Final Assessment Report
Combinatorics and Optimization (MMath/PhD)
May 2016

Summary of the Program Review:

In accordance with the University Institutional Quality Assurance Process (IQAP), this final assessment report provides a synthesis of the external evaluation and the internal response and assessments of the programs (MMATH, PhD) delivered by the Department of Combinatorics and Optimization (C&O). OCGS reviews were last conducted in 2002 and 2009 and these two programs were classified as of good quality.

A final self-study (Volume I) was submitted to the Associate Provost, Graduate Studies Office on July 2016. The self-study presented the program descriptions and learning outcomes and an analytical assessment of these two programs. Data included in the report was prepared by the Office of Institutional Analysis & Planning (IAP), the Library and the Cooperative Education and Centre for Career Action (CECA), and CVs (Volume II) for each full-time faculty member in the program were also provided.

Two arm's-length external reviewers (Volume III), Daniel Bienstock, Professor in the Department of Industrial Engineering and Operations Research from Columbia University, and Nantel Bergeron, Professor in the Department of Mathematics and Statistics at York University were ranked and selected by the Associate Provost, Graduate Studies, in addition to one internal reviewer: Professor Corey Johnson, from the Department of Recreation and Leisure Studies.

They reviewed the self-study documentation and then conducted a site visit to the University on March 2-3, 2016. The visit included interviews with the Provost (Academic); Associate Provost, Graduate Studies; Dean of the Faculty; Faculty Associate Dean of Graduate Studies, Chair and Graduate Chair of the Department, Faculty Members from the six research fields in the program, as well as staff and the majority of current graduate students. The reviewers also had an opportunity to visit the programs facilities.

This final assessment report is based on information extracted, in many cases verbatim, from the self-study, the external reviewers' report and the program response.

Program characteristics:
The Department of Combinatorics and Optimization (C&O) was founded in 1967, and is one of five departments in the Faculty of Mathematics. Since their inception, C&O has been offering the following graduate degrees: MMath (Master of Mathematics); and PhD (Doctor of Philosophy).

The Department of Combinatorics and Optimization was the first department of its kind in the world. To this day it remains the department with the largest combined concentration of faculty and researchers in its six fields of expertise: Algebraic Combinatorics; Continuous Optimization; Cryptography; Discrete Optimization; Graph Theory; and Quantum Computing.

MMath (Master of Mathematics)
Admission to the MMath program normally requires the equivalent of a Canadian Honours Bachelors Degree in Mathematics with at least a B+ average, and in practice seldom admits a student with less than an A average.

The following Masters programs are offered:
1. Accelerated Masters Program
2. Master of Mathematics (MMath):
    (a) Thesis Option, (b) Research Paper Option, (c) Co-op Option
3. Master of Mathematics in Combinatorics and Optimization (Quantum Information):
    (a) Thesis Option, (b) Co-op Option

The Masters program serves students with a variety of motivations: some are interested in study and intellectual growth beyond the level of the Bachelor's degree, whereas others enter the program seeking advanced or specialized knowledge to expand their range of career opportunities. Still other students are preparing for admission to a PhD program.

PhD (Doctor of Philosophy)
Admission to the PhD program normally requires the equivalent of a MMath Degree with an A average, background in combinatorics or optimization, and strong potential for research success. The degree requirements include graduate course work, a two-stage Comprehensive Examination, a doctoral thesis, and a lecturing requirement.

The following Doctorate programs are offered:
Doctor of Philosophy (PhD)
Doctor of Philosophy in Combinatorics and Optimization (Quantum Information)

The PhD program aims to give students the knowledge and research experience they need to build successful careers in academic or research positions.

Summary of strengths, challenges and weaknesses based on self-study:

Strengths

- Recognized as a high quality graduate program
- Very unique in its constitution and attracts strong researchers and students
- The program has an exceptional reputation among researchers at the intersection of classical discrete mathematics and classical ("hard") optimization, with a strong mathematics orientation
- The program compares well with programs at Georgia Tech, Carnegie Mellon University and MIT
- No other institution quite encompasses the same strength and diversity in the fields offered by C&O

Challenges

- Faculty recruitment: competition for the top researchers is fierce. The department was unsuccessful at filling faculty positions in 2014 and 2015.

