Canadian Mathematical Society

Société mathématique du Canada

THE STATE OF CANADIAN MATHEMATICS

A 2010 SURVEY AND PERSPECTIVE

A Review Commissioned by the
Canadian Mathematical Society

August 2011

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The Canadian Mathematical Society promotes the advancement, discovery, learning and application of mathematics.

La Société mathématique du Canada favorise l'avancement, la découverte, l'apprentissage et l'application des mathématiques.

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EXECUTIVE SUMMARY

In 2010, the Canadian Mathematical Society commissioned a review of Canadian Mathematics, as practised in university mathematics departments. This review was intended to be fairly comprehensive and to cover the university departments, institutions, and the practitioners of mathematics, and to touch upon mathematical research, teaching, and outreach to the educational community. The observations in this report are based upon a survey of universities, research and extrapolations completed in 2010. As the survey follows on a major effort in the same direction undertaken 15 years ago, with follow-ups in 1998 and 2002, the base line for comparison was a period of 10 years.

UNIVERSITY DEPARTMENTS

There are 58 university mathematics departments in Canada, some including statistics or computer science. For purposes of the study, the departments were divided into large (20 or more mathematics faculty members), medium (between 10 and 19, and small (less than 10). Together, they comprise some 1,050 mathematics faculty.

Significant findings of the study include:

- *Renewal:* Half of the faculty on staff at the universities were not there 10 years ago.
- *Growth:* Over 10 years, there has been moderate growth in faculty numbers (6%) and in undergraduate student numbers (19%). The growth at the graduate level has been spectacular, with 54% at the MSc level, 109% at the PhD level, and 136% at the postdoctoral level.
- *Gender:* While women represented only 17% of faculty in 2008, they also

RÉSUMÉ EXECUTIF

En 2010, la Société mathématique du Canada a commandé un examen de la situation des mathématiques dans les départements de mathématiques des universités du Canada. Cet examen se voulait approfondi, et a porté sur les départements, les établissements et les praticiens des mathématiques, touchant à la recherche, à l'enseignement et aux rapports avec le milieu de l'éducation. Les observations du rapport reposent sur une enquête , et sur des études et des extrapolations terminées à la fin de 2010. Puisque l'enquête est le prolongement de travaux dans le même sens entrepris il y a 15 ans, avec suivis en 1998 et en 2002, la base de comparaison choisie est une période de 10 ans.

DÉPARTEMENTS UNIVERSITAIRES

Le Canada compte 58 départements de mathématiques universitaires, dont certains sont jumelés à la statistique ou à l'informatique. Aux fins de la présente étude, ces départements ont été classés en trois catégories : grand (20 membres ou plus du corps professoral en mathématiques), moyen (de 10 à 19) et petit (moins de 10). Quelque 1050 professeurs mathématiciens enseignent dans ces départements.

Les faits saillants de l'étude :

- *Renouvellement :* La moitié du corps enseignant des départements universitaires n'y était pas il y a 10 ans.
- *Croissance :* En 10 ans, le nombre d'enseignants et d'étudiants de premier cycle a connu une croissance moyenne (6 % et 19 % respectivement), tandis que le nombre d'étudiants aux cycles supérieurs a augmenté de façon spectaculaire : de 54 % à la maîtrise

represented 29% of assistant professors, suggesting an emerging higher participation among women.

- *Interdisciplinarity:* The current student population is much more interdisciplinary than ever before (e.g. with biology, finance, computing, etc.) and departments are facilitating graduate studies outside pure mathematics. The universities have developed a variety of interdisciplinary structures to facilitate these efforts.
- *Internationalisation:* The strong international flavour of our research community continues to develop. Of the 47 Canada Research Chairs devoted to Mathematics, 23 moved to Canada from abroad.
- *Research funding:* The NSERC Discovery Grants Program continues to be the main source of research funding for departments, with 55% of the funding coming from this single source. In the last decade, NSERC funding to the departments responding to the survey grew by 40% to roughly $13 million while other funding grew 50% to around $10 million.

PROFESSIONAL SOCIETIES

Canadian Mathematical Society: With 1,000 members, the national professional society for the mathematical sciences is the self-funded Canadian Mathematical Society (CMS), which promotes the advancement, discovery, learning, and application of mathematics through semi-annual research and education meetings, public lectures, awards, publication of journals, math camps and competitions, and domestic and international representations.

(MSc), 109 % au doctorat et 136 % au postdoctorat.

- *Sexe :* Les femmes ne représentaient que 16,8 % du corps professoral en 2008, mais 29 % des professeurs adjoints, ce qui laisse supposer une tendance à la hausse de la participation féminine.
- *Interdisciplinarité :* La population étudiante actuelle est beaucoup plus interdisciplinaire qu'elle ne l'a jamais été (programmes mixtes en biologie, finances, informatique, etc.), et les départements facilitent les études supérieures dans des domaines autres que les mathématiques pures. Les universités ont prévu toutes sortes de structures interdisciplinaires pour soutenir ces efforts.
- *Internationalisation :* Le caractère international de notre communauté scientifique est de plus en plus évident. Quelque 23 des 47 Chaires de recherche du Canada consacrées aux mathématiques ont été attribuées à des personnes de l'étranger venues s'installer au Canada.
- *Financement de la recherche :* Le Programme de subventions à la découverte du CRSNG demeure la principale source de financement de nos départements; il compte pour 55 % du financement. Au cours des 10 dernières années, les subventions du CRSNG accordées aux départements qui ont répondu à l'enquête ont augmenté 40 % (ce qui représente environ 13 millions de dollars), tandis que les autres sources de financement ont connu une croissance avoisinant les 50 % (environ 10 millions de dollars).

Other important societies for the development of mathematics in Canada include the Canadian Applied and Industrial Mathematics Society (CAIMS), which represents the interests of mathematicians working in both university and industrial sectors, the Statistical Society of Canada (SSC) with about 1,000 members, the Canadian Discrete and Algorithmic Mathematics (CanaDAM) group, and the Canadian Society for History and Philosophy of Mathematics (CSHPM).

PROFESSIONAL INSTITUTES

Canada has developed a strong network of research institutes that are both national and international in scope and that have nurtured mathematics in Canada through internationalism, select scientific focus, development of highly qualified personnel (HQP), strategic initiatives, and leverage of partner resources. There are three main institutes, the Centre de Recherches Mathématiques (CRM), the Fields Institute, and the Pacific Institute for the Mathematical Sciences (PIMS); together with the Atlantic Association for Research in the Mathematical Sciences (AARMS), they provide comprehensive coverage across the country.

The Banff International Research Station has come to occupy an important place in the Canadian Research Network. With over 40 workshops per year, it is funded by the Canadian, Alberta, United States and Mexican governments

The MITACS Network of Centres of Excellence has played a key role over the last dozen years in developing Canadian industrial research in mathematics in Canada. It is coming to the end of its 14-year funding cycle, and it is unclear how these efforts will continue.

SOCIÉTÉS PROFESSIONNELLES

Société mathématique du Canada : Comptant un millier de membres, la Société mathématique du Canada (SMC) est la société professionnelle nationale en sciences mathématiques. Cette société autofinancée favorise l'avancement, la découverte et l'apprentissage des mathématiques, ainsi que des applications qui en découlent, par divers moyens : réunions semestrielles axées sur la recherche et l'éducation; conférences publiques; prix; publication de revues; camps et concours de mathématiques; représentation nationale et internationale.

Parmi les autres sociétés importantes pour le développement des mathématiques au Canada, mentionnons la Société canadienne de mathématiques appliquées et industrielles (SCMAI), qui représente les mathématiciens tant du milieu universitaire que de l'industrie; la Société statistique du Canada (SSC), qui compte environ 1000 membres; le groupe du Congrès canadien de mathématiques discrètes et algorithmiques (CanaDAM) et la Société canadienne d'histoire et de philosophie des mathématiques (SCHPM).

INSTITUTS PROFESSIONNELS

Le Canada s'est doté d'un solide réseau d'instituts de recherche nationaux et internationaux. Ces instituts soutiennent les mathématiques au Canada par divers moyens : internationalisation, initiatives scientifiques pointues, développement de personnel hautement qualifié (PHQ), initiatives stratégiques et obtention de ressources de partenaires. Les trois principaux instituts sont le Centre de recherches mathématiques (CRM), l'Institut Fields, et l'Institut du Pacifique pour les sciences mathématiques (PIMS); avec l'Association pour l'avancement de la recherche

MATHEMATICAL RESEARCH

The review surveys the Canadian mathematics research scene. It is impossible to do justice to the issue in a summary. Suffice to say that it has grown to an amazing degree over the last 10 years. A few general trends are observable: one is the important growth in applied mathematics, in particular, in the area of mathematical biology.

EDUCATION AND OUTREACH

Education and outreach activities, to one degree or another, are undertaken by virtually all mathematics organizations across Canada with the principal architect for collaboration being the Canadian Mathematics Education Study Group (CMESG). The variety of activities undertaken is far-ranging.

mathématique en Atlantique (AARMA), ils couvrent une bonne partie du pays.

La Station de recherche internationale de Banff occupe désormais une place importante au sein du réseau scientifique canadien. Offrant plus de 40 ateliers par année, elle est financée par les gouvernements du Canada, de l'Alberta, des États-Unis et du Mexique.

Le Réseau de centres d'excellence MITACS joue un rôle clé depuis une douzaine d'années dans le développement de la recherche industrielle en mathématiques au Canada. Comme ce réseau approche la fin de son cycle de financement de 14 ans, on ne sait pas exactement de quelle façon ses travaux se poursuivront.

RECHERCHE MATHÉMATIQUE

L'étude comporte également une enquête sur la recherche mathématique au Canada, dont il est impossible de bien rendre compte dans un résumé. Disons seulement que le secteur de la recherche a connu une croissance exceptionnelle depuis 10 ans. On observe quelques tendances générales, notamment l'évolution importante des mathématiques appliquées, en particulier dans le domaine de la biologie mathématique.

ÉDUCATION ET SENSIBILISATION

La plupart des associations mathématiques du Canada organisent des activités d'éducation et de sensibilisation sous une forme ou une autre. Le Groupe canadien d'étude en didactique des mathématiques (GCEDM) est le principal artisan de la collaboration dans ce domaine, où la diversité des activités est très grande.

1.0 INTRODUCTION

In early 2010, the Canadian Mathematical Society (CMS) Executive Committee decided to undertake a state of mathematics review – the first such complete review since Richard Kane ably piloted a similar study in 1997[1]. Since then, two Natural Science and Engineering Council (NSERC) reallocation documents[2] had given more summary reviews; it was felt, however, that it was time for a more complete look. The Executive felt that such a review would have a variety of users in our universities and within the community. It turned out to be particularly apposite, since in late 2010 NSERC challenged the mathematics and statistics communities to come up with a five-year plan for research funding.

The range of a review could be almost infinite. Mathematics is the prose of science: all scientists are doing it to some degree, even if they don't know it. The review committee took a much more modest approach, focusing on the universities, and, by and large, on the mathematics departments. Many of our university departments comprise both mathematics and statistics; similarly, computer science often gets folded in with mathematics at smaller universities. The committee confined its focus to mathematicians only: statisticians, in particular, have their own association[3] and any review would be within their purview. Naturally, there are boundary effects, and the committee hopes for some indulgence if it has claimed a few too many of the good people working near these boundaries as 'mathematicians'. Suffice to say, the CMS enjoys good relations with all the groups within the sector and indeed partners with and supports many of them.

The study comprises a survey of our mathematics departments, an overview of our research institutions, and an overview of Canadian research in mathematics, a sort of "catalogue raisonné". In comparison with the previous allocation documents, the review has perhaps a flatter tone, without adjectives. The review proper closes with a section on the substantial outreach efforts of the Canadian mathematics community. There follow several appendices listing members within the community who have won major research prizes over the last 30 or so years.

[1] The National Review of the Canadian Mathematical Community (May 13, 1997), available at http://cms.math.ca/Reports/

[2] The Mathematics Reallocation Document (January 1, 1998) and NSERC Reallocation and Mathematics (July 25, 2002), available at http://cms.math.ca/Reports/

[3] Statistical Society of Canada: http://www.ssc.ca

Each section has its surprises. The survey of departments, for example, brings out the recent growth of graduate studies at our universities, if not of the professorial faculty to teach them. It also highlights the extent of faculty renewal. [Message to NSERC: more money needed.] The survey of institutions (institutes, MITACS, BIRS, professional societies) highlights the extent to which they have become part of life. The survey of research areas shows that while the community remains strong in the areas highlighted 15 years ago, such as number theory, several other areas have also expanded. The applied areas, as well as the connection to applications in areas thought of as pure, have seen enormous growth. A few other areas, fairly quiet here 15 years ago, are now flourishing: partial differential equations (pde) and algebraic geometry are two areas which come to mind. Above all, one finds an extraordinary strength across the board, unthinkable 20 or 30 years ago.

The Canadian mathematical community is one with a high profile internationally. Canada is a member of group V in the International Mathematical Union (IMU), and is one of the few countries to have hosted the International Mathematical Congress in Industrial and Applied Mathematics more than once. Congresses are held every four years and the 7^{th}, ICIAM 2011, was held in Vancouver from July 18-22, 2011. Canada has also been the driving force behind the initiative *Mathematics of Planet Earth 2013 (MPE2013)*, with scientific and outreach activities taking place all around the world.

As a community, it is well organized and professional, and the CMS has been at the vanguard of these efforts for over 60 years. The Canadian mathematics institutes and BIRS have programs that compete with the best in the world and MITACS has built a model that is admired around the world and sometimes copied. Our scientific level has increased immeasurably over the last 20 years, thanks principally to an influx of new talent that has had a remarkably vivifying effect. The observations that follow highlight some of these developments.

Many individuals have helped the committee in the preparation of this review. The committee would like to thank most particularly Martin Barlow, Rustum Choksi, Tony Humphries, Bruce Shepherd, Eyal Goren, as well as Kathryn Hare for her contribution on women in Canadian mathematics, and all the department chairs who took the time to fill out the survey. Thanks are also due to the people at PIMS (Mark Gotay), the Mathematics Department at the University of Toronto (Pamela Brittain), the ISM (Alexandra Haedrich) and AARMS (David Langstroth) who helped collate the data. The mistakes and omissions are those of the committee; as a partial excuse, there is such a wide variety of activity across Canada that not everyone or everything could be named or referenced.

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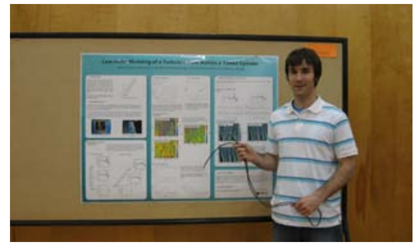


2.0 UNIVERSITY DEPARTMENTS

The past 10 years have seen a major renewal of Canadian mathematics departments, with the top ones moving up to a level of international leadership. Over half the current faculty in our departments arrived during this period, with a good fraction of them Canada Research Chairs (CRC). Graduate students have doubled in number, and there has been a plethora of structures put in place in our departments to accommodate them, in particular in multi-disciplinary areas.

