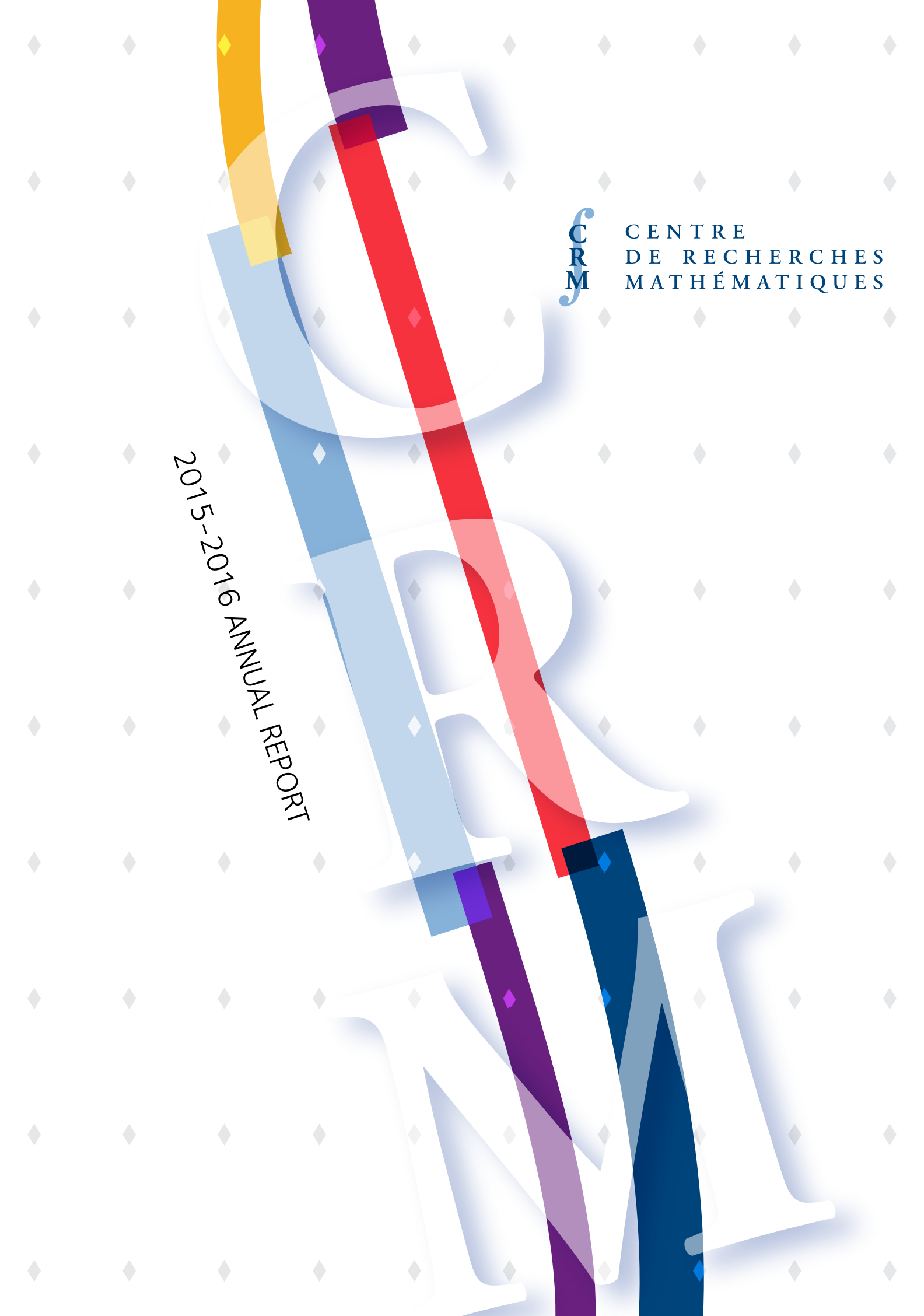


CENTRE
DE RECHERCHES
MATHÉMATIQUES

2015-2016 ANNUAL REPORT

PRESENTATION

Luc Vinet

Research in mathematical physics has played an important role at the CRM since its founding in 1968. This was especially clear during the 2015-2016 academic year, as an impressive thematic semester on AdS/CFT correspondence, holography, and integrability took place at the CRM from June 7, 2015 to January 13, 2016. The program of the semester included eight workshops, six mini-courses, and two series of lectures by Aisenstadt Chairholders (Bertrand Eynard and Nikita Nekrasov). I wish to express my gratitude to the members of the scientific committee, consisting of mathematicians and physicists based in Montreal (Marco Bertola, Robert Brandenberger, John Harnad, Alexander Maloney, and Johannes Walcher), as well as prestigious researchers from France and North America: Freddy Cachazo (Perimeter Institute), Alexander Its (Indiana), Vladimir Kazakov (École normale supérieure), Juan Maldacena (Institute for Advanced Study), and Radu Roiban (Penn State University). The second thematic semester of 2015-2016 focused on computational mathematics in emerging applications and was organized by Rustum Choksi, Jean-Christophe Nave, and Adam Oberman: I thank them for their hard work. This semester included a series of lectures delivered by Selim Esedoglu (Aisenstadt Chairholder), five workshops (including one at the Université Laval and four at the Université de Montréal), and a related activity that took place in Halifax.

Several workshops were organized in 2015-2016 to celebrate the scientific careers of CRM members. From August 31 to September 4, 2015, a workshop was held in honour of François Lalonde (holder of the CRC in differential geometry and topology at the Université de Montréal and CRM director from 2004 to 2008 and from 2011 to 2013). On November 2-3, 2015, a workshop was held in honour of Gilles Brassard (one of the founders of quantum computing). From May 4 to 7, 2016, a workshop was held in honour of André Bandrauk (holder of the CRC in computational chemistry and photonics at the Université de Sherbrooke). Finally a workshop took place in the Czech Republic on the occasion of the 80th birthday of Pavel Winternitz and the 80th birthday of Jiří Patera: these two researchers have been working at the CRM for several decades and have made fundamental contributions to mathematical physics. The 2016 CRM-Fields-PIMS Prize was awarded to Daniel Wise (McGill University) and the 2016 André Aisenstadt Prize to Anne Broadbent (University of Ottawa). Freddy Cachazo (Perimeter Institute) and Radu Craiu (University of Toronto) were the winners of the 2016 ACP-CRM Prize and the 2016 CRM-SSC Prize, respectively. In 2015-2016 the CRM continued its outreach efforts by organizing four "Grandes Conférences du CRM," geared towards the general public and featuring diverse topics: the art and science of systems with too many unknowns (Emmanuel Candès), the Twin Primes Conjecture, the mathematics of control (Enrique Zuazua), and the application of mathematics to conservation biology (Stephanie Peacock).