- Faculty retention: in the past fifteen years, a number of C&O faculty members have resigned to take up positions at other prestigious institutions.

- Gender balance: females are underrepresented in faculty and graduate student numbers.

- Graduate student recruitment: competition is especially fierce with top US universities. Furthermore, the proportion of domestic graduate students has been steadily decreasing - this parallels similar phenomena at US universities.

- Graduate student funding: NSERC discovery grants are insufficient to provide competitive compensation packages to attract top international graduate students. The grant levels are especially low in mathematics (compared to computer science and engineering), and there are very few alternative sources of funding for faculty members working in pure areas of mathematics.

Weaknesses

- Communication: seems to be a recurring theme between the various groups at the university. From students wanting better information about their requirements and options; to staff members wanting more transparency about budget and regulation; to department administrators desiring better communication regarding admission. The information gap was particularly noted by reviewers with regards to international Masters' students funding.

- Flexibility: some students expressed the desire for more flexibility in the available options for their degree. Students with a stronger mathematical background would like to have increased access to the other mathematics departments for their choices of courses and qualifying exams

- Masters' Advising: it was noted by Masters' students that the pairing of student/advisor is not always ideal. They expressed the desire to have one or two more strategic meetings directly with the Graduate Chair to address any issues that may arise

Summary of key findings from the external reviewers:
The programs were reviewed by OCGS in 2002 and 2009 and were given the classification of good quality – which the reviewers agreed is still accurate. Reviewers concluded that Combinatorics & Optimizations is a very high quality graduate program and that the department is very unique in its constitution and attracts strong researchers and students. Moreover, the program has an exceptional reputation among researchers at the intersection of classical discrete mathematics and classical ("hard") optimization, with a strong mathematics orientation. Reviewers strongly urged that this attribute not be harmed by changing the mission of the department or by pursuing hot topics of temporary interest.

In sum, the reviewers did not find any major issues with these programs, but offered minor recommendations.

Program response to external reviewer recommendations:

This section contains one subsection for each of the 8 recommendations provided in the report of the external review team. Each subsection starts with a verbatim copy of the recommendation from this report, and provides the department's response subsequently.

1. **Faculty recruitment:** The quality of the department correlates directly with the quality of its faculty. It is thus very important to always recruit the best possible candidates. The department has the good practice to keep the search as open as possible in order to attract the top candidate. We indeed encourage that practice. In some research groups it might be appropriate to have a more aggressive search. Therefore we recommend that some of the research group promote a more active, focused search.

   Response
   Faculty recruitment was identified as a high priority in C&O, and the department has been able to consistently hire strong candidates. C&O has also been highly successful in obtaining

recognition for its faculty members such as Early Researcher Awards. At the level at which the department is competing for talent, the competition is very strong. One way the department circumnavigates this is by entertaining applications from as wide a range of areas as possible. When C&O has a need for someone in a certain area, department members in that specialization are called to help attract applications from the strongest candidates they can find. Hence, the program feels they already employ the reviewer's recommendation on this topic.

2. **Faculty retention**: In most cases the department views as the loss of some good members as a necessary corollary of the strength of the department: if you hire the best people, then you expose yourself to poaching by other universities. This probably indeed explains most of the losses. But it would not hurt to also have a proactive view, and try to minimize this issue. To develop a sense of community, it may help to promote increased cross-pollination between the various institutions in the area, for example the Fields Institute.

   Response
   The number of resignations in C&O since 2006 is eight faculty rather than ten. While exit interviews are not common practice in this program, the department feels that the reasons for past departures had been adequately communicated. To verify this, faculty members that left since 2006 were contacted, and five responses were received. In sum, most individuals left to become a distinguished chair in their home countries, whereas the others left to either accommodate their spouse's career and/or family needs. Given the high caliber of faculty, the turnover rate is not unexpected as these are people who can move if they choose. A consequence of the departure of these people is that C&O has to regularly hire new people, which has resulted in a faculty age profile that is quite uniform. C&O does not see that increased connections with the Fields Institute will have any impact as Toronto is at an inconvenient distance, yet C&O has many visitors to the department and does not feel isolated.