This picture emerges from a survey sent out to Canadian mathematics departments, complemented by data that is publicly available. The survey covered faculty demographics, student populations, and research funding. The survey excludes statistics and computer science; most Canadian departments combine mathematics and statistics, and the smaller ones often include computer science as well.

The survey had a response rate of 17 out of 19 among the large departments (20 or more mathematics faculty members), 12 out of 18 in the medium-sized departments (10 to 19 faculty) and 7 out of 21 in small departments (less than 10 faculty). Sizes vary from 74 faculty members to a handful at several universities.

Additional data on the full set of departments, for faculty complements and for NSERC funding of faculty, was extracted from the Web.

2.1 DEMOGRAPHICS

TABLE 1: Mathematics Departments in Canada (2010)

	Total	Large	Medium	Small
Departments	58	19	18	21
Faculty Members	1,050	680	250	120

Source: CMS Departmental Survey and Web Survey 2010

In 2010 there were 58 mathematics departments in Canada and about 1,050 faculty members teaching mathematics within these departments. In addition, of course, there were many faculty members working outside these departments, whose research interests were essentially mathematical. As presented in Table 1, large departments employ roughly two-thirds of all faculty members, medium-sized departments employee about a fourth, and small departments represent a bit over 10% of all faculty members. The more detailed Table 2 data was developed based upon information from the 36 of 58 departments answering the survey.

TABLE 2: Mathematics Faculty Demographics (Departments responding to 2010 survey)

Size of Department	# 0f Faculty		Hires	Age of Faculty Members (2010)				# of Chairs (2010)	NSERC Funded	
	2000	2010	2000-2010	< 40	40-49	50-59	> 60		2000	2010
Large	553	616	322	164	174	146	130	51	429	516
Medium	174	164	88	41	42	47	34	5	99	103
Small	51	46	17	8	18	10	10	0	14	21
Totals:	778	825	427	213	234	203	174	56	542	640

Source: CMS Departmental Survey 2010

As one finds from Table 2, the renewal of faculty has proceeded at a remarkable rate with about half of the faculty hired in the last 10 years. On the other hand, growth in faculty numbers has been a modest 6%. This growth has been concentrated in the large universities, with the medium and small ones shrinking. There is a fairly even spread in the age groups of faculty, in contrast to the situation in the mid-1990s, when there was a bulge corresponding to the expansion in the 60s and 70s.

There were 56 chairs of all sorts reported in the survey; the CRC website lists 47 chairs in mathematics across the country.

The ratio of NSERC Discovery Grant holders to faculty ranges from 82% at the large universities, to 61% at the medium-sized ones, to 35% at small universities, with an overall ratio of 71%. The percentage of faculty funded is a bit smaller, by an order of 3% to 4%, as some of the grant holders are adjuncts, emeriti, etc. This data, of course, does not incorporate the full effects of recent changes to the administration of the NSERC Discovery Grants Program.

2.2 STUDENTS

The survey data presented in Tables 3A, 3B, and 3C, encompasses students at undergraduate, masters, PhD and postdoctoral levels.

TABLE 3A: Student Undergraduate Population Changes By Category of Study (Departments responding to 2010 survey)

Department Size	Undergraduate Category of Study						All Categories of Undergraduate Study		
	Majors and Honours Students			Interdisciplinary Students					
	2000	2010	% Change	2000	2010	% Change	2000	2010	% Change
Large	3,648	4,197	11.5%	590	870	47.5%	4,238	5,067	19.6%
Medium	610	641	5.1%	22	36	63.6%	632	677	7.1%
Small	127	179	40.9%	56	82	46.4%	183	261	42.6%
Totals:	4,385	5,017	14.4%	668	988	47.9%	5,053	6,005	18.8%

Source: CMS Departmental Survey 2010

TABLE 3B: Student Graduate Population Changes By Category of Study (Departments responding to 2010 survey)

Department Size	Graduate Category of Study						All Categories of Graduate Study		
	Masters Students			PhD Students					
	2000	2010	% Change	2000	2010	% Change	2000	2010	% Change
Large	427	632	48.0 %	313	650	107.7 %	740	1282	73.2 %
Medium	65	120	84.6 %	45	99	120.0 %	110	219	99.1 %
Small	0	6	n.a.	0	0	n.a.	0	6	n.a.
Totals:	492	758	54.1 %	358	749	109.2 %	850	1,507	77.3 %

Source: CMS Departmental Survey 2010

Over the last 10 years, the numbers of doctoral students and postdoctoral fellows in mathematics departments have more than doubled.

The number of undergraduates has, on the other hand, increased at a much slower rate, and especially at small and medium universities. The responses in the undergraduate survey regarding those registered in interdisciplinary programs, with mathematics, varied widely; possibly as a result of differences in interpretation.

TABLE 3C: Post Doctorate Population Changes (Departments responding to 2010 survey)

Department Size	Post Doctorates		
	2000	2010	% Change
Large	83	189	127.7%
Medium	6	18	200.0 %
Small	0	3	n.a.
Totals:	89	210	136.0%

Source: CMS Departmental Survey 2010

As an indicator of the size of the populations, we have extrapolated to all departments, not just those answering the survey:

TABLE 4: 2010 Mathematics Student Populations, Extrapolated By Category of Study and Type of University

Department Size	Undergraduate Majors, Honours Students		Undergraduate, Interdisciplinary Students		Masters Students		PhD Students		Postdoctoral Fellows	
	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010
Large	4,077	4,690	659	972	477	706	349	726	92	211
Medium	915	961	33	54	97	180	67	148	9	27
Small	381	537	168	246	0	18	0	0	0	9
Total	5,373	6,188	860	1,272	574	904	416	874	101	247

Source: Extrapolation from CMS Web Survey 2010

TABLE 5: Percentage Split of Student Population Between Sizes of Departments, by Type.

Department Size	Undergraduate Majors, Honours Students	Undergraduate, Interdisciplinary Students	Masters Students	PhD Students	Post-doctoral Students
Large	76	77	78	83	86
Medium	16	4	20	17	11
Small	8	19	2	0	3
Total	100	100	100	100	100

Source: CMS Web Survey 2010

The growth rate of all students studying mathematics has been substantial and the population has grown dramatically over the last 10 years. As can be expected, the larger the university, the larger the student population.

By comparison, a recent Association of Universities and Colleges of Canada (AUCC) report[4] found that over the last 30 years:

- At the undergraduate level, enrolment grew from 550,000 to 994,000 in 2010, an annual growth rate of 1.99%; and
- At the graduate level, enrolment grew from about 77,000 in 1980 to about 190,000 in 2010, an annual growth rate of 3.05%.

The same report also notes that in 2010 56% of university students were women – a percentage not reflected in the population of mathematics students.

[4] Trends in Higher Education, Volume 1 – Enrollment, 2011.

2.3 WOMEN FACULTY

According to the CAUT[5], in 2008 16.8% of the faculty members in Canadian mathematics departments were women. However, 29% of the assistant professors were women, suggesting that a higher percentage of women have been hired in recent years than in the past, and that the overall percentages of female faculty will increase with time. But there are still many Canadian mathematics departments with few women faculty. The percentage of female assistant professors is nearly the same as the percentage of women enrolled in math and physical science PhD programs,[6] (30%), but significantly lower than the percentage of women obtaining masters degrees or bachelor's degrees (39%). The reasons for this "drop off", as well as why women are less likely to choose to study mathematics than the life sciences, for example, are undoubtedly complex.

NSERC statistics show that at each level the average grant size for women is similar to that for men. In the United States, women mathematicians are more likely to hold positions at undergraduate institutions than at institutions with graduate programs and anecdotal evidence suggests the same is true in Canada. If this is the case, then women mathematicians may be more disadvantaged than men by the changing NSERC policies.

The Canadian Mathematics Society has an active Women in Mathematics committee which seeks to support, encourage and promote women mathematicians. The CMS Krieger-Nelson prize recognizes outstanding research by a female mathematician. In the last 10 years, it has been won by women from six different Canadian universities and one woman from an American university, a past director of the Fields Institute. In the past 10 years, two women have won the CMS Coxeter-James award for outstanding research by a young mathematician.

Several conferences for women working in particular research areas, such as the Women in Algebraic Combinatorics to be held at BIRS in the spring of 2011, have also been organized. These have been found to be a good way to connect women mathematicians and establish research collaborations, often between junior and senior women.

2.4 FUNDING

Departments were asked to report on their research funding in various categories: NSERC Discovery grants, other NSERC grants, provincial grants, industrial funding, MITACS funding, university funding, and other funding sources. There are a few conclusions to be drawn here:

[5] CAUT Almanac, 2010-2011.

[6] Women in science and engineering in Canada, Corporate planning and policy directorate, NSERC, 2010. Data is for 2008-9.

- There is an overall increase in funds of about 40% in NSERC Discovery Grant funding over the past 10 years.
- Funds from other sources have expanded by about 50%; there has thus been some diversification, but the amount of NSERC funding outstrips other sources by $10 million to about $13 million, indicating we are still crucially dependent on this source.
- There are about 750 discovery grants in mathematics departments. By comparison, about 650 grants were funded by the Mathematics Grant Selection Committees in 2009-10; there is thus an important disciplinary spread into such areas as computer science and engineering within mathematics departments.

TABLE 6: Evolution and Source of Funding, Departments Answering Survey

2000	Department Size	Funding in '000s						
		NSERC Discovery	NSERC other	University	Provincial	Industrial	MITACS	Other
	Large	7,343	603	1,215	180	654	774	788
	Medium	1,359	359	687	400	13	50	0
	Small	144	0	0	9	0	0	0
	Total	8,846	962	1,902	590	667	824	788
2010	Department Size	Funding in '000s						
		NSERC Discovery	NSERC other	University	Provincial	Industrial	MITACS	Other
	Large	11,073	2,265	1,297	1,015	928	583	1,975
	Medium	1,815	592	154	486	246	65	117
	Small	234	27	0	26	74	53	254
	Total	13,123	2,884	1,450	1,527	1,248	701	2,346

Source: CMS Departmental Survey 2010

Table 6 gives a rough guide to the proportions of funds available to our departments; as noted above, the NSERC Discovery Grants are still the mainstay of our enterprise. Referring to the NSERC website for our mathematics departments, we have the following split of NSERC Discovery Grants:

TABLE 7: NSERC Discovery Grants, Split by Sizes of Departments (all departments, not just survey respondants)

	Large	Medium	Small	Total
Amounts, in '000	11,761	2,725	528	15,015
Percentage	78	18	4	100

There has been an additional source of funding, in some sense transverse to all the other sources, that has had major importance in the last 15 years. The Canadian mathematics institutes together fund “local” research (i.e., in departments) in synergy with their programs. If one counts just the resources going to postdocs and to local research groups (e.g., through the CRM Laboratoires or the PIMS Collaborative Research Groups), this support adds up to several million dollars a year.

As resources for graduate training, the research funds are complemented with teaching assistantships of various kinds at the universities; an abundance of service courses in our departments generally means that there are a relatively large number of assistantships compared to other disciplines.

2.5 INTERNATIONAL RECOGNITION

It is quite clear to anyone following the development of mathematics in Canada that there has been a major jump in the level of our discipline, consistently recognized internationally. Documenting this advancement is difficult, though. There are two indicators that do, however, point to this overall phenomenon:

- Prizes to Faculty, in particular young faculty, have increased. The most telling tale is the Sloan fellowships. Though American in origin, these are open to Canadians. If one tracks winners of the Sloan fellowship currently in Canada decade by decade, five won it in the 1980s (three of these won the fellowship in the United States and later moved to Canada, on CRCs!), 10 in the 1990s, and 15 from 2000 to 2010.
- Of the 47 current CRC Chairs in Mathematics in Canada, about one half attracted researchers from outside Canada.

In addition, there are a number of other indicators that are difficult to capture in a survey but evident in looking at individual departments and faculty CVs: strong international recruitment of faculty, postdocs, and graduate students; researchers from Canadian universities playing prominent roles in international meetings, boards, and associations; and leadership in collaborative research activities internationally.

2.6 PROMOTION OF RESEARCH AND GRADUATE STUDIES

Our departments have, either individually or severally, equipped themselves with structures adapted to the promotion of research and graduate studies; these are often in applied areas, to fit better the natural interdisciplinary mix in the discipline. The development of these structures reflects a major shift in Canadian mathematics.

Mathematical Biology: There have been a number of institutional initiatives that serve as foci for the rapidly emerging field of mathematical biology: to name a few, McGill’s Centre for Applied Mathematics in Bioscience and Medicine (CAMBAM), York’s MITACS Centre for Disease Modeling, Alberta’s Centre for Mathematical Biology, Calgary’s Centre for Mathematics in the Life Sciences, and UBC’s Mathematical Biology Group, the last three combined under the umbrella of PIMS' International Graduate Training Centre (IGTC). These research centres or groups typically combine mathematicians, theoretical biologists, computer scientists, and researchers from the life sciences in a collaborative interdisciplinary group.

Mathematical Finance: In a similar vein to mathematical biology, mathematical finance institutes exist in Waterloo (Centre for Advanced Study in Finance), Toronto (Risklab), Calgary (Mathematical Finance Laboratory), McMaster (PhiMAC) and UQAM (Institut de Fienance Mathématique de Montréal). These institutes have helped focus efforts on the development of the area, often in conjunction with business schools.

Computation, Fluid dynamics: Computing and computational mathematics has also fostered several initiatives, often coordinated with major computing facilities: examples include UBC's Complex and Non-Newtonian Fluids Lab, SFU's Centre for Experimental and Constructive Mathematics (CECM), and Laval's Groupe Interdisciplinaire de Recherche en Éléments Finis (GIREF). Networks for sharing large scale computing facilities like SHARCNET, RQCHP, CLUMEQ and WestGrid have also been heavily tapped for computation.

Applied and Industrial Mathematics: Initiatives in this field include the Institute for Applied Mathematics (UBC), the Applied Mathematics Institute (Alberta), the Institute of Industrial Mathematical Science (Manitoba), and the Centre for Computational Mathematics in Industry and Commerce (Waterloo).

Others: The preceding areas do not exhaust the list of initiatives: there are in addition centres in quantum computing (Waterloo's Institute for Quantum Computing, and Institut Transdisciplinaire d'Informatique Quantique [INTRIQ] in Quebec) and cryptography (Waterloo's Centre for Applied Cryptographic Research and Toronto's Ganita).

2.6.1 Regional Structures

Quebec's ISM: Another initiative has been Quebec's Institut des Sciences Mathematiques, now approaching its 20th year of existence. Having started as a consortium of the Montreal universities, and gradually extending to all of Quebec, it functions as a graduate consortium, enabling students to move between universities, coordinating graduate offerings, as well as offering graduate scholarships and, together with the CRM, post-doctoral fellowships. It also functions as a vehicle for outreach into schools and CEGEPS. Its annual budget now approaches half a million dollars. Its impact on lifting the level of graduate training has been considerable.

