Final Assessment Report
Computer Science (BCS, BMath(CS), BCFM, MMath, PhD)
February 2014

Review Process

The review covers three undergraduate programs: the Bachelor of Mathematics in Computer Science (BMath(CS)), the Bachelor of Computer Science (BCS) and the Bachelor of Computing and Financial Management (BCFM) and two graduate programs: the Master of Mathematics (MMath) and the PhD. Some other smaller programs partly administered by the David R. Cheriton School of Computer Science are included in separate reviews. The Master of Health Informatics CS stream will be reviewed along with the Applied Health Sciences stream. The Master of Quantitative Finance will be reviewed with the graduate programs in Statistics, and the options in Quantum Information (a collaborative program) will be reviewed separately. The double degree BCS-BBA (operated jointly with Laurier) will be reviewed in two years along with the BMath-BBA. The undergraduate Software Engineering program is being reviewed along with other Engineering programs. The various undergraduate Minors and Options offered are not "programs" as defined by the IQAP (i.e. are not stand-alone qualifications which can be used to lead to a degree in the absence of a Major or Honours program), and are hence not included.

The self-studies of the BCS, BMath(CS), MMath and PhD programs were combined in a single augmented review. Co-ordinating such a large review required team input. The review was led by the Directors of Undergraduate Studies and of Graduate Studies in the School. The review was discussed with the School's Executive Committee, the Graduate and the Undergraduate curriculum committees, and at monthly School Council meetings. The Director of Undergraduate Studies also met periodically with the Director of the BCFM program (who is based in the School of Accounting and Finance) and with the Director of Software Engineering. The learning outcomes were developed at a mini-retreat, to which all faculty members, lecturer-advisors and Instructional Support Coordinators were invited. An alumni survey was also undertaken. Over 6000 alumni were contacted, and 850 responded, of whom 672 provided complete responses. Note that some of this Final Assessment Report draws verbatim from the self-study documents.

The self-study for the BCFM program was written separately, and involved a team of the two School Directors (Cheriton School and School of Accounting and Finance), the Director of Undergraduate Studies in the Cheriton School, and the two co-Directors and Program Manager from the School of Accounting and Finance. Feedback for this self-study was obtained from students at program events, and from alumni through surveys.

The review was undertaken by Dr. Anne Condon, Department Head and Professor of Computer Science, University of British Columbia, and Dr. Ken Jackson, Professor, Department of Computer Science, University of Toronto. The site visited occurred on January 13 and 14, 2014. The internal reviewer was Dr. Robert Park, Department of Anthropology.

The previous undergraduate review of the BCS and BMath(CS) (2006) resulted in a set of 14 recommendations. These ranged from advice regarding student/TA ratios, to making course evaluations available online, to providing courses in effective writing for students, and a variety of other topics. Many of these recommendations have been implemented over the period since the review, with the exception of some which required more instructional resources than could be made available, and others (such as establishing an Industrial Advisory Board) where it was felt that an alternate mechanism (good liaison with Co-op employers) was preferable. There has been no previous review of the BCFM, which began in 2006.

The previous graduate review (2007) ranked the undergraduate program as among the best in the world, and the graduate program as among the two or three finest in Canada. No recommendations were made (other than not to name one of the fields "Information retrieval" but to choose an updated name), and the program was rated as "Good Quality". The reviewers were also concerned that the School should put together a plan to achieve the planned increase in graduate enrolment. The School did in fact achieve their set target, growing from 265 to 327 graduate students by 2010. `

Characteristics of the Programs

The School is large and well established. It has offered a PhD since 1969, and undergraduate and Master's degrees since shortly after the founding of the University in 1957. As of May 2013, the School had 70 tenured or tenure stream faculty and 9 lecturers, and 300 graduate students. As stated in the preceding paragraph, the School's programs are considered to be excellent.