The CRM is proud to welcome MILA (the Montreal Institute for Learning Algorithms), which became the thirteenth laboratory of the CRM in June 2015. This institute is one of the world's top research centres in artificial intelligence and one of the research groups behind IVADO (Institute for Data Valorization): IVADO received a major CFREF grant to develop data science in Canada. In August 2015 MILA and the CRM organized a very successful Deep Learning Summer School (sponsored by CIFAR), which received hundreds of requests for participation: fewer than a third of the applicants were able to register! The CRM also experienced a surge in its industrial collaborations thanks to the Institutes Innovation Platform (IIP), a grant awarded by NSERC for the period 2014-2017: in particular the CRM organized three industrial networking workshops and two problem solving workshops in 2015-2016.

Our relations with the French mathematical community have flourished since the creation of the Unité Mixte Internationale CRM (a unit of the CNRS). During its first four years the UMI was brilliantly led by Laurent Habsieger, whom I thank for his fantastic work at the CRM. Emmanuel Giroux became the director of the UMI CRM on September 1st, 2015. Additionally, in 2016, the FRQNT awarded a grant to the CRM to create a "mirror site" of the UMI CRM in France: this grant allows Quebec researchers to conduct research in French institutions. Therefore I have one more reason to thank the FRQNT and the CNRS, as well as the other institutions that support the CRM, in particular NSERC and the National Science Foundation (NSF).

Luc Vinet
Director of the CRM
December 2017

THEMATIC PROGRAM

AdS/CFT Correspondence, Holography, Integrability (June 2015 – January 2016)

The Anti-de-Sitter/Conformal Field Theory (AdS/CFT) correspondence has been dominating research in theoretical high-energy physics for the last 15 years. It posits an exact quantum equivalence between string theory as a theory of quantum gravity on negatively curved space-times and certain conformal quantum field theories defined on the boundary of these space-times. The correspondence is an incarnation of the so-called holographic principle and is viewed as an important clue for solving the major outstanding mathematical problems of contemporary theoretical physics, quantum gravity, and strongly coupled gauge theory. As such AdS/CFT is bound to find a way into pure mathematics, following the lead of many other, physically substantially simpler, dualities, most notably the correspondence between topological string theory and Chern-Simons gauge theory.

The thematic program is the one giving the CRM its greatest visibility: each year, it gathers at the CRM hundreds of researchers from all over the world to work on specific themes and attend workshops at the leading edge of research. The thematic program always includes lectures by holders of the Aisenstadt Chair. The two themes of 2015-2016 were the AdS/CFT correspondence and computational mathematics.

For several years now, methods of integrable systems have taken centre stage for the quantitative development of the correspondence. This thematic semester, under the aegis of the Mathematical Physics Laboratory of the CRM, covered a range of topics from the mathematical underpinnings of integrability to a variety of physical applications, up to quantum chromodynamics and condensed matter physics. The participants focused on those aspects that allow for exact solutions, such as the appearance of integrability in the planar limit of N = 4 super Yang-Mills theory, lower-dimensional models, higher-spin theories, as well as topological field and topological string theories. This was the first thematic semester in the general area of gauge/gravity duality held at the CRM, and the first time that this ultimate physical duality had been featured at a mathematical research institute anywhere.

The thematic semester included eight workshops (see below), two series of lectures by the Aisenstadt Chairs (Bertrand Eynard and Nikita Nekrasov), and mini-courses taught by the following researchers: Bertrand Eynard (IPT, CEA Saclay), Dmytro Volin (Trinity College Dublin), Vladimir Kazakov (École normale supérieure, Paris), Nikolay Gromov (King's College London), Pedro Vieira (Perimeter Institute for Theoretical Physics), and Michael Gekhtman (University of Notre Dame).

Computational Mathematics in Emerging Applications (April 2016 – July 2016)

A fundamental change is taking place in the role of applied and computational mathematics. The relationship between the modelling, analysis, and solution of mathematical problems in applications has changed. In the past, computational mathematicians treated the physical models as given (for example, the Navier-Stokes equations), although in reality these models were also derived. In emerging applications, the choice of models goes hand in hand with the computational tools and the mathematical analysis. Areas such as machine learning, bioinformatics, network science, and medical imaging are increasingly making use of computation and require new computational methods that are tractable. The techniques of computational mathematics are uniquely suited to these problems. The unifying theme of the semester was the interaction of analysis with computation. Particular workshops focused on level set methods, variational problems, materials, optimal transportation, and finite element methods.

The thematic program consisted of five workshops and a series of lectures by the Aisenstadt Chairholder, Selim Esedoglu. A related workshop, on the numerical analysis of singularly perturbed differential equations, took place in Halifax.

Workshops and mini-courses

Asymptotics in integrable systems, random matrices and random processes and universality – In honour of Percy Deift's 70th birthday

June 7-11, 2015, CRM

Organizers: Jinho Baik (Michigan), Marco Bertola (Concordia), Thomas Kriecherbauer (Bayreuth), Kenneth McLaughlin (Arizona), Alexander Tovbis (Central Florida)

The goal of the workshop was to gather the largest number of researchers and interests related to the workshop theme within the short period allotted. The main topics covered can be roughly divided as follows: asymptotic spectral theory of non-invariant matrix models (Bourgade, Shcherbina, Borot); transition asymptotics in random processes (Its, Claeys); new methods in universality from classical function theory (Lubinsky); quantum and classical confinement (Nenciu); normal matrix models (Grava); asymptotics of determinants (Basor, Widom, Krasovsky, Simon); new applications of Riemann-Hilbert techniques in tomography (Tovbis); universality in nonlinear PDEs (Dubrovin); numerical analysis in random matrices and universality in numerical approaches (Bornemann, Trogdon); Dyson processes (Adler, Duits); integrable probability (Borodin, Corwin); multi-matrix models (Bothner, Kuijlaars); integrable statistical models (Bleher); random function theory (Ben Arous); and integrable systems and Töplitz determinants (Cafasso).

One special slot in the schedule was devoted to "open research directions." The workshop was held in honour of Percy Deift's 70th birthday; nine years ago a similar workshop was held at NYU to celebrate his 60th birthday and included a similar session, in which Deift produced a list of 16 problems. These problems were examined again (with status updates) and others were added to the list.