2.6.2 The Mathematics Institutes and Disciplinary Structures

The Mathematics institutes have in various ways created structures in the local community that focus on chosen areas of mathematics, which tie in to their programs, but also foster research in the related departments.

CRM laboratories. The Centre de Recherches Mathématiques (CRM) has funded a number of laboratories jointly with partner universities, on an inter-university basis, in a number of areas of strength in Quebec. The areas include topology and geometry, number theory, mathematical physics, applied mathematics, analysis, applied mathematics, computation, combinatorics and statistics. These laboratories run seminars and small workshops, fund visitors, and generally encourage the formation and consolidation of solid research groups.

PIMS Collaborative Research Groups. Collaborative research groups typically are formed by researchers with a common research interest and with a desire to collaborate actively in their research and training programs. Through the PIMS program these groups create new connections, organize joint seminars and workshops, foster stronger international connections, and advance training through joint PDF appointments or graduate training programs, and have the opportunity to do even more through the flexible resource support and structure. Primary funding runs typically through a concentration period of 2-3 years, with the collaborations continuing well beyond this concentration period. The past and present CRGs have covered the full range of pure and applied math, and extended to other disciplines such as geophysical dynamics, biological modelling, statistics, and computations.

In both the CRM and PIMS cases, the synergy of these groups with departments has had a major impact on research, through the leveraging of resources, cooperation of universities and institutes, and the expansion of international connections. Through intensive workshop and training programs these groups can support the research of an entire field while creating an energetic environment for senior and junior researchers, as well as facilitate recruitment of new talent at all levels.

3.0 PROFESSIONAL SOCIETIES

The Canadian mathematical community has a network of institutions that is envied throughout the world. Separately, they support scientific activities of the highest level; they also collaborate closely, contributing greatly to Canada's international visibility.

3.1 THE CANADIAN MATHEMATICAL SOCIETY (CMS)

The CMS, founded in 1945 as the Canadian Mathematical Congress, is the national professional society for the mathematical sciences in Canada. Self funded, with 1,000 members, the CMS plays a variety of roles:

- Organises two large meetings a year, with half a dozen plenary or prize lectures and 20 or so special sessions. Attendance currently runs to 400-500 participants per meeting. Several of these meetings are held jointly with other societies or organisations (CAIMS, MITACS, CSHPM) or with societies of other countries (for instance, Korea, France, and the United States).
- Operates two major research journals, the *Canadian Journal of Mathematics* and the *Canadian Mathematical Bulletin*, as well as two major monograph series.
- Awards several major prizes to the Canadian mathematical community for excellence in research, education, service and careers.
- Takes a leading role in mathematical education at the high school level. In particular, it administers the Canadian Mathematical Olympiad, Canada's premier annual national mathematics competition for high school students, as well as selecting, training and supporting the Canadian team to the yearly International Mathematical Olympiad. Every three or four years, it organizes the Mathematics Education Forum, which links high school mathematics teachers and the faculties in Departments of Mathematics and Faculties of Education. Finally, the CMS coordinates a network of math camps (at least one per province).
- Provides funding for a Public Lecture Series to promote awareness of mathematics.
- Represents the Canadian mathematical community with government, funding agencies, and the public. While the National Research Council of Canada (NRC) is the adhering organization of Canada at the International Mathematical Union (IMU), in practice the Canada National Committee for Mathematics (CNC-IMU) is the CMS International

Affairs Committee. This Committee has been very active to push Canadian candidates on the IMU Executive and to increase the number of Canadian speakers at the International Congresses of Mathematicians (ICM).

- Provides support to students for the organization of the annual Canadian Undergraduate Mathematics Conference (CUMC).

Through these types of activities, the CMS strives to promote the advancement, discovery, learning and application of mathematics.

3.2 THE CANADIAN APPLIED AND INDUSTRIAL MATHEMATICS SOCIETY (CAIMS)

The Canadian Applied and Industrial Mathematics Society / Société Canadienne de Mathématiques Appliquées et Industrielles (CAIMS*SCMAI) dates from 1979. It represents mathematicians working in both university and industrial sectors.

- Organizes an annual meeting, which this past year had 8 plenary lectures, 8 theme sessions, and 7 minisymposia.
- Awards a number of prizes, including the Doctoral Dissertation Award, the Arthur Beaumont Distinguished Service Award, the CAIMS Research Prize, the CAIMS/PIMS Early Career Award in Applied Mathematics and the CAIMS/MITACS Industrial Mathematics Prize.
- Publishes a newsletter once a year, and maintains a web site at http://www.caims.ca
- In addition, CAIMS*SCMAI is a member society of the International Council for Industrial and Applied Mathematics, which hosts the ICIAM Congresses every four years: the seventh of these was held in Vancouver, July 18-22, 2011.

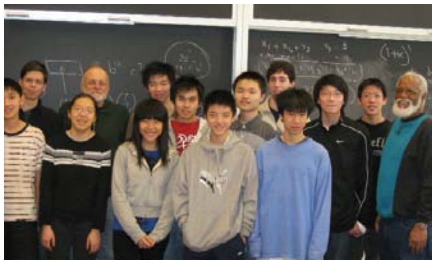
3.3 OTHER SOCIETIES

There are a number of other societies that support the Canadian mathematics community, including:

*Canadian Discrete and Algorithmic Mathematics Group (CanaDAM)***:** As an informal group, with about 330 participants, the Canadian Discrete and Algorithmic Mathematics (CanaDAM) holds an annual meeting that focuses on research related to discrete and algorithmic mathematics.

The Canadian Society for History and Philosophy of Mathematics (CSHPM): With about 240 members, the Canadian Society for History and Philosophy of Mathematics (CSHPM) promotes research and teaching in the history and philosophy of mathematics and holds an annual meeting.

Statistical Society of Canada (SSC): With approximately 1,000 members, the Statistical Society of Canada (SSC) encourages the development and use of statistics and probability through public awareness, accreditation, annual meetings, awards, and a journal publication.



4.0 PROFESSIONAL INSTITUTIONS

4.1 INSTITUTES

Canada has a rich and varied network of institutes that are both national and international in scope and that have nurtured mathematics in Canada through internationalism, select scientific focus, development of highly qualified personnel (HQP), strategic initiatives, and leverage of partner resources. The network of institutes includes:

The *Centre de Recherches Mathématiques (CRM)* in Montreal serves as a national centre for fundamental research in mathematics and their applications. The CRM coordinates advanced courses and is instrumental in the training of young researchers.

The Fields Institute in Toronto enhances mathematical activity in Canada by bringing together mathematicians from Canada and abroad, and by promoting contact and collaboration between professional mathematicians and the increasing numbers of users of mathematics.

The *Pacific Institute for the Mathematical Sciences (PIMS)* in the West promotes research in and applications of the mathematical sciences, facilitates the training of HQP, undertakes public awareness and education, and undertakes international partnerships.

4.1.1 Impacts

Functioning both individually and as a team, the institutes have helped build the mathematical culture that we know today in several ways:

Internationalisation. Through the programs and workshops hosted by the institutes, international science is brought to Canada. This develops the local mathematical culture and provides opportunities for our own community. Tied into their major impact on training, both postdoctoral and graduate, the institutes have been a powerful conveyor to bring talent to the country: as one chair of a major Canadian department was heard to remark, with humorous irony, “It is all the fault of the institutes- if they hadn’t attracted all that great faculty to Canada, we wouldn’t have this funding crunch”. There has been a concomitant increase of Canada’s profile in the international community as evident from the invitations to bid for the International Mathematical Congress in 2010 and 2014, and a Canadian vice-presidency in the International Mathematical Union.

Scientific Focus: The institutes, in their choice of programs (shaped in part thanks to their international panels) have helped to define the modern Canadian research agenda, placing it at the centre of the international evolution of the discipline.

Highly qualified personnel: The institutes play a pivotal role in training the new generation of mathematicians. As a result, students are exposed to the best the world has to offer, and the rest of the world comes here to work and study. The institutes also help to further the careers of current faculty. A good number of our faculty have had significant career boosts from institute programs. Critical postdoctoral programs provide necessary training for strong career trajectories, and make major contributions to the research programs across the community.

Initiatives: This advantage of the institutes is harder to quantify, but easy to show by examples: initiatives for which there is no pre-defined niche, but are obviously good things to do. A prime example is the launching of MITACS, an institute initiative that has taken off on its own successful trajectory. The institutes also played a key role in the establishment of AARMS. Internationally, the Canadian institutes have led the charge on several initiatives, most recently on the Mathematics of Planet Earth 2013 initiative.

Leverage: The institute model is not unique to Canada; indeed, the large number of these institutions founded across the world over the last 20 years is witness to its effectiveness. The Canadian institutes, however, are generally recognized as models of efficiency on their transfer to their scientific community. They also achieve results with funding that, by international standards, is remarkably low. NSERC's investment in the institutes is of the order of $3.6 million per year; this is leveraged from various sources (provincial, industry, university) into a combined total budget of over $10 million per year. Each Canadian institute receives roughly $1.2 million per year in federal money; the analogous investment in the United States, mostly from the National Science Foundation (NSF), in the dozen or so American institutes is to the order of $4-5 million each.

4.1.2 Operations

Organization of Scientific Events: Mathematics is a subject which thrives on personal interaction. The impact of these events on Canadian mathematics is very high, as they bring in experts from all over the world to Canada to interact with our local community. Each institute has a Scientific Advisory Committee which suggests and/or approves the programs. The members of the committee are chosen at the international level. There were about 10,000 participants in institute activities across the country last year; roughly a third of these were participants in workshops, with over half from abroad. The scientific programs consist of:

Thematic Programs: These are term-long or year-long activities, and typically comprise a series of workshops, a postdoctoral and visitor program, and a series of linked graduate courses (in the departments) or mini-courses at the institutes. Occasionally the programs are attached to a summer school. The subjects are chosen for their topicality and impact. The current year's list of these programs gives an idea of their variety: Group theory and Statistics at CRM, Asymptotic

Geometric Analysis and Dynamics and Transport in Disordered Systems at Fields, and Partial Differential Equations at PIMS.

Short programs: Reproducing to a certain degree some of the features of a thematic program, these activities, of a month or so in length, assemble a group of experts from around the world to work in a focused area. Recent topics at Fields, for example, include Quantum Information, Drug Resistance, and Infectious Disease.

Workshops: Shorter, even more focused activities, often on a recent hot topic. At PIMS alone there were more than a dozen such workshops in 2010.

Graduate Training**:** An important feature of the institutes' activities has been a widening of the range of graduate training available to Canadian students. Again, the participation numbers are impressive; roughly a third of participants at Institute activities are graduate students. A common feature of recent efforts in this area has been NSF funding, enabling American students and postdoctoral fellows to participate as well.

Mini-Courses: The institutes sponsor a wide variety of mini-courses, either attached to thematic programs or in isolation. For example, this year's CRM program in Group theory has 10 mini-courses, each with 50 or so participants; similarly, this year's programs at Fields had seven mini-courses, with similar participation numbers.

Summer Schools: A more concentrated format, with several mini-courses being given concurrently. The current year's list of topics includes: at PIMS (where they are a particular strength) algebraic topology, computer models, quantum algorithms, and risk management; at CRM, graph theory (through the well-known Séminaire de Mathématiques Supérieures); and at Fields, affine Schubert calculus.

Postdoctoral Fellows (PDF): The increase in postdoctoral training has been one of the most spectacular effects of the institutes. Typically, the postdoctoral fellows are either attached to a thematic program or to a group of researchers (and sometimes both). Last year the institutes sponsored over 100 fellows, funded either fully or partially. This area is one with a major impact. As individual grants are insufficient to support a PDF, the institutes have funded major growth in PDF numbers.

Support of the Local Scientific Community: One of the important aspects of a successful institute is transfer to the local community; all the Canadian Institutes engage in this in different ways, either through Focused Research Groups (PIMS), Laboratoires (CRM) or Working Groups (Fields). They also support the Canadian mathematical community by subsidizing the meetings of learned societies (CMS, CAIMS, SSC). As well, the three Institutes support AARMS in Atlantic Canada.

Prizes: The institutes, both separately and jointly, have a number of prizes recognising contributions of the Canadian scientific community: the CRM-Fields PIMS prize, the André-Aisenstadt prize, the CAP-CRM prize, CRM-SSC prize, the CAIMS-PIMS prize in Applied

Mathematics, and the Fields Institute Fellows. In addition, the Institutes each have their distinguished lecture series.

Multi-sectorial Outreach: The institutes support research and scientific activities in finance, mathematical physics, mathematical biology, medicine, theoretical chemistry, theoretical computer science, etc. They also reach out to a variety of sectors, for example:

Industrial outreach: The institutes participate in and indeed were the founding organisers of the MITACS Network. Moreover, they organize industrial problem-solving workshops. Fields, for example, has developed a strong series of activities in finance, with their seminar series on Quantitative Finance, and the PRIMIA Risk Management Seminar, as well as their role in hosting finance spin-offs.

Public activities: These include public lectures such as the Grandes Conférences du CRM or the Fields Public Lecture series, as well as activities in the media, poster campaigns, and participation in television series.

Education activities: These include mathematical magazines in the schools (Pi in the Sky, Accromath), summer education activities such as Math Camps, contests such as ELMACON at PIMS or the Caribou Math competition (Fields), and the Fields Education Forum, whose activities now extend to a journal. PIMS has partnered with First Nations communities in mathematical educational activities.

An International Network: The institutes collaborate with a wide variety of institutions throughout the world; the French CNRS has one Unité Mixte based in Canada at a Canadian institute, and is in the process of developing them at the two other institutes. There are extensive inter-institute accords throughout the world, including Europe, Japan, Korea, and India.

Collaboration within the Canadian Mathematical Community, with International Outreach: The CMS, CAIMS, MITACS, and the institutes have been key players in organising a variety of international joint events, beginning with Canada-China congresses in the late 1990s. More recently, they were involved in the Canada-France meetings in Toulouse in 2004 and Montreal 2008. The 2008 meeting had 800 delegates and was a partnership between CMS, CAIMS, MITACS and the institutes. Another event was the Canada-Mexico meetings in 2007 and 2009, with more meetings planned for the future. An important recent event was the International Congress of Industrial and Applied Mathematics in Vancouver in 2011 (ICIAM 2011), a partnership of CAIMS and MITACS in Canada and SIAM in the United States.

Collaboration within the Network of North-American Institutes: The institutes belong to the network of North-American Mathematical Science institutes and co-sponsor an Open House of the institutes at each Joint Mathematics meeting. Since the beginning of 2010, 13 North-American institutes have started large scale collaboration on two programs:

The *Climate Change and Sustainability Program* (CCSP) is a joint thematic program with the institutes hosting scientific workshops (www.mathinstitutes.org/climate-initiative). In parallel, some activities for the public (public lectures) and schools (a special issue of *Accromath* related to the theme) are organized. This program is run in close collaboration with the Division of Mathematical Sciences at the National Science Foundation, targeting the development of a science of sustainability.

