COMPUTATIONAL MATHEMATICS

Review Process

This was the first review of the Computational Mathematics (CM) program. To assist with the self study CM faculty members held a half-day workshop with the assistance of the Centre for Teaching Excellence to review the program, its courses and how it integrates with the University’s undergraduate degree level expectations. In addition, surveys were sent to CM faculty members, CM undergraduates and CM alumni from the undergraduate program, to determine their opinion of the program. These comments were incorporated into the document.

The self study was submitted September 8, 2010; the site visit occurred January 13 and 14, 2011; the review team’s report was received February 20, 2011; and CM’s response and that of the Dean were submitted 14 July, 2011.

Characteristics of the Program

Historical Overview

The Faculty of Mathematics was established in 1967. The Faculty boasts the largest concentration of mathematical and computer science talent in the world. With more than 5,300 students, 200 full-time faculty members and 180 courses in mathematics, statistics and computer science, the Faculty is a powerhouse of discovery and innovation.

Within its five academic units, the Faculty of Mathematics has significant strength in numerous areas of computational mathematics and scientific computing. Also, it has long been recognized that the majority of current Bachelor of Mathematics (B Math) graduates find employment in areas where these skills are highly desirable or essential.

In 2000, the then Dean of Mathematics identified Computational Mathematics as an area well-suited to Waterloo’s strengths across all academic units within the Faculty of Mathematics, and to the growing societal needs for graduates trained in mathematical modelling and computation.

The timing was opportune. The Ontario government had passed the Post-Secondary Education Choice and Excellence Act 2000 whose strategy would include reducing secondary education from a five-year to a four-year program and invest 73,000 new places at post-secondary institutions. As a consequence, a “double cohort” of Ontario high school graduates was expected to apply to Ontario universities for 2003-04 admission. To accommodate the double-cohort, the Faculty was expected to grow its first-year class by about 100 students (about 10%). A new undergraduate program in Computational Mathematics would be designed to accommodate the growth. Moreover, as a computational program it would also qualify as a deregulated tuition program in Ontario and hence generate increased revenue to the Faculty and the University from higher tuition fees.

In April 2000, an ad hoc committee to consider the development of a program in Computational Mathematics was established and met regularly over two years. By 2002, the program was approved and in fall 2003 the Faculty admitted its first students in CM. The idea was that the program would grow steadily to about 100 students in each year or about 400 in total.
The Faculty’s vision for Computational Mathematics always included the creation of a formal centre to manage, develop and promote undergraduate and graduate programs in CM, to provide educational opportunities for Faculty of Mathematics students, to serve as a catalyst for collaborative research activity within the Faculty in all areas of CM and to act as an outreach centre for collaborative research and consultation with industry. In January 2005, the University of Waterloo (UW) Senate approved the creation of the Centre for Computational Mathematics in Industry and Commerce (CCMIC).

As a result of the creation of the Centre and the new undergraduate degree program, the Faculty hired 10 new faculty members at the Assistant Professor level across the academic units in the Faculty. This increased growth in faculty complement was largely because of the 10% growth in the Faculty’s annual undergraduate cohort. The assignment of the positions of the CM complement was strategic – both to support the new initiative and to have more faculty members with computationally-oriented research interests across all academic units in the Faculty. Each new CM faculty member was assigned to a Department/School to serve as his/her academic home. The Centre’s draw on the faculty members would be slightly less than half with respect to teaching duties and it would have first draw with regard to administrative duties for CM programs and Centre activities. The distribution of the 10 new positions was: three in Applied Mathematics (AM); three in Combinatorics and Optimization (C&O); two in Computer Science (CS); one in Pure Mathematics (PM); and one in Statistics and Actuarial Science (SAS). The Faculty planned to expand the Centre to hire 34 more CM faculty members.

In 2007 the Master of Mathematics in Computational Mathematics accepted its first students.

At the time of this review CM had managed to increase its complement to 11 faculty members.

The main elements of governance of the Centre are a Director and a Steering Committee consisting of a representative from each of the five units in the Faculty of Mathematics. The Undergraduate and Graduate Officers are appointed from the membership of CCMIC in consultation with the relevant Chair/Director of the faculty member’s home academic unit. The Director has neither stipend nor course reduction to offer these Officers. Any course reduction is given at the discretion of the head of the home academic unit.

The major issues presently facing CCMIC are three. Firstly, the low enrolment in the program especially when it was imagined, prior to the program’s approval, that as many as 100 students might graduate each year. Secondly, the program has to contend with the deregulated fee structure which results in a substantial difference in tuition paid by domestic students compared to most other major plans in the Faculty. This is especially troubling since nearly all CM courses are accessible to, and largely dominated by, majors from other departmental programs who pay nearly half the tuition. Lastly, there is the lack of control by the Director of the Centre on what CM courses are offered and the instructors who are assigned to teach these courses.