3. **Gender balance**: We do not have much more to propose here. It is felt that real changes in the STEM imbalance of genders would require work to be done at a much younger age of development. The department still has to work as hard as possible to create an appropriate model for increasing diversity among young hires -- but not at the cost of quality.

   Response
   The Department shares the reviewers' desires to achieve gender balance not just in the Department, but across STEM disciplines. The Department agrees that real changes in the STEM imbalance of genders may be accomplished with attention to this issue from early education through to Postdoctoral opportunities.

The department intends to work as hard as possible to create an appropriate model for increasing diversity among our highly-qualified young hires. The department encourages applications from female and minority candidates in its hiring efforts; e.g., by advertising with the Association for Women in Mathematics and in Aboriginal Careers, by actively participating in Waterloo's Women in Mathematics Committee, and by using personal connections to faculty around the world. Despite these efforts, the proportion of strong female and minority candidates in the applicant pool is regrettably small. For example, in the 2015/2016 hiring round, there was a total of approximately 50 applicants that merited serious consideration, only six of which were women. C&O has offered positions to female candidates multiple times during the last 6 years alone: Karen Yeats was hired in the 2015/2016 hiring round, and has just recently been awarded a Canada Research Chair (tier 2). In the 2016/2017 hiring round, the department's top candidate was female, received an offer, and turned it down. The department has subsequently conducted interviews with this candidate to understand the reasons for turning down the offer. In the ongoing 2017/2018 hiring round, 3 out of 8 shortlisted candidates are female.

The department is actively promoting female and minority candidates in its graduate programs in order mitigate imbalance in STEM disciplines. The proportion of female students in the department's MMath programs is 30%, highest in the Math faculty, and the proportion is 20% in its PhD programs, third highest in the faculty. The department encourages female and minority candidate applications to its graduate programs; e.g., by providing entrance scholarships to underrepresented groups.

4. **Graduate student recruitment**: In the current demographic, there are not enough good domestic recruits to feed the vitality of the department. This is especially true in mathematics in general, and C&O must turn to international students as well to complement their strength. At the university of Waterloo, the proportion of International graduate students is 38%; in the C&O department it is 55%. This is not surprising for us and in fact we strongly recommend that the University continue to support this disparity. Reducing the proportion of international students would affect significantly the quality of the department.

   In such competitive environment, it is very important that the files of candidates be process as quickly as possible. During our visit we where given the assurance that this will be the case in future recruitment periods. We have two small suggestions that may help increase the successful recruitment of the best graduate students.

   a. Fly-in the best potential international candidate for a short visit of the University.

b. Send faculty to recruit first hand in strategic area in the USA (Boston, San Francisco, etc)

Response

The intake of graduate students in C&O varies significantly from year to year quite unpredictably. It seems clear that the department's current number of students is very close to the maximum number it can handle, being constrained by upper bounds on the financial support available and by the number of supervisors (with the latter more important). The department does fly in potential graduate students from the US each year, and will continue to do so. They also arrange skype interviews with students from outside North America, and will consider bringing some in for a campus visit. C&O makes offers to strong students as quickly as possible, which they have found impresses the applicants. The program also encourages the active involvement of their faculty in recruiting strong students, via skype calls and through contact at conferences and research visits.

5. **Graduate student funding**: This might be the greatest challenge of the department. As mentioned above, it is important for C&O department to have a higher proportion of international students. But the opportunities to fund such students are much less than domestic students and the burden then rely on PI grants. In some research groups, NSERC grants are insufficient to support the number of international students. Thus far the department has been creative in their budget to allow the funding of the best international students in all research groups. It is vital that this practice continue. It is our understanding that the new budget model of the university will serve well the faculty of mathematics. We strongly recommend that with the new model a fair proportion of the budget be allocated to the funding of international graduate students. The strong international reputation of the departments relies on this.