The *Mathematics of Planet Earth 2013* project (MPE) is even more ambitious as the institutes have decided to form a joint Scientific Committee with the mission of proposing multi-institute thematic activities. The Scientific Committee is chaired by Christiane Rousseau. It will issue a call for proposals for activities and work in close collaboration with the institutes and the North American mathematical community, as well as with the Division of Mathematical Sciences at NSF. Initially a North American venture, the initiative is now planet-wide and is targeting the participation of international scientific unions under the International Council for Science.

4.2. ATLANTIC ASSOCIATION FOR RESEARCH IN THE MATHEMATICAL SCIENCES (AARMS)

AARMS is a research institute that promotes and generates interactions among mathematical scientists both within the Atlantic region and nationally. It was founded in 1996 by mathematicians at Dalhousie University, Memorial University of Newfoundland (MUN), and the University of New Brunswick (UNB). At present all major universities and colleges in the region are affiliated with and support AARMS.

Since its inception AARMS has provided a voice, structure and resources for the mathematical sciences community in the Atlantic region. Its presence has strengthened research and graduate studies, helped universities be more competitive in recruiting and retaining faculty, and raised the profile of the mathematical sciences in the region.

The three mathematical sciences institutes — CRM, Fields and PIMS — began their support of AARMS in 2002 together with Dalhousie, MUN and UNB. In 2006, seven more universities and colleges began supporting AARMS. In 2009, the governments of New Brunswick and Nova Scotia initiated active support through a five-year funding commitment.

AARMS funds conferences, workshops, two-year postdoctoral fellowships, and an annual four-week graduate summer school. It supports all aspects of the mathematical, computational and statistical sciences; pure, applied and industrial. AARMS' activities are held throughout the Atlantic region. On average, over 60% of overall participation in scientific sessions is national or international.

AARMS has provided a focus for research areas of strength in the Atlantic provinces. Some of these areas have constituted themselves into organized subgroups: the Atlantic Algebra Centre at MUN and the Centre for Non-Commutative Geometry at UNB are examples. Other significant areas include: General Relativity and Quantum Gravity (MUN, Dalhousie, and UNB), Modeling, PDEs and Scientific Computation (Dalhousie, UNB, MUN, Acadia, SMU), and Combinatorics, Graph Theory, & Optimization (Acadia, Dalhousie, MUN, MtA, StFX, SMU, UNB, UPEI).

4.3. BANFF INTERNATIONAL RESEARCH STATION (BIRS)

Inaugurated in 2003, the Banff International Research Station (BIRS) is a joint Canada-U.S.-Mexico initiative that addresses the imperatives of collaborative and cross-disciplinary research with a focus on the mathematical sciences and their vast array of applications in the sciences and in industry. In 2005, Mexico's National Council for Science and Technology (CONACYT) joined Alberta Innovation, the U.S. National Science Foundation (NSF) and Canada's Natural Science and Engineering Research Council (NSERC) in becoming BIRS sponsors. The station now provides a wealth of new and exciting opportunities for North American faculty and students, giving them access to their international counterparts at the highest levels and across all mathematical disciplines.

The BIRS modus operandi facilitates intense and prolonged interactions between scientists in a secluded environment, complete with accommodation and board, for uninterrupted research activities in a variety of formats. BIRS embraces all aspects of the mathematical, computational and statistical sciences from the most fundamental challenges of pure and applied mathematics, theoretical and applied computer science, statistics, and mathematical physics to financial and industrial mathematics, as well as the mathematics of information technology, and the life sciences.

Every year, the station hosts over 2,000 researchers from 400 institutions in more than 60 countries who participate in over 70 different programs. The principal BIRS activities are its annual series of 49 five-day workshops, each hosting up to 42 researchers in disciplines in which mathematics, computer science and statistics are used in novel ways. The format allows scientists to exchange the latest advances in their fields of study and provides an environment that fosters new collaborations and ideas. BIRS also frequently accommodates two-day events, suitable for promoting industry-academic collaborations, and Research in Teams/Focused Research Groups, who are given the opportunity to live and to do research together in a non-workshop/non-conference style setting for periods of 1 to 2 weeks. BIRS furthermore hosts summer schools and graduate training camps.

BIRS has its own building (Corbett Hall) on the site of the world-renowned Banff Centre in Alberta. This arrangement allows it to provide cost-effective access to collaborative research by securing dedicated space for long-term use, by operating a substantial economy of scale, and by pooling the resources of several governments. The Banff Centre is already internationally recognized as a place of high culture. Its programs in music and sound, the written, visual and performing arts, and leadership and management draw in many hundreds of artists, students, and intellectual leaders from around the world. The introduction of BIRS, with its stream of creative and imaginative people, into this rich and fertile environment provides opportunities for some unique synergies. BIRS is therefore uniquely positioned to help in the dissemination of mathematical culture to a wider community and in the promotion of mathematical/scientific writing.

4.4. MATHEMATICS OF INFORMATION TECHNOLOGY AND COMPLEX SYSTEMS (MITACS)

MITACS was founded in 1999 by Canada's three mathematical sciences institutes (CRM, Fields, and PIMS) as a Networks of Centres of Excellence of Canada (NCE) with the following objectives:

- Foster high-quality multi-disciplinary research by the academic mathematical sciences community that could produce novel mathematical tools and technologies applicable to industry, not-for-profits, hospitals, and government;
- Train the next generation of graduate students in the application of quantitative research and to create venues for them to be retained in Canada;
- Build a network between the Canadian mathematical sciences community and Canadian industry;
- Ensure rapid dissemination of knowledge;
- Leverage mathematical technologies for the benefit of Canada; and
- Act as a platform for international engagement in industrial and applied mathematics.

MITACS original annual budget was $3.8 million from the federal government through the NCE program. Within a year, industry was contributing an additional $1.0 milion. By 2005, MITACS had grown to approximately 150 companies and 48 Canadian universities and had a budget of $7.5 million, of which the federal government contributed $5.4 million. The main activity was large-scale research projects each involving a group of professors working with a consortium of companies. MITACS major projects are listed in section 5.1.5.

Other programs launched and run by MITACS-NCE include:

Industrial Seminar Series: About 20 seminar series are run by MITACS projects. Recent examples include: statistical methods for genetics & genomics; seminar series on Fusion and Inference in Surveillance Networks; Applied Mathematics and Mathematical Physics Seminar, and an Optimization Seminar series.

Workshops: MITACS fosters workshops in industrial and applied mathematical sciences across the country. About 60 workshops are held each year. Sample topics include: Theory of Quantum Computation; Communication and Cryptography; Statistics in Industry and Technology; and Decision Analysis and Sustainable Development.

Graduate (summer) schools: Each year MITACS hosts 10—15 intensive graduate schools in emerging areas where mathematics plays a central role. Examples include:

- Computational Neuroscience Summer School,
- Mathematics for Biological Networks,
- École d'été Optimisation du transport et de la chaîne logistique dans le secteur forestier

Banff International Research Station (BIRS): MITACS was one of the founders of BIRS and plays a major role in its management and in supporting its scientific activities.

Note that many of these activities are run in partnership, especially with the three mathematical sciences institutes.

4.4.1 Going Beyond the NCE

To further fulfill its mandate, starting in 2004, MITACS developed a series of programs to reach out to industry in a more substantive way. The most successful was its **Accelerate** program whereby graduate students worked on high-quality research projects with industry. The goal was two-fold:

- Introduce industry to the power of high quality research on their challenges; and
- Introduce graduate students to industrial research and its potential to motivate the research enterprise.

As well, MITACS was looking to create new research employment opportunities for these graduate students.

The success of Accelerate is witnessed by its rapid growth:

- 17 projects in 2004 has grown to 1,200 expected in 2010—11;
- More than 650 Canadian companies participate in Accelerate; and
- A 27% increase in graduate student retention in Canada.

Starting in 2007, the Accelerate program went from being solely focused on the mathematical sciences to being multi-disciplinary. Today, about 25% of the 1,200 internships carried out through Accelerate are in the mathematical sciences (12% are in mathematics and statistics).

Other substantial programs MITACS has launched include:

Outreach: In collaboration with Prof. Jean-Marie de Koninck, MITACS has developed a substantive outreach program in Québec and British Columbia. The program has two highly popular components:

- *ShowMath:* An interactive multi-media presentation targeted to high school students that highlights the role of mathematics in everyday life.
- *MathAmaze:* A multi-user internet-based video game that allows players of varying skills to compete by answering mathematical questions.

Globalink: A program that brings highly talented international undergraduates to Canada to work on an applied research project.

Step: A series of workshops for graduate students on business and entrepreneurship.

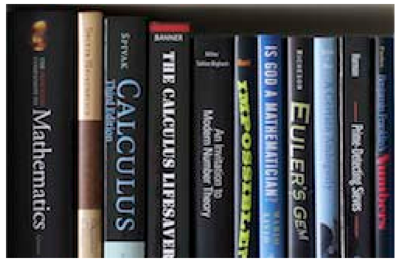
Elevate: A novel postdoctoral fellows program that develops scientific managerial skills amongst recent PhD's through partnerships with industry.

4.4.2 Mathematics within MITACS Inc.

MITACS continues to run its research projects and networking and training activities, all of which are focused on the mathematical sciences. In total, about $7.5M is expended annually on these activities. Removing the administration portion, about $3M goes directly to mathematics and statistics faculty from MITACS.

As well, the multi-disciplinary programming within MITACS has a substantial mathematics/statistics component. In the fiscal year 2010—11, this is estimated at about $3.5M.

MITACS was divided into two organizations as of April 1, 2011. The first, Mprime Inc, focuses on the original mathematical mandate of MITACS. The second, Mitacs Inc, focuses on the multi-disciplinary training aspects of MITACS.

5.0. MATHEMATICAL RESEARCH

As with any well-developed mathematical culture, mathematics in Canada encompasses an extraordinary range of subjects; there are however a few areas in which Canada has either demonstrated historical leadership, developed rapidly over the past few years, or has a greater concentration than in other areas. This section highlights these particular areas. People are mentioned, though many are omitted (apologies asked for in advance) as we try to give an overview of the various concentrations and groups. Boundaries are also blurred. Probability theory at one edge melds into discrete mathematics and at another into financial mathematics. An expert in pde can use some computational tools in his or her work, or at the other end tie into number theory.

A description of a few years ago would have gone through many of the classical areas of pure mathematics, and then tacked on applied mathematics at the end, as a subdiscipline on its own. This description does not fit reality any more. Not only has applied mathematics grown explosively in recent years, but many mathematical subdisciplines have broadened out into both pure and applied mathematics: number theory melds into cryptography, geometry into mathematical physics, discrete mathematics into a host of applications, and so on. Indeed, the full pure-applied spectrum is often exhibited in single researchers, with for example, one whose web page exhibits papers both in holomorphic dynamics and in mathematical biology.

5.1 APPLIED MATHEMATICS

Applied mathematics in Canada has seen dramatic growth over the last decade, with advances taking place both within mathematics departments and in related fields. This presence is symbolized by the fact that Canada hosted the 2011 ICIAM congress. Since working in applications generally involves a mix of modeling, analytical, and computational approaches, it is often not possible to put a particular researcher into any specific area.

There are also areas of “applicable mathematics” that may sit between the actual applications and more theoretical areas, making connections across these different perspectives. For the sake of providing a picture of applied math in Canada, we have attempted to give snapshots of different areas, with an indication of how these different areas overlap provided in the summary of research directions.

One feature has been the growth of centres for applied mathematics, or subareas of applied mathematics, attached to universities, as highlighted in section 2.6.

5.1.1. Scientific Computation and Numerical Analysis

Scientific computation and numerical analysis have been well represented in Canada for some time, and over the last decade there has been growth in the size of this community, as well as the range of applications where it has become prominent. The range of focus covers analysis of numerical methods and development of algorithms for classes of applications.

Covering various areas of computational methods, each with a variety of applications, are U. Ascher (UBC, numerical methods for DEs with constraints), S. Ruuth (SFU, numerical methods for curve and surface networks, methods for PDEs on manifolds), W. Enright (Toronto, numerical solution of ODEs, DAEs, DDEs, boundary-value problems), R. Russell (SFU, moving mesh methods for differential equations), J. Bowman (Alberta, exponential time-integration methods), C. Greif (UBC, numerical linear algebra) and R. Spiteri (Saskatchewan, novel Runge-Kutta methods).

In the area of development of finite element methods, there is A. Fortin and the GIREF group at Laval, working on finite element methods, applications to fluid mechanics, elasticity problems, and many applications. In Galerkin methods, there is D. Schoetzau (UBC). Connections with new representations include the work of N. Kevlahan (McMaster), focusing on wavelet methods for fluid mechanics.

Computational optimization has seen expansion through the work of P. Forsyth (UBC; application in mathematical finance), E. Haber (UBC, PDE constrained optimization in the context of imaging), T. Coleman (Waterloo, practical and efficient algorithms for continuous optimization), M. Friedlander (UBC, fast methods for convex optimization), S. Vavasis (Waterloo, continuous optimization and numerical analysis), H. Wolkowicz (Waterloo, matrix theory and optimization theory), I. Mitchell (UBC, algorithms for Hamilton-Jacobi equations) and A. Oberman (SFU, algorithms for nonlinear elliptic equations).

5.1.2. Fluids

The area of fluids is widely represented across Canada, with strengths in classical areas such as Navier-Stokes, water waves, geophysical fluid dynamics and thin films, as well as areas which have expanded such as non-Newtonian fluids, or connections with networks and interacting particle systems. There are also strong ties with PDEs and mathematical physics.

In the area of Applied Complex Fluids and Geophysical Fluids, one notes the Complex Fluids lab at UBC, with N. Balmforth, J. Feng, I. Frigaard, and B. Homsy, working on such areas as geophysical fluids, polymers and biofluids, and multiphase flows, as well as J. Grace, who does large scale simulations of fluidized beds and D. Muraki (SFU), also studying geophysical fluid dynamics. There is also a fluids lab at Western, with R. Khayat and J. deBruyn working on computational and fluids and non-Newtonian fluids. In Toronto, one has D. James, R. Peltier (rheology, geophysical flows and atmospheric science), and a group (with S. Morris) working on blood flow. In Calgary, J. Azeiz studies displacement processes in energy/oil production. In Montreal, R. Owens examines novel numerical methods for micromechanical models of complex polymeric and biological fluids, and A. Bourlioux does multiscale simulations of reactive and non-reactive fluid flows with interfaces.

The general area of Navier-Stokes flow, waves, and thin films is also well represented by W. Craig (McMaster) and C. Sulem (Toronto), who work on water waves, Navier-Stokes, and Euler equations; D. Pelinovsky, who works on non-linear waves; M. Pugh (Toronto), on thin films; R. Fetecau (SFU) on nonlinear PDEs, Lagrangian methods, and S.Kocabiyik (Memorial) on Navier- Stokes problems.