Most contributions revolved around asymptotics in different contexts: the sinh-model of gas particles (Borot); mesoscopic scale in Wigner

Marco Bertola

ensembles (Bourgade); critical transition in asymptotics of Fredholm determinants (Its, Krasovsky); singular values of the multi-interval finite Hilbert transform (Tovbis); and universality in small dispersion nonlinear PDEs (Dubrovin). A new direction in this field is the study of numerical approximations for Riemann–Hilbert problems (Olver, Trogdon) and Fredholm determinants (Bornemann), in which there have been tremendous advances towards effective numerical computations. This problem is related to the "Painlevé project," proposed by Percy Deift ten years ago (the problem is still on the list!). The talks of Adler, Borodin, and Corwin could be chalked off in the emerging area of "integrable probability," a phrase coined by Deift himself years ago. Several talks (Krasovsky, Basor, Widom, and Claeys) were devoted to applications of Töplitz determinants, a topic that has a distinguished history starting with the Onsager solution of correlation functions of the Ising model.

Random Matrix Theory was well represented: the talks of Bothner and Kuijlaars both addressed spectral theory of multiple random matrix models and presented evidence of a new universal behaviour that is expressed in terms of Meijer G-functions. Grava discussed the relationship between orthogonal polynomials on the plane and the normal matrix model and Lubinsky discussed the approach towards universality using techniques of potential theory and complex function theory. A special issue of the journal SIGMA, edited by Baik, Corwin, and Rider was announced at the workshop; it was published in 2017 and consisted of refereed contributions celebrating the seventieth anniversaries of both Percy Deift and Craig Tracy.

Robert Brandenberger

AdS/CFT, self-adjoint extension and the resolution of cosmological singularities

July 6-10, 2015, CRM

Organizers: Robert Brandenberger (McGill), Walter Craig (McMaster), Niky Kamran (McGill)

The workshop brought together cosmologists (R. Brandenberger, Y. Cai, Y. Wang), string theorists (T. Banks, S. Das, D. Kabat, D. Lowe, A. Maloney), and mathematicians (S. Alexakis, W. Craig, A. Enciso) to discuss applications of the AdS/CFT correspondence to the question of singularity resolution in cosmology. The first day, the talks were devoted to the question of how bulk quantities in anti-de-Sitter space (AdS) can be reconstructed from the boundary conformal field theory. This question is crucial for several research projects of the workshop participants. The second day was devoted to presentations on some mathematical aspects relevant to AdS/CFT and to applications of the AdS/CFT reconstruction to cosmology and other time-dependent problems. The third day, the focus of the talks turned to reconstruction in the context of the proposed de Sitter (dS)/CFT correspondence. The morning speaker on the fourth day was Tom Banks, who presented his approach to holographic cosmology. The afternoon talks on the fourth day focused on cosmology while the fifth day talks focused on black holes, three-dimensional gravity, and string theory.

There are at least four research projects where much progress was achieved during the workshop. In all four cases drafts of the articles were written and revised during the workshop. One such collaboration involved R. Brandenberger, Y. Cai, S. Das, E. Ferreira, I. Morrison, and Y. Wang. The fact that the collaborators were all in the same room helped them converge on the key issues in the draft. Another collaboration included A. Pathak, G. Ng, S. Collier, and A. Maloney. The workshop talks played a crucial role in these research projects and the workshop itself led to the development of new links between mathematicians and physicists. To conclude we note that many very promising postdocs (e.g. D. Anninos, P. MacFadden, I. Morrison) and excellent graduate students (e.g. A. Pathak and E. Ferreira) were among the presenters. Many graduate students (e.g. from McGill, Harvard, and Brown) took a very active part in the program.

Mini-course on cluster algebras, Poisson structure, networks and integrable systems

July 6-10, 2015, CRM

Lecturer: Michael Gekhtman (Notre Dame)

Beyond integrability: The mathematics and physics of integrability and its breaking in low-dimensional strongly correlated quantum phenomena

July 13-15, 2015, CRM

Organizers: Jean-Sébastien Caux (Amsterdam), Masudul Haque (MPI-PKS), Robert Konik (Brookhaven Lab.)

The workshop was designed to focus on integrable models, their applications to strongly correlated quantum systems, and the theory of systems in which integrability is weakly broken. It brought together mathematical physicists from the Bethe Ansatz community, theoretical physicists working on the relationship of integrability and its breaking to physical questions (prominently involving non-equilibrium dynamics), and four leading experimentalists, two from the cold-atom community and two from the neutron-scattering community. Each day started with a long (45-minute) talk by an experimentalist, followed by a series of half-hour theory talks. In addition there was a public lecture by G. Mussardo and a poster session featuring the work of younger participants.

A noteworthy aspect of this workshop was the breadth of viewpoints, both in the topics covered and in the expertise and background of the researchers. The themes ranged from experimental details to cutting-edge issues of mathematical physics. The organizers took care not to segregate the talks and sessions according to theme or community, thus maximizing interaction between researchers of different backgrounds; they also took measures to maximize the participation of female and junior scientists. The workshop covered a broad range of themes connected in various ways to integrability and its breaking in quantum many-body systems. We now discuss some of these themes.

The first theme was the role of integrability in real-time evolution and quantum quenches. A major topic was real-time evolution in systems finding themselves in a state out of equilibrium (e.g., after a quantum quench), and real-time evolution results, for both integrable and non-integrable systems, with a focus on the role of integrability in such evolution. One prominent aspect was that of thermalization of isolated systems. The role of integrability and conserved quantities in thermalization properties, in particular in determining the validity of the Generalized Gibbs Ensemble (GGE) to describe the steady state a long time after a quench, is an issue at the forefront of current research activity in the field. Several talks touched on this theme (Andrei, Goldstein, Prosen, Takacs, van den Berg, and Weiss). Other non-equilibrium phenomena discussed in the workshop included the role of disorder (Friesdorf, Rigol, Santos); the light cone effect (Läuchli); propagation along spin chains (Evertz, Vlijm); the use of integrability techniques to calculate time evolution (Andrei, Deguchi, James, van den Berg, Vlijm); short-time dynamics after a quench (Kormos, Mitra, Santos); steady-state transport involving both heat and particle currents in both integrable and integrability-broken systems (Bhaseen, Boulat, Doyon, Vasseur); and pre-thermalization (Fagotti, Robinson).