   Response

   The department feels that graduate student funding is in a satisfactory state. The department will continue to investigate ways in which it can assist the principal investigators to fund their students.

6. **Communication**: We recommend that the department work with all interested parties to improve communications issues.

   Response

   C&O recognizes the need to pay more attention on an ongoing basis to communication with new students (and with new faculty). Since the review took place, C&O students organized a meeting to discuss their concerns amongst themselves, and these were brought to a

department meeting. Department meetings are now always attended by a graduate student representative that can voice graduate student concerns directly. A number of suggestions of graduate students were readily accommodated such as revising some web pages that were out of date or incomplete as this was the source of many of the problems. The students have indicated that they are happy with this response, and C&O will monitor these websites more closely. Departmental staff is closely involved in the budgetary process, and hence the department feels that there is adequate transparency about budget and regulation. The department also feels that admission-related information is adequately communicated.

7. **Flexibility**: Within reason, the department should be open to special request of the students. In particular students should be aware of their options.

   Response
   C&O indicates that they normally grant approval for special requests, if a student offers reasonable academic grounds for a variation in their rules and normally, if the variation is approved by the student's supervisor, then their Graduate Committee accedes to the request. This practice is commonplace and will continue. The department will ask its Graduate Chair to review student rights and options in her/his personal meeting with the student at the end of semester 1 (see response to recommendation 8). The department will also adapt its existing graduate student seminar (mandatory for all students) to incorporate material on student options and rights.

8. **Masters' Advising**: For Masters' students, plan one-on-one short meetings with the Graduate Chair shortly after arrival and maybe once again in the course of the year.

   Response
   It is common practice for the Mathematics Faculty to organize a graduate student orientation in the Fall. This orientation is organized in collaboration with the departments, and C&O does of course take part. In addition to this, C&O will arrange for the Graduate Chair to have personal meetings with each of the incoming students on arrival, and at the end of their first semester.

Implementation Plan:

	Recommendations	Proposed Actions	Responsibility for Leading and Resourcing (if applicable) the Actions	Timeline for addressing Recommendations
1.	Faculty recruitment	The reviewers recommend that the department promotes a more active, focused search in areas of need. This is C&O's current policy.	Chair	
2.	Faculty retention.	Contact faculty members that left the department since 2006 and inquire for reasons. In the future, determine reasons for leaving prior to the event.	Chair	Started, and ongoing
3.	Gender balance	No concrete recommendation was made. The department will continue to encourage applications from women and minority candidates by advertising in appropriate venues, and by supporting local initiatives enhancing gender balance. The department will also continue its efforts to encourage female and minority students to join its graduate programs.	Chair	
4.	Graduate student recruitment	The department currently flies in strong applicants for visits, conducts skype interviews with those applicants, and involves faculty members in this process. The department will continue these practices.	Chair	

5.	Graduate student funding	No recommendation to the department was made		
	Recommendations	Proposed Actions	Responsibility for Leading and Resourcing (if applicable) the Actions	Timeline for addressing Recommendations
6.	Communication	Spend more time explaining policies and procedures to new students, and to new hires. Add elected graduate student representative to department meetings. Adapt curriculum of mandatory graduate student seminar to include material on options and rights.	Chair, Graduate Chair	Already started, and ongoing
7.	Flexibility	We are already very flexible. Graduate Chair will review options with students in meeting after semester 1. Will include discussion of student options and rights into graduate seminar.	Chair, Graduate Chair	Started in Fall'16, and continued
8.	Masters advising	Introduce meetings as suggested.	Graduate Chair	Started in Fall'16, and continued.

The Department Chair/Director, in consultation with the Dean of the Faculty shall be responsible for monitoring the Implementation Plan.

Date of next program review: 2022

Date

Signatures of Approval:

Chair/Director	Date
AFIW Administrative Dean/Head (For AFIW programs only)	Date
Faculty Dean	Date
Associate Vice-President, Academic (For undergraduate and augmented programs)	Date
Associate Vice-President, Graduate Studies and Postdoctoral Affairs (Formerly the Associate Provost, Graduate Studies) (For graduate and augmented programs)	Date