5.1.3. Materials Modeling

This is an area which melds into the study of PDE; see section B.2. There is a variety of topics being touched upon in Canada. At Western, C. Denniston works in the area of computational materials science, and M. Karttunen on soft matter and biological physics. A number of Canadian mathematicians have contributed to the field of Bose-Einstein condensates: I. Sigal, R. Jerrard, S. Alama, L. Bronsard, and notably R. Seiringer (winner of the 2009 Henri Poincaré prize for his work in the area). Others working in the area include M. Delfour (Montreal; thin shells), A. Pierce (UBC, failure and fracture processes in granular materials), M. Pugh (Toronto, piezoelectrics), R. Choksi (McGill, pattern formation) and A. Rey (McGill, liquid crystals).

5.1.4. Mathematical Biology

This is one area whose importance in Canadian mathematics has increased dramatically over the past 10 years. Indeed, while Canada has been somewhat of a precursor in the field over the last 40 years, with the work of Clark and Ludwig (UBC) on mathematical ecology, that of L. Glass and M. Mackey (McGill) on biological rhythms in medicine, or the work of D. Sankoff at the CRM in developing the algorithms of genomics, it is only within the latter part of this period that a large community has been built up. A glance at the list of Canada Research Chairs recruited to Canada in the past few years makes this growth quite clear. The relative importance of Canada on the international scene is evidenced by the fact that both the current President and President-Elect of the Society for Math Biology are Canadian (M. Mackey and G. de Vries, respectively). Past Canadian presidents of this Society include L. Keshet, L. Glass and M. Lewis.

One feature of the area is that its development has been conditioned and shaped by a certain number of research groups throughout the country, with certain well developed clusters. At McGill, there is the CND (Centre for Non-Linear Dynamics in Physiology and Medicine), and its successor organization, CAMBAM (Centre for Applied Mathematics in Biology and Medicine), with L. Glass, M. Mackey, M.Guevara, M. Chacron, J. Belair (U. of M.), Y. Bourgault and A. Longtin (Ottawa); at Alberta, the Centre for Mathematical Biology, under the leadership of M. Lewis, G. deVries, T. Hillen; at UBC, the Mathematical Biology Group, comprising among others D. Coombs, E. Cytrynbaum, L. Keshet and M. Doebeli; at Calgary, the Centre for Mathematics in the Life Sciences, with P. Binding; at York, the MITACS Centre for Disease

Modelling (Director Jianhong Wu, Huaiping Zhu, Jane Heffernan. Niel Madras); and no doubt several others.

Within the discipline, there is a wide variety of subjects:

Mathematical Ecology has connections to fisheries, epidemiology, biodiversity, and habitat destruction, through researchers such as M. Lewis (Alberta), H. Wang (Alberta), and J. Watmough (UNB). A number of researchers bridge the area of Mathematical Ecology to Mathematical Evolutionary Biology, including F. Lutscher (UBC), M. Doebeli (UBC), and P. Abrams (Toronto). Mathematical Evolutionary theory is also well represented across Canada, making connections with populations genetics, game theory, and human behavior, through researchers such as T. Day and P. Taylor (Queen's), S. Otto and C. Hauert (UBC), and R. Cressmann (Wilfrid Laurier). At the University of Montreal, S. Lessard works on genetics and evolutionary biology and collaborates with biochemists H. Philippe and N. Lartillot.

Physiology, with connections to mathematical medicine, has been a strength throughout Canada. For example G. de Vries and T. Hillen (Alberta) and M. Mackey and L. Glass (McGill) cover a range of applications across different scales. Cell physiology is well represented at UBC, for example by L. Keshet and E. Cytrynbaum. Along with Glass and Mackey, M. Guevara and A. Vinet in Montreal work on issues related to cardiac modeling, as does Y. Bourgault in Ottawa. Also of note is the work of A. Longtin and M. Chacron (Ottawa) on biophysics and neural processing.

Epidemiology, in its mathematical (as opposed to statistical) manifestations, has long been well represented in Canada, e.g. by P. van den Driessche (Victoria). There is a strong next generation in this area, represented by D. Earn and B. Bolker (McMaster), C. Bauch (Guelph), A. Gumel and J. Arino (Manitoba), and J. Wu, H. Zhu, J. Heffernan and N. Madras (York).

An emerging area related to cell biology, mathematical medicine and epidemiology is *mathematical immunology*. In Canada, D. Coombs (UBC) and L. Wahl (Western; viral dynamics) represent two new directions of strength.

5.1.5. Industrial Mathematics

The MITACS network has promoted an extensive development of industrial ties with Canadian mathematical scientists. The broad range of subjects and team leaders within the purview of MITACS projects include:

Control of Cardiac Arrhythmias (L Glass, (McGill) and E.Vigmond (Calgary)

Statistical Genetic Modelling and Analysis of Complex Traits (S. Bull, University of Toronto)

Transmission Dynamics and Spatial Spread of Infectious Diseases: Modelling, Prediction and Control (J. Wu, York)

Advanced Mathematical Modelling and Simulation of Transport Phenomena. (R. Spiteri, Saskatchewan)

Multi-scale Adaptive Modelling and Numerical Methods for Reactive Flows (C. Groth, Toronto)

Network for Biological Invasions and Dispersal Research (J. Watmough, UNB)

Novel Methods for Three-Dimensional Aerodynamic Optimization (D. Zingg, Toronto)

Optimizing Multimodal Transport in the Forestry Sector (B. Gendron, Montreal)

Pseudodifferential Operator Theory in Seismic Imaging (G.F. Margrave & M. Lamoureux, Calgary)

Simulating Climate Processes with High-Resolution Regional Climate Model (L. Sushama, UQAM)

Advanced Parameter Estimation Tools for Building Mathematical Models of Chemical Processes (K. McAuley, Queen's)

Facility Location Optimization (B. Bhattacharya, Simon Fraser)

High Performance Optimization: Theory, Algorithm Design and Engineering Applications (A. Vannelli, Guelph, and M. Anjos, Waterloo)

Mathematical Surface Representations for Conceptual Design (K. Singh, Toronto)

Mathematics of Computer Algebra and Analysis (M. Monagan, Simon Fraser and G. Labahn, Waterloo)

Statistical Learning of Complex Data with Complex Distributions (Y. Bengio, Montréal)

Statistical Methods for Complex Survey Data (C. Wu, Waterloo)

Finsurance: Theory, Computation and Applications (T. Salisbury, York)

Mathematical and Statistical Methods for Financial Modelling and Risk Management (J.M. Dufour, McGill)

Modelling Trading and Risk in the Market (M. Davison, UWO)

Fusion and Inference in Surveillance Networks (M. Coates, McGill)

*Modelling and Mining of Networked Information Spaces (*J. Janssen and E. Milios, Dalhousie)

Quantum Information Processing (B. Sanders, Calgary)

Useful Privacy Enhancing Technologies (I. Goldberg, Waterloo, and Rei Safavi-Naini, Calgary)

Outside of MITACS, there are other Canadian mathematicians who have made extensive contributions in an industrial context: I. Frigaard (UBC; complex fluid applications to oil wells), B. Wetton (UBC, fuel cell modeling), P. Forsyth (Toronto, petroleum reservoir simulation, computational finance), A. Bourlioux (Montreal, CFD and forest fire modeling), E. Haber (UBC, seismic imaging and optimization), A. Fortin (Laval; CFD, blood modeling, elasticity and contact problems), J. Stockie (SFU, industrial math and mathematical modeling), N Nigam (SFU, numerical solution of PDEs in materials), K. Murty (Toronto, GANITA Lab), L. Seco (Toronto, Risk

Lab, Sigma Analysis and Management), and M. Lamoureux (Calgary,seismic imaging, applications in geophysics).

5.1.6. Inverse Problems and Imaging, Signal Processing

This is not an area extensively represented in the Canadian mathematical community, but we note the presence of A. Nachman (Toronto), working on MRI, tomography, and current imaging, and O. Yilmaz (UBC) on A/D conversion and compressed sensing. There are also the researchers of the CRM PHYSNUM laboratory with F. Lesage and J.M. Lina and strong ties to the Parisian group at La Pitié-Salpétrière.

5.1.7. Mathematical Finance

This is one particular industrial area that has seen a great development in recent years. It is a strongly interdisciplinary area with mathematicians, economists and statisticians adding their efforts to the development of the subject. Several major Canadian universities have established institutional frameworks for the teaching of financial mathematics: the Mathematical Finance Laboratory (Calgary), Risklab (Toronto), the Mathematics Finance Laboratory (McMaster), and the Mathematical Finance group at Western Ontario. There are also several MITACS funded projects in Finance. Mathematicians working in the area include I. Ekeland and P. Forsyth (UBC), T. Ware and R. Elliot (Calgary), A. Candenillas and A. Melnokov (Alberta), L. Seco (Toronto), M. Grasselli and T. Hurd (McMaster), and M. Davison (Western).

5.2. TRANSITIONS

We next highlight six areas which exhibit the full range of pure to applied mathematics.

5.2.1 Dynamical Systems

There is a huge range of work being done in dynamical systems in Canada, ranging from the applied to the quite pure; in applications**,** approaches based on dynamical systems are widespread in areas such as mathematical biology, fluids, and industrial modelling, all considered above.

Canada has noticeable strength in modelling and analysis of delay differential equations with a range of applications in biology, mechanics, and medicine covered in the research of S. Campbell (Waterloo), and J. Wu and H. Zhu (York) who work in bifurcation analyses related to these; at McGill, one notes the work of G. Haller (mechanical engineering), M. Mackey, and L. Glass (biological systems).

Localized pattern formation has emerged prominently in many applications, and expertise in Canada includes researchers such as M. Ward (UBC), and Th. Kolokolnikov and D. Iron (Dalhousie). Stochastic dynamical modelling in applications with and without delays is represented in the research of R. Kuske (UBC) and A. Longtin (Ottawa).

Computational dynamical systems is represented through a number of different researchers, including A. Humphries (McGill), studying dynamics of numerical methods, P. Tupper (SFU), developing numerical algorithms for interacting particle systems and E. Doedel (Concordia) with widespread contributions in computational bifurcation theory.

At Memorial, H. Brunner (Numerical analysis of Volterra-type integral and integro-differential equations) leads a Differential Equations and Dynamical Systems Group comprising A. Foster, G.H Ou, D. Summers, Y. Yuan and X. Zhao.

The more pure end of the subject is strongly represented in Toronto, with M. Yampolsky, E. Braverman and M. Shub studying holomorphic dynamical systems. Classical questions of bifurcations and limit cycles are studied by C. Rousseau and D. Schlomiuk (Montreal), P. Speisseger (McMaster), and Alexander Brudnyi (Calgary) and continue with Hamiltonian dynamics (O. Bogoyavlensky and D. Offin at Queen's, B. Khesin in Toronto). There are ties to dynamical systems with operator algebras (I. Putnam (Victoria), and the applied ends of the subject are rejoined through ties to ergodic theory, developed through the work of P. Gora and A. Boyarski (Concordia; applied discrete dynamics) and C. Bose and A. Quas (Victoria), as well as Brian Marcus (UBC).

5.2.2 Partial Differential Equations

The area of PDE has expanded considerably in Canada in recent years. It covers more or less a continuum from applied to pure, and individual researchers often work in a wide variety of areas.

Linear PDEs and mathematical physics: Spectral theory of linear differential operators, and its natural relation to energy levels in quantum mechanics, is one particular area in which Canada is a world leader. At Toronto, I.M. Sigal has made fundamental contributions to quantum asymptotic completeness in many-body problems, and to stability questions, and V. Ivrii has done fundamental work on the asymptotics of eigenvalues of the Laplacian, with a far-reaching version of micro-local analysis. At UBC, J. Feldman is a world leader in the problems of constructive field theory, in particular theories of superconductivity and liquid crystals, and R. Froese has made important contributions on resonance states and random potentials. Montreal has a strong group of spectral theorists, mainly at McGill: D. Jakobson (quantum chaos and spectral theory of compact manifolds), V. Jaksic (non-equilibrium statistical mechanics), I. Polterovich (heat kernels and spectral theory of compact manifolds), J. Toth (eigenvalues in a semi-classical regime) and R. Seiringer (phase transitions in infinitely extended systems).

PDEs describing nonlinear waves: With applications throughout physics and engineering (optics, quantum physics, ocean/atmospheric waves, etc.) and deep connections to harmonic, functional, variational, spectral, and numerical analysis – this subject has emerged in recent years as a big field, and Canada has strong representation with several international leaders on some crucial directions of research: for example, J. Colliander (Toronto) on nonlinear Schrödinger equations, R. Illner (Victoria) on the equations of kinetic theory, W. Craig (McMaster) and C. Sulem (Toronto) on Hamiltonian PDE such as water-wave equations, and

A. Shnirelman (Concordia) on aspects of the Navier-Stokes equations of fluid mechanics. UBC's S. Gustafson and T. Tsai have established fundamental properties (stability, singularities, asymptotics) of solutions to nonlinear dispersive PDE, as has S. Ibrahim (Victoria), while D. Pelinovsky (McMaster) and R. Fetecau (SFU) approach equations of this type with both analysis and numerics.

Elliptic and geometric PDEs: The Canadian community boasts a strong group of researchers in these areas. At UBC, N. Ghoussoub is an expert on borderline elliptic PDEs, and has recently introduced a selfdual variational calculus for equations that are not of Euler-Lagrange type. P. Guan, at McGill, works on the Monge-Ampère equation and applications to geometric PDE. R. McCann (Toronto) is one of the main actors in the recent renaissance of the theory of optimal transport and its applications, while Young-Heon Kim (UBC) and Martial Agueh (Victoria) have authored major contributions to diverse aspects of this theory. R. Jerrard (Toronto) has developed state of the art techniques for the analysis of Ginzburg-Landau equations and is currently working on several problems in hyperbolic equations and on the Monge-Ampere equation. A. Oberman (SFU) emphasizes numerical aspects of fully nonlinear elliptic problems. In a different direction, A. Nachman (Toronto) is one of the leading experts in inverse problems, and their applications in medical imaging.

PDEs and Differential Geometry: There is also a good young Canadian school developing in PDEs and differential geometry. In Ontario, we have A. Nabutovsky (geodesics and Morse theory), S. Alexakis (conformal invariants for varieties), L. Guth (systoles for varieties), S. Karigiannis (special holonomy), and M. Wang (Einstein manifolds). At UQAM, V. Apostolov has done important work on special holonomy. At UBC, J. Chen has had a substantial impact on mean curvature flow, in particular for Lagrangian submanifolds; A. Fraser works on minimal surfaces; and A. Chau studies the Kahler-Ricci flow. P. Guan, at McGill, works on the Monge-Ampère equation and applications to geometric PDE. In the related area of general relativity, McGill's N. Kamran, in work with Finster, Smoller and Yau, has made fundamental contributions to the theory of linear field equations in a general gravitational background. In Atlantic Canada, the University of New Brunswick (UNB) has a cohort of promising researchers in this direction: J. Gegenburgh (quantum gravity), and V. Husain (black holes and quantum gravity).

