departments, in compliance with the requirements listed in the SGS calendar, and subject to approval of the program director. Of eligible courses, the following are examples that are particularly relevant to the data science concentration:

- MAT1060 – Partial Differential Equations I
- MAT1061 – Partial Differential Equations II
- MAT1302/APM461 – Combinatorial Methods
- MAT1304/CSC2429 – Topics in Combinatorics: Circuit Complexity
- MAT1508/APM446 – Techniques of Applied Mathematics: Applied Nonlinear Equations
- MAT1509 – Mathematical and Computational Linguistics
- MAT1525 – Topics in Inverse Problems and Image Analysis
- MAT1750 – Computational Mathematics: Numerical Methods
- MAT1751/CSC2451 – Quantum Computing: Foundations to Frontier
- MAT1840/APM482 – Control Theory
- MAT1855 – Mathematical Problems in Economics
- MAT1866/APM466 – Mathematical Theory of Finance
- CSC2508 - Advance Data Management Systems
- CSC2525 - Evaluating Data Curation
- CSC2541 - Topics in Machine Learning
- CSC2542 - Topics in Knowledge Representation & Reasoning

Developed by the Office of the Vice-Provost, Academic Programs

Template updated on March 7, 2017
CSC2545 - Kernel Methods & Support Vector Machines
CSC2515 - Machine Learning
CSC2501 - Computational Linguistics
CSC2511 - Natural Language Computing
CSC2506 - Uncertainty & Learning
CSC2502 - Knowledge Representation & Reasoning