The second theme was the study of excitations probed through neutron scattering. Two experimentalists from the neutron-scattering community (Lake, Zaliznyak) presented results on one-dimensional magnetic systems. Dynamical structure factors obtained through neutron scattering are of significant interest for the theory of one-dimensional magnetism, both as a stringent test of theory and as a motivation for practical application of Bethe Ansatz techniques. The third theme included several talks on technical advances and new analytical results for integrable models. In particular the workshop included presentations of results on a separation of variables approach to the XYZ chain, and analytical results on correlation functions and the Drude weight, central spin models, spin chains with boundary terms, etc. (Frahm, Göhmann, Kitanine, Klümper, Kozlowski, Faribault, Terras, Weston). The fourth theme was the study of non-equilibrium dynamics with cold atoms. Two of the keynote experimental talks were from leaders in the field of cold atoms. They presented experiments related to relaxation (Weiss) and spin diffusion (Kohl). Theory calculations motivated by cold atom setups were also presented (Minguzzi, Vidmar).

This workshop had significant impact for two reasons. First, it took place at a time of rapid advances in the topics being covered (thermalization in particular). Several very recent results (e.g. on the role of string solutions in the applicability of the GGE) were discussed in detail immediately after their appearance at the meeting. Second, by bringing together scientists with different backgrounds, the workshop provided an unusual opportunity for interaction between communities that normally do not overlap with one another. Finally the workshop included two "outreach" components: a public lecture by Giuseppe Mussardo (SISSA, Trieste, Italy), entitled "A brief history of low temperature physics," and an interview within the "La Grande Équation" radio program featuring J.-S. Caux (to be broadcast in September). In the interview Caux discussed quantum physics for a general audience, with an emphasis on the questions of integrability, relaxation, and equilibration in many-body systems.

Mini-course on Networks on Surfaces and Integrable Systems

July 20-24, 2015, CRM

Lecturer: Michael Gekhtman (Notre Dame)

Positive Grassmannians: Applications to integrable systems and super Yang-Mills scattering amplitudes

July 27-31, 2015, CRM

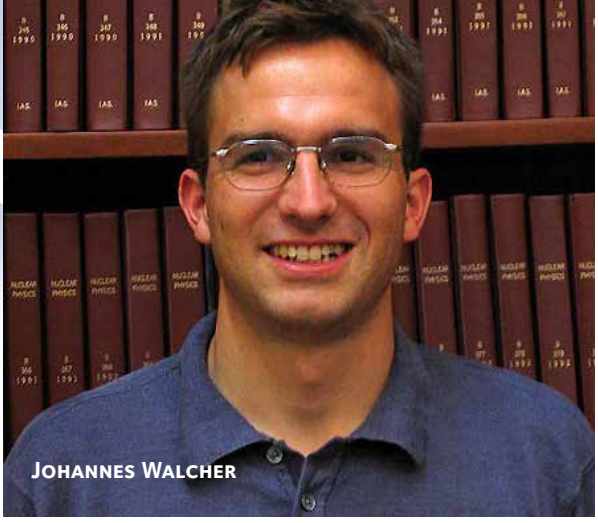
Organizers: Marco Bertola (Concordia), Michael Gekhtman (Notre Dame), John Harnad (Concordia)

The theory of Grassmannians and their positive substructures has been developed by mathematicians without a particular application to physics in mind; on the other hand, in the past years, theoretical physicists have recognized that certain computations they performed laboriously by hand can be framed within that theory. The encounter is thus one of those serendipitous events in science, such as the development of non-Euclidean geometries (a purely mathematical topic, without any "real" application at the time of their invention) and the development of general relativity later on. The main goal of the workshop was therefore to bring together mathematicians and theoretical physicists who have discovered lately that the tools developed in the study of positive Grassmannians are useful in seemingly unrelated fields such as computation of scattering amplitudes, soliton interactions, discovery of new discrete integrable models, mirror symmetry, parametrizations of rings of invariants, etc.

Each session of the workshop was loosely tied to a unifying theme, although none of these topics was isolated within the general flow of the workshop. These included: integrable maps generated by cluster mutations (Glick, Pylyavskyy, Shapiro, Kenyon); combinatorics of positive Grassmannians with applications to geometry and analysis (Farber, Muller, Neitzke, H. Williams, L. Williams); scattering amplitudes, on-shell diagrams, and the amplituhedron (Arkani-Hamed, Franco, Thomas, Trnka); cluster structures in Poisson geometry and invariant theory (Fomin, Gekhtman); solitons and positive Grassmannians (Abenda, Kodama); conformal field theory and quantum cluster algebras (Di Francesco, Kedem, Marshakov); twistor theory (Mason); and cluster combinatorics (Garver, Musiker).

The scope of presentations ranged from analyzing a particular illustrative example to reporting on a progress in a long-term research program to providing a broad overview of future directions of research. For example, Shapiro and Kenyon presented two different approaches to the construction of discrete integrable systems associated with toric quivers: one relying on rational boundary measurement matrices arising from directed networks on cylinders and another based on dimer configurations constructed from Newton polytopes of algebraic curves. These talks were complemented by Glick's report on a new rich family of discrete maps that can be analyzed via either of these approaches and by Pylyavskyy's account of conjectures on integrability of certain compositions of cluster mutations associated with bipartite quivers (complete with supporting examples). Similarly, lectures of Arkani-Hamed and Thomas presented complementary perspectives on the definition and properties of the amplituhedron: one is motivated by theoretical physics and the other is geometric and combinatorial in nature. Then Franco and Trnka provided a fascinating array of concrete examples and conjectures arising in the study of the amplituhedron.

New exciting applications of the combinatorics of plabic networks in a disc (to the mirror duality and to Legendrian knots) were outlined in talks by L. Williams and H. Williams, while Fomin described how more complicated networks (on higher genus surfaces, possibly) provide novel insights in the classical theory of invariants. He concluded with a list of concrete conjectures that will certainly attract a lot of interest. The workshop succeeded in building bridges between the abstract mathematical community and the theoretical physics community, in developing a common language, and in fostering interactions between the two communities. Particularly enlightening was the panel discussion; a panel of experts representing the main workshop themes (Gekhtman, Harnad, Kodama, Mason, Trnka, L. Williams) invited the audience to discuss notions and problems inspired by the workshop.


Johannes Walcher

Hidden symmetries and integrability methods in super Yang-Mills theories and their dual string theories

August 3-14, 2015, CRM

Organizers: Freddy Cachazo (Perimeter Institute), John Harnad (Concordia), Vladimir Kazakov (École normale supérieure), Juan Maldacena (IAS), Radu Roiban (Penn State), Pedro Vieira (Perimeter Institute), Johannes Walcher (Heidelberg)

This workshop was one of the core activities of the thematic semester. The two-week long event was a remarkable occasion to gather roughly 50 specialists in a quickly developing area: the study of the physical properties of supersymmetric gauge theories in various non-perturbative regimes. Particular attention was paid to the superconformal gauge theories, such as the N=4 SuperYang-Mills theory (SYM) and the ABJM model, where the progress was especially noticeable in recent years due to the discovery of efficient methods (AdS/CFT correspondence, integrability, recursion relations, localization, Grassmannians, etc.) for computing scattering amplitudes, correlation functions, and spectra of anomalous dimensions.