PDE and material science: There is also interest in equations/variational problems at the interface with the materials sciences. For example, S. Alama and L. Bronsard (McMaster) work on problems addressing the structure of vortices in type-II superconductors. R. Choksi (McGill) works on phase field equations and nonlocal variational problems with a focus toward their application to pattern formation in materials. M. Pugh (Toronto) is an expert on the modeling and analysis of thin films, while A. Burchard studies related problems, often with a geometric flavour. N. Ghoussoub (UBC) and his students developed important analytical tools for PDEs modeling certain Micro-Electro-Mechanical Systems (MEMS).

5.2.3. Probability Theory

Probability is an area of remarkable and traditional strength in Canada. The two traditional foci for its development were the Ottawa area, around D. Dawson and M. Csorgo, and UBC, with its initial strength originally built around J. Walsh and R. Chacon. The UBC group has continued to develop into an extremely strong school whose senior leaders are now M. Barlow, D. Brydges, E. Perkins and G. Slade. The focus in eastern Canada is now centred in the Toronto area where there is considerable strength at both Toronto (J. Quastel and J. Rosenthal) and York (N. Madras and T. Salisbury). There is also a strong group focused on the interface of probability and discrete mathematics at McGill (L. Devroye and B. Reed). All of these groups also have exceptional junior researchers who will continue this strong tradition in Canadian mathematics into the next generation. Notable here are Sloan Fellows Omer Angel (UBC) and Balint Virag (Toronto). Other areas of strength in probability are Concordia (L. Popovic, W. Sun, and X. Zhou), Ottawa (G. Ivanov and D. McDonald), and Alberta (M. Kouritzin and B. Schmuland).

Probability has become a ubiquitous subject in both pure and applied mathematics. It touches on a wide variety of subjects, merging into analysis and differential geometry at one end, and discrete mathematics at the other; important developments tie it quite closely to theoretical physics, in particular statistical physics. It has some very pure aspects, as well as some very important areas of application, including mathematical biology, computer science and financial mathematics where the impact of Ito's theoretical work on stochastic calculus led to his Gauss Prize at the 2006 ICM.

Areas of strength in Canada include stochastic PDE, statistical physics, Markov chain Monte Carlo, random media, population and genetic models, and random matrices.

The pioneering work of J. Walsh, D. Dawson and E. Perkins on stochastic PDE and measure valued processes has had a huge impact on the worldwide development of these fields. Don Dawson was the founder of what are now called Dawson-Watanabe superprocesses, and he and Perkins developed the fundamental properties of these processes which have become important tools in a variety of models in ecology and immunology as well as genetics. Recent highlights are Quastel's work on invariance of white noise for the Kortweg-deVries equation and effect of noise on traveling fronts, and Perkins' work on pathwise uniqueness for parabolic SPDE's with Hölder continuous coefficients.

In statistical physics, Brydges and Slade are the mathematical leaders in applications of the renormalization group method and especially the lace expansion to stochastic models such as self-avoiding walk and branched polymers. In addition, N. Madras and C. Soteros (Saskatchewan) work on problems arising from the statistical mechanics of polymers such as entanglements. Both Brydges and Quastel were invited speakers at the 2010 ICM for their work on 4-dimensional self-avoiding walk and stochastic PDE's, respectively.

N. Madras and J. Rosenthal are leaders in obtaining rates of convergence for Markov chains to their equilibrium, motivated by Monte Carlo applications in statistics and statistical physics. M. Barlow is the leading probabilist in the world working in transport properties of random media. His results include invariance principles for random walk in super-critical percolation, and more recently, fractal behaviour for scaling limits of critical systems such as two-dimensional uniform spanning trees.

Population models involve a mix of discrete branching/resampling and migration. At the discrete end, L. Devroye has been a major player in Random Trees. At the continuous end, L. Popovic and X. Zhou (Concordia) and B. Schmuland have done fundamental work on related models used in population genetics. Balint Virag is a major player in the relatively new and important fields of random matrices and determinantal processes. His work with Omer Angel, Ander Holroyd and Dan Romik on random sorting networks in computer science has attracted major international recognition.

The overall strength of Canadian probability is very well recognized internationally: three Canadian probabilists have recently been elected to the Royal Society of London in the last five years, and six ICM speakers (out of 29) since 1986 were Canadians.

5.2.4. Mathematical Physics

Physics is in some sense one large application of mathematics, though it is not typically viewed as applied mathematics. The flavour, however, of work done in the area varies widely, from links between string theory and algebraic geometry to quite concrete studies of pde in non-linear optics. Many aspects of this area have been covered or will be covered elsewhere, for example under the rubric of geometry, or pde, or probability theory. One aspect of work in the area does seem to be us to be worth considering separately, and that is general relativity.

Relativity has long had a strong presence in Canada, with the efforts of W. Unruh at UBC and of W. Israel in Alberta. Currently, at McGill, N. Kamran, in work with Finster, Smoller and Yau, has made fundamental contributions to the theory of linear field equations in a general gravitational background.

The Maritimes have a good concentration of active researchers in relativity. Ivan Booth (MUN) works on several aspects of mathematical relativity including the study of isolated horizons and aspects of the ADS/CFT correspondence. Alan Coley and Robert Milson (Dalhousie) and Robert Van Den Hoogen (St. Francis Xavier) work on the classification of symmetries of spacetimes, and on the application of dynamical systems to study cosmological problems. Viqar Husain, Jack Gegenberg and Sanjeev Seahra at UNB work on several aspects of classical and quantum gravity using analytic and numerical methods. Most recently, the group is working on aspects of the Kerr/CFT correspondence, background independent quantization methods, and simulation of gravitational radiation in braneworld models, and has initiated the study of gravitational collapse with quantum gravity corrections.

5.2.5. Discrete Mathematics

This is an area of historical strength in Canada, in particular in graph theory and polyhedral combinatorics, thanks to the efforts of pioneers such as W. Tutte and J. Edmonds at the department of Combinatorics and Optimization at Waterloo.

Today, Canada's school of graph theory spans the whole country. In the Maritimes, there is a strong group at Dalhousie, with J. Brown, J. Janssen and R. Nowakowski. In Montreal, there is a strong and diverse group in discrete mathematics at McGill with D. Avis, L. Addario-Berry, L. Devroye, B. Reed, B. Shepherd, M. Singh and A. Vetta, which together with V. Chvatal at

Concordia, represent considerable strength in the pure end of the subject, with an emphasis on probabilistic and algorithmic approaches. On the more applied end of the discipline, there is world-beating strength in discrete optimization at the Université de Montréal, with P. Hansen, G. Laporte, P. Marcotte, F. Soumis, and several others.

In Ontario, Waterloo remains the base, with a significant presence in many of the areas of discrete mathematics: on the structural side of combinatorial optimization, there is W. Cunningham, J. Geelen, and B. Guenin; in graph theory, P. Haxell and B. Richter; and in combinatorial algorithms, J. Cheriyan, J. Koenemann, and C. Swamy. In probabilistic combinatorics there is also N. Wormald, forming, together with M. Molloy in Toronto, a significant presence. UofT also is home to S. Todorcevic who has been working on Ramsey theory and connections between combinatorics and set theory.

The West also has considerable strength in discrete mathematics. At SFU, this includes Mohar, Devos, and Goddyn in graph theory, P. Hell and Tardos in algorithmic theory. At UBC, J. Friedman (expander graphs) and J. Solymosi (additive combinatorics) are at the pure end while A. Condon's research focuses on combinatorial algorithms in bioinformatics. UVic includes people such as F. Ruskey, W. Myrvold and G. MacGillivray working in combinatorial algorithms, and we also mention M. Salavitipour working in algorithm theory at Alberta. Several of the UBC school of probability (G. Slade, M. Barlow, O. Angel, A. Holroyd) have also made contributions to the interface of discrete mathematics with combinatorics.

A more recent trend, not only in Canada but on the world scene, has been the development of algebraic combinatorics: Waterloo, again, has some of the pioneers of the subject, with C. Godsil (algebraic graph theory), I. Goulden (combinatorial enumeration), D.M. Jackson (algebraic enumerative combinatorics), and L.B. Richmond (asymptotic enumeration). The LACIM group at UQAM has also played an important role, with C. Reutenauer (free Lie Algebras and descent algebras) and F. Bergeron (combinatorial algebra, coinvariants) leading a laboratory with 15 members, working on algebraic and enumerative combinatorics. At York, N. Bergeron and at UBC, S. van Willigenburgh (UBC) have also made important contribution to combinatorial algebra. B. Szegedy at Toronto works in combinatorics and group theory. At SFU, J. Bell’s interests exploit the ramifications of non-commutative algebra in combinatorics and number theory.

The area has a certain number of centres, built around local concentrations, and often with a computational theme: the Combinatorial Computing Centre at Memorial, LACIM at UQAM, the Centre for Computational Discrete Geometry at Calgary, and the Centre for Experimental and Constructive Mathematics at SFU.

5.2.6. Number Theory

The area of number theory, in particular in one of its modern manifestations through the study of automorphic forms and their related L-functions, is an area of particular strength in Canada. In Toronto, J. Arthur, a world leader in the Langlands program, has developed through his wide-ranging generalization of the Selberg trace formula a platform for establishing new cases of functoriality and base-change, which are central topics in the Langlands program; S. Kudla’s work on arithmetic cycles has far-reaching consequences in number theory and geometry, connecting, via generating series originating in geometry, the century-old theory of complex multiplication (considered by David Hilbert as the crown jewel of mathematics), the very modern theory of arithmetic intersection on moduli spaces and the theory of automorphic forms. H. Kim is an expert in the Langlands program and has done some ground-breaking work in this area by establishing new cases of functoriality. K. Murty is an expert in the application of automorphic forms to number theory, especially in the context of L-functions, and is also heavily involved in applications of number theory to cryptography. In Montreal, H. Darmon is one of the world's experts in the theory of elliptic curves. Together with A. Iovita, he has been a leader in developing p-adic versions of the standard conjectures and theorems on elliptic curves. Moreover, Darmon's conjectures, developed in collaboration with a team of colleagues, students and postdoctoral fellows, are considered among the most exciting problems in the theory of elliptic curves. At McGill, E. Goren has been exploring the number-theoretic ramifications of the geometry of moduli spaces, and has done much work in the context of hyperelliptic curves cryptography. At Queen's, R. Murty, known for his work on the L-functions of elliptic curves and on Artin's primitive root conjecture, heads a group that includes E. Kani and N. Yui. Yui has been a great promoter of research into the number theory aspects of K3 surfaces, Calabi-Yau manifolds and physics in general.

In analytic number theory, Toronto's J. Friedlander has made spectacular progress on the asymptotic sieve, leading to breakthrough results in representing primes as sums of powers. In Montreal, A. Granville, a leading figure in analytic number theory, works on a wide variety of questions linking number theory, algorithmic questions, and combinatorial theory. In his recent work he has developed a new approach to analytic number theory, which seems to have great potential to settling some outstanding problems. Waterloo's Cam Stewart is a leading expert in Diophantine equations and Diophantine inequalities. At McMaster, M. Kolster is a world expert in Iwasawa theory and K-theory. Vancouver's Sujatha Ramdurai is a leading expert in non-commutative Iwasawa theory, a rapidly developing area of algebraic number theory.

All three of Canada's largest cities have substantial groups in number theory that have provided a thriving scientific base for graduate training. Montreal's CICMA laboratory includes A. Granville, H. Darmon, E. Goren, H. Kisilevsky, C. David, J. Getz, A. Iovita, M. Lalin, as well as D. Roy from Ottawa; in Toronto, J. Arthur, S. Kudla, H. Kim, F. Murnaghan, K. Murty and F. Herzog are the core members of an active group. Vancouver's group with D. Boyd, M. Bennett, G. Martin, D. Ghioca, S. Ramdoari and V. Vastal at UBC, and a more computationally oriented group at SFU with P. Borwein, S. Choi, I. Chen, N. Bruin and P. Lisonek. They form the core of a PIMS research group that has expanded considerably in recent years to include a number of talented young researchers, principally in Alberta, at Calgary and Lethbridge. The Canadian number theorists have given themselves an association, the CNTA. It holds a biennial meeting which is one of the principal events in the discipline in the world.

Number theory melds into cryptography at the applied end, and Canada has demonstrated considerable leadership in developing spin-offs tied to cryptography: in Waterloo, Certicom, under the scientific leadership of S. Vanstone, and working together with the Centre for Applied

Cryptographic Research at Waterloo, is one of the main players in the field of elliptic curve based cryptography, and in Toronto, K. Murty's lab is doing very interesting research in hyperelliptic curves cryptography and hash functions . Another exciting development has been the opening of the new Institute for Security, Privacy and Information Assurance (ISPIA), with H. Williams as its first director, developing Canada's presence in the world of security research.

5.3. PURE MATHEMATICS

5.3.1. Algebra

Algebra, of course, is a wonderful tool in all of mathematics. This simple fact often makes the demarcation of algebra as a field of mathematics rather difficult — is it algebra, or is it number theory, or algebraic geometry, or representation theory, or combinatorics…? Thus many individuals who could be mentioned under this heading appear elsewhere. With this caveat, we can divide algebra in Canada under four headings.

Commutative algebra: which means here mostly the computational aspects of commutative algebra; it is a slave of algebraic geometry, yet has a life of its own. One should mention here the work of R.-O. Buchweitz (Toronto), A. Geramita (Queen's) and G. Smith (Queen's).

Iwasawa theory, Galois cohomology, homotopy theory, category methods and K-theory: a combination of subjects that is hard to separate. The assortment is perhaps justified by the fact that each person mentioned below touches on two of the topics in the title. These include A. Joyal (UQAM), M. Kolster (McMaster), S. Ramdorai (UBC), J. Minac (UWO), N. Lemire (UWO), R. Jardine (UWO), and M. Barr and M. Makkai at McGill.

Lie algebras, quivers and representation theory: again a mix of many topics. The University of Alberta has a strong school, following on the tradition set by R. Moody, with G. Cliff (integral and modular representations of finite and algebraic groups), V. Chernousov (linear algebraic groups and Galois cohomology), T. Gannon (Moonshine and conformal field theory), N. Guay (affine Lie algebras), J. Kuttler, A. Pianzola (infinite dimensional Lie algebras), A. Weiss (group representations and number theory). There are other places where this theme is well represented: the Ottawa area, with an annual meeting: people here include E. Neher and A. Savage (Ottawa) and Y. Billig, V. Dlab and B. Steinberg (Carleton); the University of Sherbrooke, with a strong group working in and around the theme of cluster algebras and representations of quivers (I. Assem, T. Brustle, S. Liu, and V. Schramchenko) and Memorial, whose Atlantic Algebra Centre includes Y. Bahturin, E. Goodaire, and M. Kotchetov. In a category all his own, for his deep influence in bringing to light hidden links between seemingly disparate subjects (such as the McKay correspondence, or moonshine), is Concordia's J. McKay.