Program Objectives

The CCMIC is simultaneously a research centre, an interdisciplinary academic unit offering undergraduate and graduate programs, an outreach centre for collaborative research and consultation with industry. Its mission is as follows:
“The CCMIC will oversee the development and teaching of the new undergraduate program in Computational Mathematics and will facilitate and promote an expansion of graduate studies in the area. The mission of the CCMIC is also to advance fundamental knowledge and application of all areas of computational mathematics. The CCMIC will sponsor seminar series in computational mathematics, provide advice and guidance to both graduate and undergraduate students in computational mathematics, promote collaboration with people outside the Faculty who work in areas of application of computational mathematics, publicize its activities across campus, and facilitate the development of research relationships with government and the private sector. All faculty members who have interests and expertise in computational mathematics are eligible to be members of the CCMIC.” (Brief to UW Senate, January 2005)

The above continues to be the mission of CCMIC. The reviewers are of the opinion that the goals of the program are appropriate in the context of those of the Faculty and the University.

Distinctiveness/Benchmarking

Although programs in Computational Mathematics are offered at other universities, very few can offer the range of courses that are offered at UW. UW’s CM program is distinguished not only by the breadth of available topics but also by its depth of strength in each.

Academic Programs Offered

The following undergraduate programs are offered by Computational Mathematics:

- B Math (Honours) in Computational Mathematics (Regular and Co-op)
- B Math (Honours) in Computational Mathematics/Bio-Medical Option (Regular and Co-op)
- B Math (Honours) in Computational Mathematics/Data-Mining Option (Regular and Co-op)
- B Math (Honours) in Computational Mathematics/Earth and Science Option (Regular and Co-op)
- B Math (Honours) in Computational Mathematics/Economics Option (Regular and Co-op)
- Minor in Computational Mathematics

Students

CM is a small undergraduate program composed primarily of full-time students. The program is a first-year entry program, though some students may choose to enter the program as late as graduation since all mathematics students, whatever their stated plan, have access to all courses in the undergraduate CM program and so could “shadow” the program without declaring CM as a major. One reason to do this would be the significant difference in tuition costs between CM and other B Math programs for domestic students.

The average annual number of applicants to CM, over the period 2003 to 2008 inclusive, was 137. The number has steadily decreased from a high of 193, when the program started in 2003, to 112 in 2008. Of these students, 31 registered in the program in 2003, this decreased to seven in 2006, then rose to 18 in 2007 and 13 in 2008. The decline in numbers is worrying. The decline has been mostly in the area of domestic applicants since the number of international applicants has held steady from 27 in 2003 to a high of 42 in 2006, and was 31 in 2008.
The CM program is identical to all other B Math programs for nearly the whole of the first two years of study. Thereafter, all non-CS and most CS courses in the CM program are open to all students in the Mathematics Faculty. Yet domestic students registered in CM pay a much higher fee each term than do domestic non-CM students because CM is a deregulated program. In 2009-10, the differential tuition per term between CM and Mathematics Regular domestic students was about $1,600. This differential in tuition may contribute to the decline in CM majors. Anecdotal evidence tends to substantiate this position.

CM attracts some of the top students in the Faculty. Over the last five years the number of applicants offered a position in CM who had a high school average of 90% or better has risen from 16.6% in 2004 to 55.8% in 2008. It is clear that CM is attracting high quality students.

The high quality of CM applicants is also attested to by the number of scholarships awarded on entry to the program. Over the period, 2003-04 to 2008-09 inclusive, an average of 24 scholarships has been given each year, each averaging $1,500, to CM students on entry to the program. The number of scholarships was 10 in 2003-04 and has risen in 2008-09 to 38. Also over the same time period, 182 upper year scholarships, each averaging $1,100, have been awarded to CM students.

Although only two CM students have taken advantage of an international exchange, many foreign students have come to UW for a period to study CM. They have come from universities in Hong Kong, France and England.

Normal time to graduate for regular students should be four years and five for students in the co-op stream. Five years after 30 students entered CM in 2003-04, 14 graduated from CM, six graduated from a different program, seven are still in the program and three withdrew. The 2004-05 student cohort showed a similar trend. The cohorts of 2005-06 and 2006-07, also show a relatively large number of students withdrawing from the program. The attrition out of the program is of concern and may be a result of the deregulated fee structure.

Of the students that the review team talked to all were appreciative of the material presented in their courses and the professors who teach them.

Nine students graduated from CM in 2007, 18 in 2008 and seven in 2009. Many of these students went to graduate school but where their careers took them after that is unknown.

**Faculty**

Members of CCMIC are designated as either complement faculty members or affiliated faculty members depending on whether they have been specifically hired as part of the CM faculty complement or not. At the time of this review there were 11 complement faculty members and 38 affiliated faculty members. The 11 complement faculty members, two full professors, six associate professors and three assistant professors, are housed in one of the five units in the Faculty of Mathematics. Three are housed in AM; two in SAS; one in PM; two in C&O; and three in CS.