The workshop featured topics of broad and current interest in the area, including: computation of the BFKL limit and higher loop perturbation theory of anomalous dimensions in N=4 SYM (Volin, Gromov); computation of correlators in N=4 SYM (Komatsu); supersymmetric Wilson loops (Beisert, Kruczenski); the quantum spectral curve of the ABJM model (Tateo); and large spin computations of anomalous dimensions (Alday). Important information came from worldsheet methods (Roiban, Vicedo), localization (Zarembo), the conformal bootstrap (Serban, Komatsu, Kostov, Bajnok), and the analysis of N=4 as a hydrogen atom (Caron-Huot). A great impulse came from the preceding week's workshop on positive Grassmannians, with several participants attending both meetings. This allowed the speakers to highlight the exciting recent progress on the reformulation of perturbative amplitudes in terms of the amplituhedron (Arkani-Hamed, Bourjaily, Trnka). The stunning progress on scattering amplitudes (Dixon, He) and the related mathematical progress (Henn, Volovich) were discussed, as was the application of twistor methods (Berkovits, Mason, Sokatchev) to 4d SYM and other theories (Stieberger, Cachazo, Maloney).

The workshop included two mini-courses of five lectures each: one given by P. Vieira and the other by D. Volin, V. Kazakov, and N. Gromov.

Mini-course on integrability beyond the spectrum: correlation function and scattering amplitudes

August 3-7, 2015, CRM

Lecturer: Pedro Vieira (Perimeter Institute)

Mini-course on "Quantum Spectral Curve of AdS5/S5"

August 10-14, 2015, CRM

Lecturers: Dmytro Volin (Trinity College Dublin), Vladimir Kazakov (École normale supérieure), Nikolay Gromov (King's College London)

AdS/CFT and quantum gravity

September 14-16, 2015, CRM

Organizers: Patrick Hayden (Stanford) and Alexander Maloney (McGill)

Over the last fifteen years, our understanding of quantum gravity in string theory has been transformed by the discovery and exploitation of D-branes and the AdS/CFT correspondence in string theory. Many problems that were thought insuperably difficult have been solved, at least partially: (i) the entropy and thermodynamic properties of many extremal and near-extremal black holes have been precisely explained in terms of microscopic degrees of freedom; (ii) light has been shed on the physics of spacetime singularities; (iii) the holographic principle, positing massive reduction of the degrees of freedom in quantum gravity, has been understood precisely in spacetimes with a negative cosmological constant via a duality between gravity and gauge theory. This program of research has been so successful that it is now being used as a tool to shed light on otherwise intractable problems involving strongly coupled systems in other fields of physics.

In recent years, one of the focal points of much activity has been the study of certain toy models, in which typically both sides of the correspondence are amenable to an exact solution. One example is 2- and 3-dimensional models, in which gravity is non-dynamical (yet topologically non-trivial), while the field theory is completely integrable (e.g., 2-d minimal model CFTs). A rather different type of examples are vector-like field theories, which are conjectured to be dual to higher-spin theories of gravity. In either instance the basic idea is to exploit the fact that the reduced set of degrees of freedom is completely governed by a large symmetry algebra. While there is a tremendous amount of evidence for the AdS/CFT correspondence, obtained through exactly solvable models or otherwise, the fundamental mechanisms behind such holographic behaviours remain unclear.

One of the goals of the workshop was to use the potential of recent progress on AdS/CFT to bring together mathematicians and physicists working on aspects of black hole physics and AdS geometry. Another goal was to elucidate the mechanisms behind holographic behaviours and understand the limits to (or generality of) their applicability. In particular the following points were addressed during the workshop:

(i) How general is holography?: To what extent do the above lessons rely on the particular constructions used to date? Are they tied to stringy effects and to string theory in particular, or are they general lessons for quantum gravity?

(ii) The information paradox: Holography in string theory strongly suggests that information is not lost in black hole evaporation. Is it clear that this interpretation is correct? If so, how is this consistent with known bulk physics and the validity of Einstein gravity as a low-energy effective theory? How fast can information be extracted, under what conditions, and with what fidelity?

(iii) The geometry of information: Why is the entropy of a black hole proportional to horizon area, and not to some other geometrical construct? In holographic contexts, how does the interior of a black hole (where information about the microstate is hidden) get represented in its holographically dual description as a state in a non-gravitating field theory? How can the thermodynamic properties of black holes and gravity be explained in flat space, far from extremality?

(iv) Emergence of spacetime and locality: In the context of the gauge/gravity duality, can we give a constructive description of the emergence of additional spacetime dimensions as the effective description of strongly coupled field theory dynamics? How does spacetime locality emerge in this formulation? Can spacetime always be regarded as an emergent concept, or is this special to some classes of universes? How is locality in gravitational physics to be understood more broadly?

Mini-course: Introduction to topological recursion

September 29-October 15, 2015,
CRM and Concordia University

Lecturer: Bertrand Eynard (CEA Saclay)

Applications of AdS/CFT to QCD and condensed matter physics

October 19-23, 2015, CRM

Organizers: Keshav Dasgupta, Charles Gale, and Sangyong Jeon (McGill)

Much of what is known about the phases of strongly coupled gauge theories (particularly QCD) comes from a variety of techniques, each of which accompanied by its attendant limitations. Perturbative (i.e. weak coupling) computations can probe a large part of the parameter space of the theory, such as allowing one to deal with a varying number of colours or flavours. These results, however, are valid only at temperatures well above the deconfinement temperature, and/or at large values of the baryon number chemical potential (in order for the QCD coupling to be small, and thus the perturbation valid). These constraints put almost all of the interesting region of the parameter space explored by RHIC and the LHC data beyond the reach of perturbative computations.

Lattice gauge theory, which provides a rigorous non-perturbative starting point for QCD, is not without its limitations as well. It is difficult to incorporate realistic quark masses, and results from the traditional lattice simulations are limited to the regime near the deconfinement temperature and where the baryon chemical potential is very small. Nonetheless a combination of such conventional methods of analysis (including insights from effective theories like chiral models) suggests that the gauge theory possesses a "color superconductivity" phase at asymptotically large values of the baryon number chemical potential. The literature is replete with conjectures for the phase diagram of QCD in the parameter plane, especially for small values of the temperature and large values of the potential.