Geometric group theory: There is in Canada a small but active set of people working on geometric group theory, centred around McGill, with O. Kharlampovich and D. Wise, but including also I. Bumagin (Carleton) and D. Morris (Lethbridge).

5.3.2. Analysis; Functional Analysis

The field of operator algebras has long been one in which Canada is strongly represented. We quote from the 2002 Mathematics Reallocation document: "This is an area of international importance and Canadian researchers have contributed some of the best work in the field. The subject area of Operator Algebras is a blend of algebraic, analytic, and topological techniques and has extensive applications in quantum mechanics and computation, physics, and electrical engineering." Among its notable practitioners (again, quoting to a certain degree from the allocation report):

G. Elliott (Toronto) is the leader of an ambitious program to classify all C* algebras through their K-theoretic invariants; K. Davidson (Waterloo) is widely known for his fundamental work in nonselfadjoint operator algebras, and structural theorems for triangular algebras.; D. Handelmann (Ottawa) and I. Putnam (Victoria) have discovered new and important interactions between C*-algebras and topological dynamics.; R. Speicher and J. Mingo (Queen's), and A. Nica (Waterloo) have been developing the theory of free probability, and using it to great effect in combinatorics, classical probability, and mathematical physics, for example in the study of random matrices.

The University of Alberta has a strong school in functional analysis. In geometric functional analysis, N. Tomczak-Jaegermann is a leader in the use of sophisticated probabilistic and geometric techniques in the exploration of convexity in Banach spaces. A. Litvak's work in geometrical functional analysis has recently been recognised by A Steacie fellowship. A. T-M Lau works on Banach algebras associated to locally compact groups, with application to harmonic analysis; V. Runde works on the interplay of Banach algebras with abstract harmonic analysis, in particular on the phenomenon of amenability. Other strong presences in the field include Matthias Neufang (Carleton), Brian Forrest (Waterloo), Nico Spronk (Waterloo), Zhiugo Hu (Windsor) and Fereiduoun Ghahramani (Manitoba).

In harmonic analysis, E. Sawyer (McMaster) works on harmonic analysis, partial differential equations and function theory. Kathryn Hare (Waterloo) has had significant work in both the concrete and abstract ends of the field. At Laval, T. Ransford is the leading figure of a group of analysts including L. Baribeau, J. Mashregi and J. Rostand. In Vancouver, I. Laba works on problems connecting harmonic analysis with combinatorics.

We have already mentioned, under the rubric of p.d.e., the extensive group of spectral analysts all across Canada.

5.3.3. Geometry, Topology and Ties to Mathematical Physics

A broad area, well represented in Canada, with a wide variety of subfields.

One of the features of the area in the last 15 years has been the emergence of a strong Canadian school in symplectic geometry and topology. In and around Toronto, M. Harada, L. Jeffrey, Y. Karshon, E. Meinrenken and B. Khesin are the leaders of a school that occupies a terrain which is essentially symplectic, but with substantial inputs from differential geometry, algebraic geometry and algebraic topology. In Montreal, F. Lalonde and O. Cornea are the main

Canadian representatives of the new field of symplectic topology and have developed surprising new invariants for symplectic varieties.

Algebraic geometry is an area which has expanded considerably in Canada in recent years. In the Toronto area, E. Bierstone and P. Milman have long been leaders, in particular in developing constructive methods for resolution of singularities. They have been joined in recent years by A. Khovanski, author of some highly original works on the representability of functions, as well as a cohort of young and promising researchers: M. Gualtieri (generalized complex structures), S. Arkhipov and J. Kamnitzer (geometric and combinatorial representation theory), as well as M. Roth (representation theory) and G. Smith (toric geometry) at Queen's, A. Dhillon (stacks and essential dimension) at Western and R. Moraru (non-Kähler structures) and B. Charbonneau at Waterloo. In the Vancouver area, a school of algebraic geometry has developed around K. Behrend (algebraic stacks), P. Brosnan (essential dimension), J. Bryan (enumerative geometry), J. Carrell (torus actions), K. Karu (toric geometry and mirror geometry) and Z. Reichstein (invariant theory and essential dimension), that has put the West Coast on the map in the discipline.

In Atlantic Canada, the University of New Brunswick (UNB) has a Centre for Research in Noncommutative Geometry and Topology, with a cohort of promising researchers: J. Gegenburgh (quantum gravity), V. Husain (black holes and quantum gravity), D. Kucerovsky (non-commutative topology), B. Rangipour (Hopf algebras); in addition, H. Thomas works on algebraic combinatorics and algebraic geometry.

The various areas of topology are represented in Canada; low dimensional topology by S. Boyer(UQAM), with a leading program to classify Dehn surgeries, D. Bar-Natan (Toronto) and D. Rolfsen (UBC) who work on knot invariants; in high dimensional topology, by I. Hambleton at McMaster (high dimensional topology) and A. Adem at UBC (cohomology of groups and homotopy theory). R. Jardine (Western) and A. Joyal (UQAM) have both had an important impact in their study of homotopical methods in algebraic geometry. At Western, Jardine is the leading figure in a school that explores the boundaries of topology and geometry: J. Christensen (homotopy theory and quantum gravity), A. Dhillon (motivic integration and the cohomology of moduli space), M. Khalkhali (operator theory and non-commutative geometry), and L. Renner (equivariant topology of group embeddings). Computational methods to calculate homology groups with applications in imaging are developed by Tomasz Kaczynski (Sherbrooke).

There is a strong young school developing in differential geometry, mostly in Ontario, with A. Nabutovsky (geodesics and Morse theory), S. Alexakis (conformal invariants for varieties), L. Guth (systoles for varieties), S. Karigiannis (special holonomy), V. Apostolov (special holonomy) and M. Wang (Einstein manifolds).

One of the themes of recent developments in geometry has been the constant interaction with ideas and themes from physics, and Canada has a good young cadre of workers in the various areas of this interaction. In Vancouver, physical ideas feature in J. Bryan's work on the computation of Gromov-Witten invariants, and of Karu's on mirror symmetry; at Alberta,

C. Doran and V. Bouchard work on the mathematics of string theory; at McMaster, H. Boden works on gauge theory, and in Montreal, there is a group centred on the general theme of integrable systems with J. Hurtubise working on geometrical ramifications, and J. Harnad, M. Bertola, M. Korotkin on integrable systems and random matrix theory.

Montreal has a well established laboratory (CIRGET) in the various areas of geometry and topology, with an extensive recording of training postdoctoral fellows and graduate students.

6.0. EDUCATION AND OUTREACH

The Canadian mathematical community has a long, internationally recognized, tradition of involvement in education and outreach activities. Since its foundation, the Canadian Mathematical Society (CMS) has been very active in these areas; it has been joined in the last decades by the three institutes and, more recently, MITACS. The communities of mathematicians and mathematics educators collaborate closely, in particular through the Canadian Mathematics Education Study Group (CMESG), an association of university professors from mathematics and mathematics education. The Canadian Mathematical Society organizes an education session at each of its semi-annual meetings.

Canadian Mathematics Education Fora: The community has started to hold the Canadian Mathematics Education Forum on a regular basis. The first was held in 2003 (Montreal), followed by 2005 (Toronto) and 2009 (Vancouver). These forums welcome mathematicians, mathematics educators and K-12 school teachers as well as a few CEGEP teachers, with the purpose of promoting and advancing mathematics education in the country. It was the forum of 2003 which brought to the fore the issues of mathematics education within aboriginal communities. Since then, several follow-up activities were launched, especially by PIMS in the West, where aboriginal communities are more numerous. The tentative medium-range plan for the forums is to hold them every four years at the midpoint between the International Congress on Mathematical Education (ICME) meetings, and to vary the location across Canada. The next Forum is tentatively scheduled for late Spring 2014, hopefully in Atlantic Canada.

Competitions: Canada has a long tradition of mathematics competitions. The Canadian Mathematical Society organizes two competitions every year: the Canadian Open Mathematics Challenge, which is open to all students throughout the country, and acts as the qualifying paper for the second competition, the Canadian Mathematical Olympiad, which is by invitation. The CMS also selects the Canadian team that represents Canada at the International Mathematical Olympiad. The team is trained beforehand in a two-week long camp. In several provinces, there are other competitions organized by the provincial associations of school teachers. For instance, in Quebec, the AMQ (Association mathématique du Québec), which groups CEGEP and university professors, organizes one competition at the secondary level and one at the CEGEP level. The AQJM (Association québécoise des jeux mathématiques) founded by Frédéric Gourdeau (Laval) organizes four rounds of competitions of mathematical games. The winners are sent to the international competition in Paris. In BC, the Elmacon contest is organized jointly between the PIMS and the BC Association of Mathematics teachers. The

Center for Education in Mathematics and Computing (CEMC) of Waterloo develops and administers many internationally recognized mathematics and computing contests for grades 7-12. In addition to these examples, there are a large number of provincial and regional contests, some involving the solving of problems on contest papers, while others have more the flavour of Math Fairs where students prepare and present a project.

Math camps: For over a decade, there have been regional math camps taking place all across Canada. There were 17 math camps sponsored by the CMS in 2010. These camps usually last from 7 to 10 days, and attract an average of 20 participants. At most of these camps, participation is by invitation only. During these camps, the students are put in contact with mathematics researchers. The activities vary from competitions to projects to problem solving and to exploration of research matters.

Activities in the schools: The Canadian mathematical community is very active in the schools. Many university professors give lectures in the schools and also at meetings of teacher associations. *Sciences and Mathematics in Action* (SMAC), a program produced by Jean-Marie de Koninck (Laval) in collaboration with MITACS, now exists in French and English. One part of the program is the interactive multimedia game*, MathAmaze*, accessible on-line where users must answer mathematical questions. Another part is *ShowMath* which is presented in many schools; *ShowMathInClass* allows for a follow-up in the classroom after the students have seen the show. Mathematics is represented at science fairs, and there are always a number of projects in mathematics. The community provides judges for these projects. *Math Mania*, organized by PIMS, is a popular alternative math education event which has run three to four times a year in elementary schools in Victoria, Saanich, Sidney and Sooke since 1997. *Math Mania* presents a variety of interactive demonstrations, puzzles, games and art.

Magazines: There are two semi-annual magazines distributed freely in the schools. *Pi in the Sky* (http://www.pims.math.ca/resources/publications/pi-sky) is produced by PIMS and distributed freely in the West, while *Accromath* (www.accromath.ca), produced by ISM (Institut des sciences mathématiques) and CRM, is distributed freely in Quebec. Both magazines are also accessible on the web. *Accromath* has accumulated prizes: a bronze medal in the worldwide *Summit Creative Awards* in 2007, a "Grand Award," in the *Apex Awards* in 2008, a special prize from the Ministry of Education of Quebec in 2009 and, in 2010 a special mention for the prestigious d'Alembert Prize of the Société mathématique de France (SMF). The reputation of *Accromath* in the francophone community continues to grow.

Web Resources: Produced in Regina and supported by the CMS, Math Central (http://mathcentral.uregina.ca/) is now trilingual (French, English, Spanish) and offers resources like *Mathematics with a human face* (portraits of mathematicians and careers in mathematics), *Quanderies and queries*, and *Math beyond school,* as well as a link to *Aboriginal perspectives.*

Canadian Undergraduate Mathematics Conference (CUMC): Coordinated by the CMS Student Committee (Studc), the CUMC is Canada's premier conference for undergraduate students interested in mathematics and related fields. The conference aims to give students of all abilities a valuable experience in mathematics beyond what is available in their normal studies.

Students get the valuable opportunity to practice giving mathematical talks as well as listen to renowned keynote speakers.

Outreach for the public: There is a tradition of public activities throughout the country. In particular there are public lectures at each CMS semi-annual meeting. Since 2006, CRM has a series of public lectures, *Les grandes conférences du CRM,* three to four times a year, either in Montreal or Quebec City. In 2007, the Fields Institute started a public lecture series: *The Nathan and Beatrice Keyfitz Lectures in Mathematics and the Social Sciences,* with approximately one lecture per year. Arvind Gupta has been a regular guest on the Christy Clark Show on CKNW AM980 in Vancouver where he provides fun (and surprising) ways for parents to keep their children excited about mathematics.

International outreach: The expertise of the Canadian mathematical community in education and outreach activities is recognized worldwide. Bernard Hodgson (Laval) was General Secretary of the International Commission of Mathematical Instruction (ICMI) from 1999 to 2008. Christiane Rousseau was one of the four panellists at the last International Congress of Mathematicians (ICM 2010) on the theme "Communicating mathematics to the public at large". She is also a member of the Design team of the *Klein Project*, a joint project between the International Mathematical Union (IMU) and ICMI. Inspired by Felix Klein's famous book *Elementary Mathematics from an Advanced Standpoint,* published one century ago, the project is intended as a stimulus for mathematics teachers, to help them to make connections between the mathematics they teach and the field of mathematics in general, while taking into account the evolution of this field over the last century. Andrew Granville wrote a theatre show: *MSI* (*Math Sciences Investigation): Anatomy of Integers and Permutations,* which was presented at the Institute of Advanced Studies (Princeton), but not yet in Canada. The Math in Moscow program, co-sponsored by NSERC and CMS, sends two undergraduate students each year to spend a term in Moscow at the Independent University.

MPE2013 and outreach: A wide range of outreach activities will be organized in the context of MPE2013 and coordinated with international partners: special issues of *Accromath* and *Pi in the Sky*, public lectures, web resources for teachers, etc. Provincial associations of teachers have been invited to hold their congresses on the theme. These activities will raise the awareness of the public, teachers and students to the role of mathematics in planetary issues.