The relatively new BCFM is one of only two programs currently at Waterloo recognized as providing 70% of the Chartered Financial Analysis Candidate Body of Knowledge and emphasizing the CFA Institute Code of Ethics and Standards of Practice for the CFA designation. Waterloo was the second university in Canada to qualify for this recognition. The program has also been recognized under the Canadian Information Processing Society, which allows graduates to proceed towards two industry designations.

Academic Programs Offered

At the Bachelor's level, the BCS is offered both as a regular and a co-op program, and the BMath(CS) (which has a more detailed grounding in mathematics) is likewise offered both as a regular and a co-op program. The co-op only BCFM is offered in conjunction with the School of Accounting and Finance. As mentioned in the introductory section, other programs offered, but not the subject of this review, include a double degree BCS-BBA with Wilfrid Laurier University and the co-op only BSE (Bachelor of Software Engineering) offered in conjunction with Engineering.

The graduate programs include a Master's of Mathematics in Computer Science, which is offered in three different formats: thesis (the most popular format), research paper, and coursework only (students in this program are not funded). Students can also elect a co-op option. The School also offers a PhD.

Program Objectives

The mission of the David R. Cheriton School of Computer Science is to conduct high calibre research that is recognized nationally and internationally, provide first-rate undergraduate and graduate teaching and degree programs, and provide beneficial public service. The School's goal is to conduct research and provide degree programs that cover the

breadth of computer science as well as interdisciplinary fields that combine computer science with important applications.

The objective of the two large undergraduate programs (**BCS, BMath(CS)**) is to provide a comprehensive grounding in Computer Science as a branch of mathematics. Students receive a world-class education including extensive mathematical foundations, and knowledge of the theory, systems, and applications of Computer Science. They are also exposed to the broader intellectual landscape of ideas beyond mathematics and Computer Science. The programs provide students with the knowledge and skills that enable them to pursue successful careers in industry, or proceed to graduate studies.

The **BCFM** aims to develop professionals that can bridge the gulf between the two disciplines of computer science and financial management. In addition to developing interdisciplinary expertise, students can further specialize in either computer science or finance to set themselves up for graduate studies or employment in computer science, finance, or business

The **MMath program** has two objectives:
1. To prepare students for further studies at the PhD level, and
2. To prepare students for research and/or development careers in industry.
The program aims to provide the necessary background to demonstrate individual accomplishment at a high professional and academic standard.

Admission to the MMath program comes from a variety of undergraduate programs, but primarily from students with a background in computer science. A small number of students come from related disciplines such as electrical and computer engineering, and various areas of mathematics. Many of these students must take undergraduate courses in computer science in order to prepare them for the MMath program.

The objective of the **PhD** program is to train students to become independent research investigators. The PhD program aims at giving graduate students the required theoretical background and research methodology to demonstrate accomplishment of independent and original research work. The criteria for a successful PhD are the pursuit of knowledge and excellence as well as technical expertise. The PhD thesis consists of original research that provides significant contributions to knowledge. The PhD program prepares students for a University teaching and research career or for a high level research and development career in industry.

Specific Learning Outcomes

All three undergraduate programs reviewed here have seven core outcomes expected for all programs: program design and development, programming methodology and practice, computer systems and applications, communication skills, breadth of knowledge outside of CS, advocacy and stewardship, and personal disciplinary limitations. In addition there are two additional specific learning outcomes in mathematics for all three programs (mathematical foundations, and core algorithms and data structures), in which the expectations are higher for the BMath(CS). All co-op students are expected to attain two additional learning outcomes, professionalism, and workplace skills (see self-study document for curriculum maps).

For the **BCFM,** in addition to the learning outcomes required in the previous paragraph, the Learning Model adopted by all School of Accounting and Finance programs recognizes the following competency areas: functional competencies, understanding business, thinking and problem-solving skills, communication

skills, leadership and collaborative skills, learning how to learn, and ethical conduct. Learning outcomes have been identified within each competency area.