In recent years, there has been a considerable advance in understanding the behaviour of U(N) gauge theories at finite temperature using the gauge/gravity duality. That this development is more than timely is beyond dispute, as the new and interesting results from RHIC and the LHC have provided a glimpse into a wide variety of interesting phenomena arising in the strong coupling regime of QCD. For instance the quark-gluon plasma (identified as a new state of matter) displays many properties of a fluid with low (shear) viscosity, explanations for which are difficult to obtain from traditionally available tools in perturbative QCD.

One of the most important probes of the QGP properties is modification of high-energy jet properties. A striking phenomenon has been observed, where 100 GeV jets fail to emerge from the collision blocked by the hot and dense QGP. As the underlying plasma is strongly coupled, perturbative QCD alone does not provide a complete solution. Fortunately, one can cleanly formulate and solve a version of this problem using the gauge/gravity duality, which can provide us with a complementary and very insightful picture. Many (perhaps most!) analytic results coming from gauge/gravity duality are derived for gauge theories with N=4 supersymmetry or with N very large, and in the limit of the theory possessing exact conformal symmetry. One may thus be genuinely concerned about their applicability to QCD when these assumptions do not all hold. Recent progress in this area, however, has provided us with strong hints for overcoming these limitations, and moving towards models of gauge/gravity duality that are not supersymmetric and are non-conformal.

With this in mind, we organized a workshop that unifies aspects of AdS/QCD with the more recent developments in the subject, dealing with non-conformal aspects of QCD and including studies on strongly coupled quark-gluon plasma (sQGP) and on the colour superconductivity phase discussed above. The sQGP poses theoretically challenging yet experimentally accessible questions. The formation of QGP at RHIC is an example where theoretical descriptions are completely lacking at low energies because our perturbative techniques fail at strong couplings. Probing the non-perturbative regime of large N gauge theory through a gravity dual, however, has led to some interesting results for the physics of the quark-gluon plasma. The dual description is studied at both zero and non-zero temperatures and has been quite successful in analyzing various aspects of strongly coupled nuclear matter in the IR. But there are limitations arising, most prominently, from the absence of UV completions, and from the absence of a supergravity description for strongly coupled QCD incorporating various phases of quark matter.

The workshop unified themes related to the connection between QCD and condensed matter physics (for example colour glass condensate and colour superconductivity phase of QCD) using appropriate gravity duals. These developments are new and therefore a complete workshop devoted to analyzing these ideas proved very useful to the participants. The interconnections spelled out during the various talks illustrated the rich structure of gauge/gravity dualities in unravelling these fundamental aspects of the subjects in a beautiful unified way.

Here is a list of the topics included in the workshop, along with the speakers: (i) Study of thermal QCD (N. Brambilla, H. Boschi-Filho, Y. Bu, S. Sugimoto, S. Caron-Huot, G. Knodel); (ii) Study of thermal and non-thermal aspects of QCD using AdS spaces (G. Mandal, T. Morita, G. S. Ng, A. Maloney, A. Buchel, P. Chesler, L. Joshi, L. Yaffe, C. Herzog); (iii) Study of thermal and non-thermal aspects of QCD using non-AdS spaces (A. Buchel, F. Bigazzi, A. Misra, A. Cotrone, L. Pando Zayas); (iv) Study of CMT using AdS spaces (C. Herzog, S. Kachru, S. Sachdev, W. Witczak-Krempa). On the last day of the workshop Nora Brambilla and Shigeki Sugimoto gave special lectures on new developments in lattice thermal QCD and mesonic spectra from string theory, respectively.

Mini-course on integrable systems, random matrices, Hitchin systems and CFTs

October 21-November 3, 2015, CRM and Concordia University

Lecturer: Bertrand Eynard (CEA Saclay)

Moduli spaces, integrable systems, and topological recursions

January 9-13, 2016, CRM

Organizers: Jacques Hurtubise (McGill) and Dmitry Korotkin (Concordia)

The computation and enumeration of invariants of moduli spaces took a sudden turn with the conjecture of Witten that they could be combined into a formal series that solved the KdV hierarchy. This conjecture, subsequently proven by Kontsevich, was motivated by considerations of quantum gravity. It was followed by a series of developments in the same direction, notably in the computation of invariants for Hurwitz spaces and for Gromov-Witten invariants, for example in the work of Okounkov and Pandharipande, tying Gromov-Witten theory to the 2-Toda hierarchy. Kontsevich's proof involved a detour through the theory of random matrices, and subsequently Eynard and Orantin proposed a vast generalization of the technique, with a wide variety of implications. The theory has physical motivations, and has advanced with the rapid mixture of calculation and heuristic reasoning that characterizes theoretical physics; mathematicians have in many but not all cases provided proof, and, it is hoped, some understanding.

Thus a first piece of the puzzle is the theory of moduli spaces. The moduli spaces of interest are mainly associated with complex algebraic curves: moduli spaces of (pointed) curves, moduli spaces of meromorphic functions on curves (Hurwitz spaces and spaces of admissible covers), and, more generally, moduli spaces of stable maps. A second part of the puzzle, brought to the fore by Chekhov, Eynard, and Orantin, has its origin in the theory of random matrices; invariants are combined into generating series that can be computed directly from a single spectral curve, by what has come to be known as the topological or Eynard-Orantin recursion. A third theme comes with the theory of Frobenius manifolds, introduced around 1990 by Dubrovin as a geometrization of quantum cohomology that originated from the Witten-Dijkgraaf-Verlinde-Verlinde (WDVV) associativity equation in topological field theories. The quantities associated to the Frobenius manifolds are computable in terms of the topological recursion.

The theory of integrable systems seems to lie at the heart of the subject, providing a thematic link. It is fair to say, though, that the way in which it happens is still ill-understood. Indeed, so far, it is more the tools, computational devices, and actual functions that appear, rather than flows and conserved quantities.

The workshop covered all these themes, and contributed greatly to completing the picture. Thus Hurwitz numbers of many sorts are now seen to have a computation in terms of a family of spectral curves; the same goes for the Gromov-Witten invariants of toric Calabi-Yau manifolds, where the spectral curve is in effect the mirror. The theme of topological recursion is extending its remit to knot invariants and Chern-Simons theories. Likewise, one now has a clear idea of which spectral curves correspond to Frobenius manifolds. From the integrable systems side, the ties between the topological recursion and WKB approximations for either Schrödinger operators or Hitchin systems are gradually becoming clearer. The workshop was a veritable hotbed of ideas and discussions, with lively scientific exchanges not only during the talks but also between them and well into the evening afterwards.