All CM courses are cross-listed with courses in the home Department/School and though cross-listing entails responsibility of all units involved in the design and delivery of a cross-listed course, the latter is problematic for CM.
The problem is twofold: the Centre does not have a say over who teaches CM courses, and the Centre does not assign any of the CM complement faculty members to teaching assignments.

All teaching assignments of CM complement faculty members is done by their home Department/School. The responsibility of finding teaching resources for all cross-listed CM courses is that of the academic units which share in the cross-listing of the course, with the exception of CM. This has led to some interesting outcomes which are not always best for the students in the program, the development of the program, and for the complement and affiliated faculty members. For example, over the five year period, 2005 to 2010, CM 339, the “Algorithms” course, has been taught 23 times but only twice by a CM complement faculty member.

The other side of the coin is the number of CM teaching units there are available that come from CM complement faculty members. These, at least, could be split equally between the responsibilities of the CM program and that of the person’s home Department. Assuming this to be the case, the teaching duties of a CM complement faculty member can be worked out. The teaching responsibility of every research active faculty member in the Faculty of Mathematics is three courses per year. Faculty members are eligible for an annual sabbatical year once every six years. Therefore annually, on average, a research active faculty member is responsible for 3 X \( \frac{1}{2} \) courses, and 11 such faculty members over a period of five years will be responsible for 11 X 5 as many courses, or a total of 141.5, approximately 141.4 course units. If only half of the courses taught by CM complement faculty members are taken to be CM courses, then the total teaching units over five years for CM courses by CM complement faculty members should be approximately 70.7 courses. Over the past five years CM complement faculty members have been assigned to only 48 CM courses. Three of the five academic units (AM, C&O and CS) assigned only about 62% of the CM courses they are responsible for, PM assigned its one faculty member less than a third of the CM courses that should be available. Only SAS has, in the past five years, assigned more CM courses to CM complement faculty members than half of their full load.

Had half of the CM complement teaching responsibilities been available for the CM program directly, the content and delivery of the program might be significantly improved.

Centre members engage in a variety of pure and applied research strengths across the spectrum of Computational Mathematics. Two faculty members focus on Biological Applications; eight are actively involved in Computational Finance and Risk Management; three in Computational Number Theory and Cryptography; 12 in Computational Statistics; two in Control Systems; two in Medical Imaging; 11 in Numerical Algorithms, Linear Algebra and Differential Equations; 13 in Optimization and Operations Research; five in Symbolic Computing; and seven in Weather and Ocean Current Applications.

Many of the Centre’s faculty members are affiliated with research groups, such as: the Artificial Intelligence Research Group; the Centre for Applied Cryptographic Research; the Computational Neuroscience Group; the Interdisciplinary Centre for Climate Change; the Vision and Image Processing Group; and the Waterloo Research Institute in Insurance, Securities and Quantitative Finance.

These faculty members, since the start of the program in 2003, have published 149 refereed journal articles, 91 refereed conference proceedings, five book chapters and 67 conference presentations. They have also obtained 37 grants amounting to $5.2 million.
Centre members have received many academic awards such as: Canada Research Chairs; a Guggenheim Fellowship; an IBM Faculty Award; and the NSERC Synergy Award for Innovation. In addition, members have held elected positions in professional societies such as: the Association for Computing Machinery; the Society for Industrial and Applied Mathematics; and the Statistical Society of Canada.

CCMIC members have served in editorial roles in numerous national and international research journals over the last five years. They have been editors of Statistics and Computing, Numerical Linear Algebra with Applications, Journal of Computational Finance, and sat as editorial board members on 21 different academic journals.

CCMIC faculty members have been very active in their respective professional societies and academic journals.

**Concerns and Opportunities for Improvement**

The review team is of the opinion that the low enrolment is a problem especially given the number of faculty member hired to support it.

The review team makes a number of recommendations:

1. That tuition fees for the CM program be reduced to the same level as that of the other Mathematics programs.
2. That the CM program should become a second-year entry program instead of a first-year entry program.
   
   *Response to recommendations 1 and 2:* CM will become a second-year entry program similar to most other mathematics’ programs, with tuition fees lowered to the same level as most other mathematics programs.

3. That the sequencing of language programs be changed so that students are proficient in a high-level programming language by the end of the second year.
4. That CM 339/CS 341 Algorithms be added to the “second layer” list of courses for the fourth year.
5. That students be allowed to select any four courses from the entire list of “second layer” courses.
   
   *Response to recommendations 3 to 5:* A high-level programming course in C++. CS 246, will be added to the list of CM core courses. In addition, the various streams of upper-year courses will be removed, replaced by a single choice list of upper-year courses.

6. That CCMIC be given more control over instructor assignment to CM course.
7. That a Board or Advisory Committee be established, with representation from CCMIC and the Faculty, to oversee the CM program.
   
   *Response to recommendations 6 and 7:* The following changes will be made to the administrative structure of the CM program: the CM labels on all courses will be removed, and some of the academic advising of Cm students will be handled by the team of advisors in the Dean’s Office. Advising that is specific to CM will be handled by CCMIC.