In the **MMath** program, learning outcomes are that:
1. Students demonstrate knowledge of computer science at an advanced level.
2. Students are familiar with a variety of research styles and methods.
3. Students are aware of the field's limitations and open problems.
4. Students critically assess current research publications and present the results to their peers.
5. Students synthesize a solution based on state-of-the-art knowledge of appropriate theoretical and technological bases to a specified research problem in their field of computer science.
6. Students display sustained and collaborative engagement with a significant problem using appropriate design and implementation skills.
7. Students communicate ideas effectively in written and oral form to their peers.
8. Students demonstrate ethical and professional behavior.

In the **PhD** program, learning outcomes are that:
1. Students demonstrate knowledge of computer science at an advanced level across the categories of Applications, Computing Technology, and Mathematics of Computing, as well as a deep understanding of a chosen area of research
2. Students a familiar with a variety of research styles and methods and have in-depth knowledge of one or more styles that are used in their own work
3. Students are aware of the limitations of their personal knowledge of computer science, and of the field's limitations and open problems.
4. Students critically assess the state of the art in a research field and present the results to their peers.
5. Students autonomously synthesize and analyze a solution that extends the state-of-the-art for a specified research problem in their field of computer science of a quality to satisfy peer review, and to merit publication.
6. Students display sustained engagement with a significant thesis problem over an extended period of time, thus developing new skills, tools, techniques, theories, or practices, as appropriate.
7. Students communicate complex and potentially ambiguous ideas effectively in both oral and written form.
8. Students demonstrate ethical and professional behavior.

The two self study documents explain how these map to degree expectations, and to the components of the curriculum.

Significant strengths of program

The School is active in all major areas of computer science research and there are 17 fields offered in the graduate programs. The School is very well known for its applied research based on strong theoretical foundations leading to the development of practical systems. The WATFOR compiler, the MAPLE symbolic computation package, SPARSPAK (sparse matrix software), and the New Oxford English Dictionary project are some examples of software packages that were developed as a direct result of research work in the School of Computer Science. In the 2014 QS rankings, computer science and mathematics both were ranked 24th in the world (and second in Canada). No other Waterloo units ranked in the top 25 in the world. Waterloo ranked in the top 200 in accounting and finance and in the top 5 in Canada.

"Graduates from the undergraduate program are actively recruited by leading information technology firms, such as Amazon, Google and IBM. Although possibly a little less acclaimed, the graduate program in CS is also very strong. Graduates from the PhD program hold academic positions in virtually all computer science departments in Canada and many leading universities around the world, as well as many preeminent research laboratories such as Oak Ridge and Lawrence Livermore……In recognition of the strength of UW CS program, the School was recently awarded a Canada Excellence Research Chair (CERC) in Cryptography, Privacy and Security. This will allow the School to become an international leader in this area." (Reviewers' Report, 2014).

Since 1993, the Cheriton School has been an active participant in the ACM Programming Contest. Undergraduate teams from Waterloo have won the world championship twice, in 1994 and 1999, and have been North American champions in 1998, 2000, and 2005.

Faculty

The School had at the time of the review 80 faculty, of whom 71 are in the professorial rank, and the other 9 are Lecturers, either Continuing or Definite Term. Three positions were vacant. Only five are currently Assistant Professors. The School is consistently in hiring mode (it takes more than one year to fill positions), and with anticipated retirements averaging 3-4 per year, the hiring is likely to continue steadily. Approximately 50 courses per year are covered on a stipendiary basis. There are around 18 adjunct faculty, who do not teach, and four Research Professors, some of whom teach, as well as supervise graduate students.

The usual classroom teaching load for a faculty member in the School is three courses per academic year based on a notional load of four courses and a reduction for the teaching activity associated with graduate supervision or significant administration. New faculty are given a reduction of one course per year for the first two years in order to devote more time to establish their research programs. On average, each faculty member supervises four graduate students: three MMath and one PhD, with the average being somewhat less for newer faculty. A lecturer typically teaches four to six courses per academic year depending on his/her other duties.