Applications and new frontiers for the finite element method

May 9-13, 2016, Université Laval

Organizers: Jean Deteix (Laval), Miguel Ángel Fernández (INRIA Paris), André Fortin (Laval), André Garon (Polytechnique Montréal), José Manuel Urquiza (Laval)

Since its beginning in the 1950s, the finite element method has become one of the most popular numerical methods for solving Partial Differential Equations (PDEs). It has given birth to famous commercial and industrial codes developed or used by engineering and industrial companies. On another hand, it has been of particular interest to a very large number of applied mathematicians and numerical analysts. Along with the exponential increase of computing power and memory capabilities, new challenges arise continuously from applications, the increasing level of complexity of the models involved (multi-physics, multi-scale, nonlinearities, etc.), and the need for high-performance computing.

The main part of the workshop consisted of three mini-courses (each lasting approximately eight hours) on some recent developments and challenging applications: (i) Nitsche's method for unilateral contact problems (given by Franz Chouly, from the Université de Franche-Comté); (ii) Structural optimization (given by François Jouve, from Université Paris Diderot); and (iii) Numerical techniques for uncertainty quantification in random PDEs (given by Lorenzo Tamellini, from the CNR-IMATI). Participants were allowed to give a talk on any subject related to the finite element method. Advanced doctoral students, postdoctoral students, and young researchers were particularly encouraged to do so. The audience was composed of graduate and post-doctoral students and academic and industrial researchers familiar with the finite element method or any related numerical method for PDEs.

Rustum Choksi

New challenges for the calculus of variations stemming from problems in the materials sciences and image processing – Workshop in honour of the 60th birthday of Irene Fonseca

May 16-20, 2016, CRM

Organizers: Rustum Choksi (McGill), Nicola Fusco (Federico II), Christopher J. Larsen (Worcester Polytechnic Institute), Giovanni Leoni (Carnegie Mellon)

This workshop addressed contemporary problems in the calculus of variations that are directly driven by current problems in the materials sciences and computer vision, in particular image processing, segmentation in computer vision, and the understanding of structures in shape-memory alloys, ferroelectric and magnetic materials, composites, liquid crystals, and thin films. In all these areas, regularity and convergence results have a direct impact on the ability to perform reliable computations. This spectrum of topics and applications was reflected in the many different talks delivered by leading researchers in the contemporary calculus of variations as well as junior researchers at the start of their careers. The workshop had four prevalent themes: variational modelling at discrete length scales, dimensional reductions to address thin structures, variational modelling in fracture in plasticity, and gradient flows and optimal transportation.

The workshop opened with Dick James' talk on twisted X-rays, orbital angular momentum, and the determination of atomic structure. This talk clearly demonstrated that the modern calculus of variations and the contemporary material sciences (both experimental and theoretical) are directly intertwined. There were many other highlights including (to name only a few) Luigi Ambrosio's retrospective on some recent developments of the calculus in metric measure spaces, Andrea Braides' talk on dimension reduction for discrete thin films, and David Kinderlehrer's provocative talk on identifying gradient flows in terms of weak topology kinetics. There were also many interesting talks by junior researchers on variational problems stemming from the denoising and deblurring of images.

The workshop served to honour Professor Irene Fonseca, the Mellon College of Science Professor of Mathematical Sciences at Carnegie Mellon University, on the occasion of her 60th birthday, for her many research accomplishments, the impact she has had on the careers of many students and postdocs, and the tireless work she has done to promote the modern calculus of variations worldwide. Irene's presence was felt throughout the week, and her scientific and mentoring impact was directly addressed in many of the talks. The celebratory nature of the workshop also led to many friendly scientific discussions between groups from different countries.

Partial order in materials: analysis, simulations and beyond

June 21-30, 2016, CRM

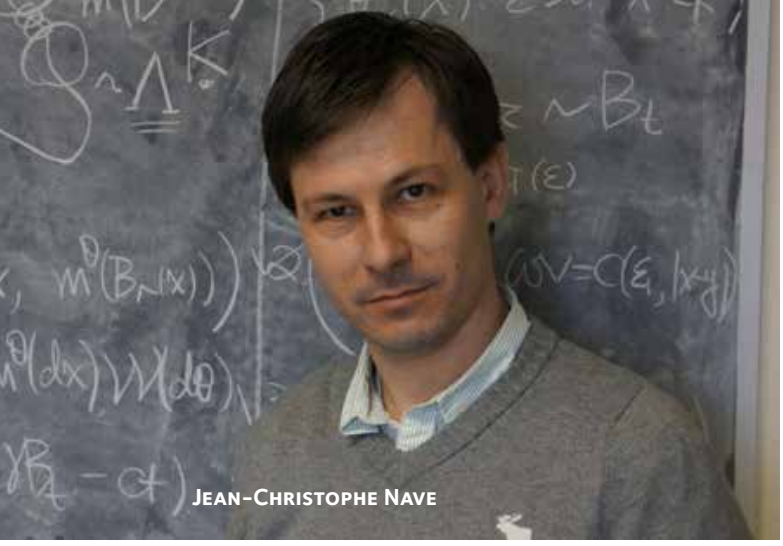
Organizers: Stanley Alama and Lia Bronsard (McMaster), Apala Majumdar (Bath), Alejandro Rey (McGill)

This workshop was devoted to the mathematical modelling, analysis, and simulations of partially ordered materials, whose properties lie between the conventional solid and liquid phases of matter. Such partial order can be found in nature in diverse contexts, including granular media, colloidal suspensions, bacterial suspensions, cytoskeletons, micromagnets, and superconductors. Most of the discussion in our workshop centred on the very rich and active area of liquid crystals. The workshop was spread over two weeks with a total of 32 hours of lectures, including three mini-courses of three lectures each as well as the more usual talks presenting new research. We typically had five lectures per day, two of which were usually mini-course lectures. The opening speaker was Alejandro Rey, who gave an excellent overview of the biological applications of liquid crystalline materials. Apala Majumdar delivered two talks on two distinct research projects and Stan Alama presented some of his recent work on Ginzburg-Landau vortices. Lia Bronsard nominated junior researchers from her group to present her ongoing research program, which was very well received.