ANNEX A

EXTERNAL AWARDS

A.1. SLOAN FELLOWS (since 1980, now in Canada, with current University)

2010 O. Angel (UBC)
S. Alexakis (Toronto)
M. Devos (SFU)
L. Guth (Toronto)
B. Szegedy (Toronto)
2008 V. Blomer (Toronto)
2006 J. Solymosi (UBC)
2004 R. Seiringer (McGill)
B. Virag (Toronto)
2003 J. Colliander (Toronto)
2002 J. Geelen (Waterloo)
V. Vatsal (UBC)
2000 M. Pugh (Toronto)
J. Toth (McGill)
2001 D. Jakobson (McGill)
1999 J. Bryan (UBC)
J. Chen (UBC)
1997 G. Haller (McGill)
L. Jeffrey (Toronto)
B. Khesin (Toronto)
1996 H. Darmon (McGill)
J. Quastel (Toronto)
L. Seco (Toronto)
1993 P. Guan (McGill)
1992 A. Granville (Montreal)
1988 W. Craig (McMaster)
1987 R. Jardine (Western)
1984 D. Peterson (UBC)
1982 D. Brydges (UBC)
1981 S. Kudla (Toronto)

A.2. ICM SPEAKERS

2010 (Hyderabad)
D. Brydges (UBC)
L. Guth (Toronto)
A. Nabutovsky (Toronto)
J. Quastel (Toronto)
Z. Reichstein (UBC)
C. Rousseau (Montreal)
A. Shnirelman (Concordia)

2006 (Madrid)	H. Darmon (McGill)
	F. Lalonde (Montreal)
	M. Shub (Toronto)
	V. Vatsal (UBC)
2002 (Beijing)	S. Kudla (Toronto)
	E. Meinrencken (Toronto)
	B. Reed (McGill)
1998 (Berlin)	J. Arthur (Toronto)
	S. Todorcevic (Toronto)
	N. Tomczak-Jaegermann (Alberta)
	B. Hodgson (Laval)
1994 (Zurich)	D. Dawson (Carleton)
	G. Elliott (Toronto)
	J. Friedlander (Toronto)
	E. Perkins (UBC)
	G. Slade (McMaster)
1990 (Kyoto)	M. Barlow (UBC)
	S. Cook (Toronto) (Plenary)
	J. Feldman (UBC)
	I.M. Sigal (Toronto)
1986 (Berkeley)	V. Ivrii (Toronto)
	I. Kupka (Toronto)
	A. Lachlan (SFU)

A.3. ICIAM PLENARY SPEAKERS

2011 (Vancouver)	M. Lewis (Alberta)
2007 (Zurich)	I. Ekeland (UBC)
	M. Fortin (Laval)
	B. Keyfitz (Toronto)

1995 (Hamburg) M. Ward (UBC)

A.4. SIAM FELLOWS

U. Ascher (UBC)
A. Bandrauk (Sherbrooke)
P. Caines (McGill)
M. Delfour (Montreal)
L. Glass (McGill)
M. Mackey (McGill)
R. Russell (SFU)

A.5. MATHEMATICAL FELLOWS OF THE ROYAL SOCIETY OF CANADA

J. Aczél (Waterloo)
J. G. Arthur (Toronto)
M. Barlow (UBC)
E. Bierstone (Toronto)
T. Bloom (Toronto)
A. B. Borodin (Toronto)
D. W. Boyd (UBC)
D. Brydges (UBC)
M.-D. Choi (Toronto)
W. Craig (McMaster)
M. Csörgö (Carleton)
K. R. Davidson (Waterloo)
D. A. Dawson (Carleton)
H. Darmon (McGill)
M. Delfour (Montreal)
V. Dlab (Carleton)
G. A. Elliott (Toronto)
J. S. Feldman (UBC)
L. Jeffrey (Toronto)
A. Joyal (UQAM)
N. Kamran (McGill)
F. Lalonde (Montreal)
J. Lambek (McGill)
P. Lancaster (Calgary)
L. A. Lorch (York)
J. McKay (Concordia)
E. Meinrenken (Toronto)
P. Milman (Toronto)
R. V. Moody (Victoria)
K. Murasugi (Toronto)
M. R. Murty (Queen’s)
V. K. Murty (Toronto)
E. A. Perkins (UBC)
I. F. Putnam (Victoria)
B. Reed (McGill)
P. Ribenboim (Queen’s)

P. A. Fillmore (Dalhousie)

J. B. Friedlander (Toronto)

N. Ghoussoub (UBC)

I. Goulden (Waterloo)

A. Granville (Montreal)

E. E. Granirer (UBC)

P. C. Greiner (Toronto)

P. Guan (McGill)

C. K. Gupta (Manitoba)

D. Handelman (UBC)

J. Hurtubise (McGill)

V. Ivrii (Toronto)

D. Jackson (Waterloo)

P. G. Rooney (Toronto)

I. M. Sigal (Toronto)

G. Slade (UBC)

C. L. Stewart (Waterloo)

N. Tomczak-Jaegermann (Alberta)

A. Weiss (Alberta)

A.6. CANADA RESEARCH CHAIRS (CRC) IN MATHEMATICS

As for many areas of science in Canada, the Canada Research Chairs have had a profound impact on the development of the discipline. The following lists all those identified as working in Mathematics on the CRC web site.

Person	**Tier**	**University**	**Area**
A. Adem	1	UBC	Topology
H. Baushke	2	UBC	Convex analysis and optimization
N. Bergeron	2	York	Discrete Mathematics
K. Beszdek	1	Calgary	Discrete Mathematics
D. Brydges	1	UBC	Probability and Mathematical Physics
V. Chernousov	1	Alberta	Algebra
W. Craig	1	McMaster	PDE
M. Davison	2	Western	Financial Mathematics
T. Day	2	Queen’s	Mathematical Biology
H. Dowlatabadi	1	UBC	Modelling and global change
H. Eberl	2	Guelph	Mathematical Biology

I. Ekeland	1	UBC	Mathematical Economics
G. Elliott	1	Toronto	Functional Analysis
J. Geelen	2	Waterloo	Discrete Mathematics
A. Granville	1	Montreal	Number theory
P. Guan	1	McGill	PDE
A. Iovita	2	Concordia	Number theory
R. Jardine	1	Western	Topology
V. Kaimanovich	1	Ottawa	Probability and Operator Algebras
A. Kempf	2	Waterloo	Quantum Information
S. Kudla	1	Toronto	Number theory
R. Kuske	2	UBC	Industrial Mathematics
F. Lalonde	1	Montreal	Geometry
M. Lewis	1	Alberta	Mathematical Biology
R. Melnik	1	Wilfrid Laurier	Mathematical Modelling
B. Mohar	2	SFU	Discrete Mathematics
N. Nigam	2	SFU	Scientific computing
E. Perkins	1	UBC	Probability
I. Polterovich	2	Montreal	PDE
I. Putnam	1	Victoria	Functional Analysis
A. Quas	2	Victoria	Dynamics
S. Ramdorai	1	UBC	Number theory
D. Sankoff	1	Ottawa	Mathematical Biology
T. Ransford	1	Laval	Analysis
C. Reutenauer	1	UQAM	Discrete Mathematics
D. Schotzau	2	UBC	Scientific Computing
A. Shnirelman	1	Concordia	PDE
F. Soumis	1	E. Polytechnique	Optimization
P. Speisseger	2	McMaster	Logic
C. Stewart	1	Waterloo	Number theory
D. Tardos	1	SFU	Computational complexity

S. Todorcevic	1	Toronto	Discrete Mathematics
N. Tomczak-Jaegermann	1	Alberta	Functional analysis
P. Tupper	2	SFU	Scientific Computing
B. Virag	2	Toronto	Probability
L. Wahl	2	Western	Mathematical Biology
N. Wormald	1	Waterloo	Discrete Mathematics
J. Wu	1	York	Mathematical Biology

A.7. KILLAM FELLOWS

2009	W. Craig	McMaster
2008	H. Darmon	McGill
2007	E.A. Perkins	UBC
2006	R. Speicher	Queen’s
2006	N. Kamran	McGill
2003	J.B. Friedlander	Toronto
2002	V. Ivrii	Toronto
2000	F. Lalonde	Montreal
1999	P. Milman	Toronto
1998	M.R. Murty	Queen’s
1997	N. Tomczak-Jaegermann	Alberta
1996	G Elliott	Toronto
1995	K. Davidson	Waterloo
1992	D. Handelman	Ottawa
1991	J. Patera	Montreal
1990	C.L. Stewart	Waterloo
1989	M. Delfour	Montreal
1988	I.M. Sigal	Toronto
1987	A. Granas	Montreal
1986	G. Gratzer	Manitoba
1985	A. Joyal	UQAM

1983	H. C Williams	Manitoba
1982	R. Wong	Manitoba
1979	F. Clarke	UBC
1978	M. Csorgo	Carleton
1977	D. Dawson	Carleton
1975	S. Dubuc	Montreal

A.8. STEACIE FELLOWS

	J. Arthur	Toronto
	R. Moody	Saskatchewan
	D. Handelman	Ottawa
	M.R. Murty	McGill
	K. Davidson	Waterloo
	E. Perkins	UBC
2011	A. Litvak	Alberta
2008	T. Day	Queen’s
2007	E. Meinrencken	Toronto
2005	M. Doebeli	UBC
2004	L. Jeffrey	Toronto
2002	H. Darmon	McGill
1998	M. Ward	UBC
1995	K. Murty	Toronto

ANNEX B

INTERNAL RESEARCH PRIZES

B.1. CANADIAN MATHEMATICAL SOCIETY (CMS)

B.1.1. Coxeter-James Prize (Junior Prize)

Year	**Prizewinner**	**Affiliation at time of award**
2011	I. Polterovich	Montreal
2010	B. Virág	Toronto
2009	P. Brosnan	British Columbia
2008	R. Vakil	Stanford
2007	V. Vatsal	British Columbia
2006	J. Geelen	Waterloo
2005	R. McCann	Toronto
2004	I. Laba	British Columbia
2003	J. Chen	British Columbia
2002	L. Jeffrey	Toronto
2001	K. Behrend	British Columbia
2000	D. Roy	Ottawa
1999	M. Zworski	Univ. of Cal., Berkeley and Toronto
1998	H. Darmon	McGill
1997	M. Ward	British Columbia
1996	N. Higson	Penn State
1995	G. Slade	McMaster
1994	M. Spivakovsky	Toronto
1993	J. Hurtubise	McGill
1992	J.F. Jardine	Western Ontario
1991	K. Murty	Toronto
1990	N. Ghoussoub	UBC
1989	A. Dow	York

1988	R. Murty	McGill
1987	J. Borwein	Dalhousie
1986	E. Perkins	UBC
1985	P. Selick	Toronto
1984	M. Goresky	Northeastern
1983	M.D. Choi	Toronto
1982	J. Mallet-Paret	Brown and Michigan
1981	J. Millson	UCLA and Toronto
1980	F. Clarke	UBC
1979	D. Boyd	UBC
1978	R. Moody	Saskatchewan

B.1.2. Jeffrey-Williams Prize (Senior Prize)

Year	Prizewinner	Affiliation at time of award
2011	K. Behrend	UBC
2010	M. Lyubich	Stony Brook and Toronto
2009	S. Kudla	Toronto
2008	M. Barlow	British Columbia
2007	N. Ghoussoub	British Columbia
2006	A. Granville	Montréal
2005	P. Milman	Toronto
2005	E. Bierstone	Toronto
2004	J. Feldman	British Columbia
2003	R. Murty	Queen's
2002	E. Perkins	British Columbia
2001	D. Boyd	British Columbia
2000	Not Awarded	
1999	J. Friedlander	Toronto
1998	G. Elliott	Toronto and Copenhagen

1997	S. Halperin	Toronto
1996	M. Goresky	Northeastern
1995	R.V. Moody	Alberta
1994	D. Dawson	Carleton
1993	J. Arthur	Toronto
1992	I. Sigal	Toronto
1991	P. Lancaster	Calgary
1990	R. Steinberg	UCLA
1989	E.C. Milner	Calgary
1988	J. Lambek	McGill
1987	L. Nirenberg	Courant
1986	C. Herz	McGill
1985	L. Siebenmann	Paris-Sud
1984	C.S. Morawetz	Courant
1983	R.H. Bott	Harvard
1982	J. Lipman	Purdue
1981	J.E. Marsden	Berkeley
1980	R.P. Langlands	Princeton
1979	I. Halperin	Toronto
1978	G. Gratzer	Manitoba
1977	G. Duff	Toronto
1976	M. Wyman	Alberta
1975	N.S. Mendelsohn	Manitoba
1974	H.J. Zassenhaus	Ohio State
1972	P.J. Davis	Brown
1971	W.T. Tutte	Waterloo
1970	W.A.J. Luxemburg	Cal Tech
1969	R. Pyke	Washington
1968	I. Kaplansky	Berkeley

B.1.3. Krieger-Nelson Prize (Women in Mathematics)

Year	Prizewinner	Affiliation at time of award
2011	R. Kuske	British Columbia
2010	L. Bronsard	McMaster
2009	Y. Karshon	Toronto
2008	I. Laba	British Columbia
2007	P. van den Driessche	Victoria
2006	P. Haxell	Waterloo
2005	B. Keyfitz	Houston
2004	Not Awarded	
2003	L. Keshet	British Columbia
2002	P. Greenwood	British Columbia and Arizona State
2001	L. Jeffrey	Toronto
2000	K. Gupta	Manitoba
1999	N. Tomczak-Jaegermann	Alberta
1998	C. Sulem	Toronto
1997	C. Morawetz	New York
1996	O. Kharlampovich	McGill
1995	N. Reid	Toronto

B.2. CANADIAN APPLIED AND INDUSTRIAL MATHEMATICS SOCIETY (CAIMS)

B.2.1. CAIMS Research Prize

Year	Prizewinner	Affiliation at time of award
2010	U. Ascher	UBC
2009	M. Lewis	Alberta
2008	A. George	Waterloo
2007	G. Swaters	Alberta
2006	M. Mackey	McGill
2005	M. Fortin	Laval

2004	R. Russell	SFU
2003	J. Wu	York

B.2.2 CAIMS-PIMS Early Career Award

2010	Daniel Coombs	UBC

B.3. INSTITUTE RESEARCH PRIZES:

Institutes also give prizes in cognate disciplines (statistics, theoretical and mathematical physics) or in education, fellowships, and they all have prestige lecture series. For more information visit the respective web site.

B.3.1. CRM-Fields-PIMS (CRM-Fields before 2005)

Year	**Prizewinner**	**Affiliation at time of award**
2011	M. Lewis	Alberta
2010	G. Slade	UBC
2009	M. Barlow	UBC
2008	A. Borodin	Toronto
2007	J. Feldman	UBC
2006	N. Tomczak-Jaegermann	Alberta
2005	D. Boyd	UBC
2004	D. Dawson	Carleton
2003	J. McKay	Concordia
	E. Perkins	UBC
2002	J. Friedlander	Toronto
2001	W. Tutte	Waterloo
2000	I. Sigal	Toronto
1999	S. Cook	Toronto
1998	R.V. Moody	Alberta
1997	J. Arthur	Toronto
1996	G. Elliott	Toronto
1995	H.S.M. Coxeter	Toronto

B.3.2. André-Aisenstadt Prize (Junior Prize)

Year	Prizewinner	Affiliation at time of award
2011	J. Kamnitzer	Toronto
2010	O. Angel	UBC
2009	V. Blomer	Toronto
2008	J. Solymosi	UBC
	J. Taylor	Montreal
2007	G. Smith	Queen's
	A. Holroyd	UBC
2006	I. Polterovich	Montreal
	T.-P. Tsai	UBC
2005	R. Vakil	Stanford
2004	V. Vatsal	UBC
2003	A. Brudnyi	Calgary
2002	J. Chen	UBC
2001	E. Meinrencken	Toronto
2000	C. Gui	Connecticut
1999	J. Toth	McGill
1998	B. Khesin	Toronto
1997	H. Darmon	McGill
	L. Jeffrey	Toronto
1996	A. Lewis	Waterloo
1995	N. Higson	PSU
	M. Ward	UBC
1994	Not awarded	
1993	I. Putnam	Victoria
1992	N. Kamran	McGill