The faculty hold many awards, including Fellow of the Royal Society of Canada (4), Fellow of the Associate of Computing Machinery (5), Fellow of the Institute of Electrical and Electronics Engineers (3), Killam fellowships (1), Steacie fellowships (1), Canada Research Chairs (2 Tier 1: 2 Tier 2), Outstanding Young Computer Science Researcher (3), in addition to numerous similar province-level awards.

Faculty in the Cheriton School bring in around $20m/year in research funding, one quarter from the Tri-Agency, half from the public sector, and the balance from the private sector. About 40% of this is related to the work of the Institute for Quantum Computing (IQC).

The School of Accounting and Finance has 31 professorial faculty, and 11 Lecturers/Continuing Lecturers, as well as stipendiary faculty.

Staff/Administration

The Cheriton School is large, and as such has 7 faculty members in administrative positions, and about 44 staff – 20 in the technical area, and 24 in administrative and program support areas. The School experiences difficulty in maintaining a full complement, since staff with computer-related expertise are

typically highly marketable, and the on-and-off staff hiring freezes at the University can impede replacement.

Students

Over the last 7 years, there have been on average around 500 non-co-op full-time, and 1200 co-op students in the BCS and BMath(CS) programs (over all four years of the program), and the numbers have grown steadily over the period, from a total of 1647 full-time students in 2007/07 to 2014 full-time students in 2012/13, an increase of 24%. During the same time period, part-time regular and co-op students increased slightly from 130 to 141 students. Of these numbers, the BMath(CS) program is about 10% of the total. The BCFM program is considerably smaller with first-year enrollments averaging approximately 35 students each year.

Entering averages have been increasing, and recently more than 80% of students have grades of 85% and above, especially in the co-op programs. The proportion of international students has increased to around 30% recently, while the proportion of women students has risen from around 10% in 2006, to around 16-20% currently. The BCFM program aims to admit 40 students per year; over three-quarters of these have Grade 12 averages of 85% and above. Around a third of students are international, and around a third are women, a somewhat higher proportion than in Computer Science.

Retention in CS programs between Year 1 and Year 2 during the review period averaged 84% for regular students and 92% for co-op students. From entering classes between 2004 to 2006, approximately 75% of students in each cohort obtained degrees, with up to almost one quarter earning their degrees in other programs. The retention statistics for more recent cohorts in the review period are not reported because of the high numbers of students still working towards degree completion. For the BCFM program, retention between Year 1 and Year 2 averaged 92%. The 2006 cohort of 44 students saw 82% of the students obtain degrees, with half of those degrees earned from completing other programs.

Three quarters or more of students in the three programs combined are in co-op, and receive excellent ratings from their employers. The School's reputation has given co-op students an enviable advantage in excellent co-op placements, and in first jobs upon graduation.

The survey of over 6000 Bachelor's graduates (mentioned in the initial section of the report) indicated that the large majority (over 75%) work in the private sector (12% were in the public sector, 2% in non-profits and the balance in "other" employment). 23% of graduates had gone on to further study (some were still in the process of further study), mainly at the Master's level.

At the Master's level, about 70 students/year are admitted. Over the period 2006/7-2012/3 the proportion of international students has increased from 15% to 45%, while the proportion of women has declined from about 25% to about 15%. The median completion time is two years for Master's students, and about 90% do complete (a few withdraw due to job opportunities). Over the period, a rising proportion has been accepted to the course-based Master's rather than the thesis-based or research-paper one. (Course-based students do not receive funding, whereas those in the research paper and thesis streams do). On average, faculty members supervise about 3 Master's students and 1 Doctoral student.

Few students have opted to register in the Master of Quantitative Finance or the Master of Health Informatics from the Cheriton School, and the School is considering withdrawing its participation in both programs.

At the Doctoral level, about 30 students per year entered the program at the start of the period, a number which has fallen to closer to 25 per year currently, a source of concern to the School. The international proportion has increased from 35% to 50% over the period, and the proportion of female students has held steady at around 20%. Mean completion time for the PhD is six years which may be normal for computer science but is on the high side for STEM disciplines at University of Waterloo, and attrition rates are around 20% (some students cannot meet the standards required; while others get good job offers and opt not to complete). Those students who are within time limits (4 years) receive on average $36,000/year (note, this includes the value of the waiver of the international fee differential, which is standard for most international doctoral students).

Summary of programs' strengths and challenges

Strengths
- o Programs are in demand, challenging and attract high-achieving students
- o Faculty are active in all major areas of computer science research and the School is very well known for its applied research based on strong theoretical foundations leading to the development of practical systems
- o Graduates are highly sought after
- o Broad course offerings in undergraduate and graduate programs
- o CS faculty and staff members are proactive in developing and adopting efficient and user friendly mechanisms and software tools for managing program administration

Challenges
- o The School of Computer Sciences is faced with the retirment of 18 faculty members over the next five years
- o Gender balance – females are underrepresented in faculty as well as undergraduate and graduate student numbers
- o Decreasing reliance on sessional instructors required to teach CS courses
- o Graduate students identified infrastructure support (e.g., access to printers) and space as problematical issues
- o Attracting more highly-qualified graduate students
- o Average time to completion for PhD students (~5-6 years) is on the high side
- o Well recognized best practices for introductory programming classes, such as pair programming and mechanisms for peer learning in the classroom, appear not to be widely adopted

Reviewers' Recommendations/Departmental response regarding program enhancements

The reviewers commented fulsomely on the program strengths. They did however caution that the School cannot rest on its laurels, and noted four areas for work, namely faculty hiring, attracting high-quality graduate students, attracting more women students, and decreasing the use of sessional instructors (these are four of the five issues on which the School had sought advice). The fifth issue on which the School requested input, was on an appropriate strategy for online teaching, on which the reviewers also provided input. The reviewers provided a great deal of practical advice which will assist the School, the highlights of which are summarized in five key recommendations (taken verbatim from the review), as follows. The Departmental response is also provided, but abridged somewhat from the original.

Recommendations

1. Develop a hiring plan that takes into account what research areas are priorities for the School as well as how hiring more women faculty members might improve the learning environment for women students and how hiring more lecturers might reduce the need to hire as many sessional instructors and might also reduce class sizes.

   Response: (Re research priorities) *Because the School expects to have so many faculty retirements in the next five years, we have not done this. We agree that School-wide discussions about priorities in hiring are appropriate, but given the breadth of subfields of computer science in which our incipient retirements will occur, we are leery of such prioritization. We will, presuming a successful search for a Canada Excellence Research Chair, be prioritizing hiring in the area of privacy and security.*

   (Re women faculty) *We will be working closely with the Women in Computer Science committee in upcoming years to build strategies to expand the number of women in our faculty complement.*

   (*Re lecturers) We are quite concerned about the increased number of sessionals in our undergraduate program. However, three facts do need to be mentioned in this area.*

   First, the quality of our sessionals has been very high of late: …..Indeed, it is good enough that we tend to hire Lecturers from this pool.

   Second, a worry with hiring Lecturers is that they are often highly sought by other universities. Hiring Lecturers to solve our sessional problem is clearly a good way to have excellent teachers in front of our classes, but we seem to hire them quite often, but not expand the actual pool very easily.

   Third, we have a sense that hiring Lecturers brings a decline in the number of professorial-rank faculty that we are allowed to hire. Given the daunting wave of retirements we are facing in that set of faculty, we are loath to move faculty "slots" from the "Professor" category into the "Lecturer" category.

2. Appoint a senior faculty member to work closely with the Directors in developing bold new strategies to attract women at the undergraduate, graduate, postdoctoral and faculty levels.

   Response: *With the upcoming change of leadership in the School, we are planning to identify appropriate strategies of this sort with the chair of the Women in Computer Science committee, who will be returning in the 2014/2015 academic year. Early plans include changes to admissions (to be discussed later in this document) and study groups for first- and second-year female students, but this set will surely expand.*

3. Step up efforts to promote the CS graduate program at Waterloo, and to ensure timely and smooth communication with prospective and accepted graduate students. Consider introducing an alternative pathway for excellent students from other disciplines to transition into the graduate program.

Response: *(Re promotion) We have an active 'Graduate Recruiting Committee' that has been constituted just for this purpose. This committee coordinates a grad visit day, runs the graduate ambassador program, and maintains a comprehensive website for prospective graduate students. We believe that the committee is doing an excellent job already and do not anticipate the need for additional actions with regard to this suggestion.*

(Re communication) We are keenly aware of this need. Faculty supervisors invariably maintain frequent contact with admitted students. We do not believe additional actions are required at this point.

(Re alternative pathway) The graduate program already includes a provision to encourage applications from undergraduate students from other disciplines…. a transitional student is normally required to complete a program of at most 5 undergraduate or graduate one-term courses in addition to those required of regular students…. Nevertheless, we believe that we can do more to strengthen this program. Therefore, we propose the following two action items: To re-invigorate our transitional program for Master's students, making it possible for them to spend their transitional time without a supervisor; and to evaluate applicant quality independently of their undergraduate degree, so that top applicants from other disciplines are evaluated on a level playing field.

4. Increase the number of lecturers, as a means of reducing the number of sessionals. Ensure that lecturers and faculty in the professorial ranks strengthen their partnership in advancing and delivering the curriculum, are supported in adopting and assessing new practices pertaining to curriculum or pedagogy and extracurricular enrichment, and avail of professional development opportunities, e.g. through participation in SIGCSE.

   Response: (Re lecturers): see (3) above.
   (Re new practices in pedagogy): *Some resources at Waterloo exist to support this process, such as the Centre for Teaching Excellence, but the Reviewers are right that the School hasn't done much in this area. An exception was the School's 2012 retreat, which focused on exactly this topic and stimulated some faculty members' interest in online discussion systems or video lectures. Proposed action: Create regular events where faculty at all ranks can discuss innovative teaching practices and share their experiences.*

5. Review the non-majors undergraduate program in CS in light of increasing enrollments in the School and changes in the CS curriculum at peer institutions.

   Response: *A subcommittee of our curriculum committee is currently exploring changes to our non-major courses, and will report later this term.*

Two-Year Plan: Action steps	Who is responsible?	Who will provide resources?	Timeline
1. Require all applicants to CS undergraduate programs to complete the "Additional	Director, Undergraduate Studies	n/a	2014

Information Form" as part of their application and focus our admissions process more closely on both what is in these forms and on increasing the gender diversity of our classes.			
2. Create regular events where faculty at all ranks can discuss innovative teaching practices and share their experiences.	Teaching fellow? Other?	n/a	2014
3.Re-invigorate our transitional program for Master's students, making it possible for them to spend their transitional time without a supervisor.	Director, Graduate Studies	n/a	2015
4. To evaluate applicant quality independently of their undergraduate degree, so that top applicants from other disciplines are evaluated on a level playing field.	Director, Graduate Studies	n/a	2014
5. To work with the Graduate Studies Office to improve the clarity of the admission offer letter.	Director, Graduate Studies	n/a	2014
6. To work with the Graduate Studies Office to inform a supervisor when an offer has gone out to an applicant.	Director, Graduate Studies	n/a	2014
7. To create USRA opportunities at UW and to advertise these at other Canadian universities.	Director, Graduate Studies/ Director Undergraduate Studies	n/a	2014
8. To create a slide deck for use by faculty to advertise the graduate program during visits.	Director Graduate Studies and School Recruitment Coordinator	n/a	2014
9. To transition printing support to UW IST.	Director, Infrastructure	n/a	2014
10. To investigate the use of non-CS TAs in introductory CS UG courses to allow TA support for CS graduate courses, as necessary.	Director, Undergraduate Studies	n/a	Initiate 2014, may take longer
11. To set up a focus group to get feedback from graduate students in the program.	Director, Graduate Studies	n/a	2014

This report will go to Waterloo Senate Graduate and Research Council on April 14 2014, to Senate Undergraduate Council on May 13, and to Senate on June 16 2014.