The program was structured so that we had a mix of analytical, theoretical, numerical, and applications-oriented talks every day. Of the 32 lectures, 14 lectures were devoted to the analysis of mathematical models in different branches of materials science, 8 lectures focused on various numerical simulations of partially ordered materials, and the remaining 10 lectures were based around novel physical and biological applications of partially ordered materials, including new experiments. The participants were an unconventional mixture of mathematicians, experts in scientific computation, physicists, and engineers, which provided a fertile interdisciplinary environment and exposed attendees to new research approaches and directions. The participants were a good mix of world-leading experts in mathematics and experiments, mid-career researchers, and early-career researchers from 20 different institutions in Europe and North America. The bringing together of researchers from such different backgrounds and communities was an essential feature of the meeting and made it a unique experience for all participants.

The first week was slightly more concentrated on the mathematical aspects of liquid crystals. Radu Ignat delivered a mini-course on the stability of defects in liquid crystals and superconductors, a theme which was revisited by several other talks. The second mini-course, in which Colin Denniston discussed modelling and numerical simulation of colloidal aggregates, made the bridge to the second week, which featured many new experimental and numerical studies by physicists and engineers. The third mini-course, given by Oleg Lavrentovich on chromonic and biological liquid crystals, anchored the second week. Some common themes included director vs tensorial modelling of liquid crystals, stability of point and line defect structures, and numerical approaches to defect structure and dynamics. While most of the models for liquid crystals have been known for some time, the workshop presented recent mathematical analysis and new physical and biological applications and insights that justify and refine these models and give new impetus to their study.

The exceptional features of this workshop were its strong interdisciplinary flavour and the eagerness of the participants to make connections and exchange ideas across disciplines. Many of the participants were meeting for the first time and the workshop provided a uniquely fertile environment for discovery and the creation of new networks and collaborations. Much of this interaction was due to the relaxed schedule and the pleasant environment provided by the CRM, facilitating informal discussions in small groups. We expect that the contacts initiated at the workshop will grow into working collaborations between researchers, yielding new insights and scientific breakthroughs in the near future.



Jean-Christophe Nave

Complex boundary and interface problems: theoretical models, applications and mathematical challenges

July 4-8, 2016, CRM

Organizers: Jean-Christophe Nave (McGill), Robert G. Owens (Montréal), Pascal Poullet (Antilles), Hongkai Zhao (UC Irvine)

Problems involving interfaces or boundaries are ubiquitous in mathematics and in models from physics and engineering. These problems arise in many contexts such as fluid dynamics, electromagnetism, and generally multi-phase and multi-physics systems in science and engineering. Much of the effort surrounding computation of boundary and interface problems and consideration of complex boundaries is taking place in different communities. The aim of this workshop was to bring together mathematicians and numerical analysts who develop algorithms and applied scientists who use their algorithms for solving complex boundary and interface problems. The organizers decided to have only two "long" talks in the morning; the afternoons had a focus on applications and included "short" presentations by graduate students. The morning lectures were given by established researchers and addressed fundamental topics. Each lecture was supposed to last for one hour but the organizers promoted open discussions and interruptions that sometimes led to longer sessions.

The scientific outcome of the meeting may be summarized in three phrases: grid-based approaches, multi-physics, and efficiency. The group reached a consensus that for computing efficiency reasons, grid-based methods should be at the centre of future efforts. Also many engineering problems (such as the in-flight ice formation problem presented by Habashi) or large-scale geophysics problems (such as the magma and ice flows problem presented by Suckale) require the solution of equations of different types at different scales within the same framework. Furthermore, development of non-grid-based methods (e.g. boundary integral methods), which may be more natural for some problems, is now being coupled to the grid solutions of other problems. The training component of this workshop was important. It included talks by five graduate students and one postdoc. Almost every workshop talk was attended by several other graduate students and a few undergraduate students. The workshop schedule allowed many of the students to interact with researchers. Finally we mention two activities related to the workshop: a course on incompressible Navier-Stokes equations given at McGill by J.-C. Nave and P. Poullet and a working seminar on the same topic as the workshop that ran every week during the entire Winter semester.

Computational optimal transportation

July 18-22, 2016, CRM

Organizers: Jean-David Benamou (INRIA Paris) and Adam M. Oberman (McGill)

Computational Optimal Transportation is a field that barely existed in 2012. It has grown immensely, in large part due to a productive collaboration between the French group, largely based at INRIA and Paris-Dauphine, and the North American group, spread across several universities in Canada. This collaboration started as a working group of 8 researchers in Banff four years ago and has grown into a workshop attended by 50 people, interested in a growing number of topics. The mathematical theory of Optimal Transportation

has seen a great deal of activity in the last fifteen years. Applications, however, require numerical methods, and the (apparently) intractable nature of the computations seemed to impede their design. Progress in PDE and linear programming methods led to substantial gains in the complexity of problems that could be solved. The entropic regularization method (a modification of the OT problem adding entropy to the measures involved) is a recent breakthrough due to Cuturi, Peyré, and their collaborators.

The workshop was remarkable in that the majority of speakers were early career researchers and postdocs. Since the field is growing very quickly, significant and novel contributions are being made by young researchers. The excitement of working in an emerging field with many opportunities was palpable during the workshop. The talks were notable in that each half-day session was organized thematically and they addressed new subjects. This feature made the talks very interesting with a focus on ideas and methods rather than technical detail. There were reports on recent progress in machine learning and big data applications: in particular the Gromov-Wasserstein model, discussed by Peyré, which uses intrinsic metrics to compare shapes. Solomon gave a talk on quadratic optimal transport on graphs. The Wasserstein metric has natural applications to statistics. Novel approaches to nonlinear nonparametric regression were discussed by Cuturi. These approaches have also been used by Triglia to explain variability in spatially distributed or biased data.

Among others the workshop included talks on the following topics: PDE methods (Mirebeau, Froese, and Duval); economic and finance applications (Carlier, Kim, and Dupuis); the far field refractor problem (Gutierrez); the entropic regularization method (Louet); and applications to weak solutions of the Euler PDE for incompressible fluids (Nenna and Gallouët).

Past Thematic Programs

The CRM has held a thematic program every year since 1993. From 1987 to 1992 the CRM organized various types of activities, including special semesters, concentration periods, and thematic activities. Here is a list of the main activities organized by the CRM since 1987.

2014–2015 Number Theory, from Arithmetic Statistics to Zeta Elements
January–June 2014 Lie Theory
July–December 2013 Mathematics of Planet Earth 2013 — Thematic Semester on Biodiversity and Evolution
January–November 2013 Mathematics of Planet Earth 2013 — The Pan-Canadian Program on Models and Methods in Ecology, Epidemiology and Public Health
January–September 2013 Mathematics of Planet Earth 2013 — International Program in Celestial Mechanics
2012–2013 Moduli Spaces, Extremality and Global Invariants
January–June 2012 Geometric Analysis and Spectral Theory
June–December 2011 Quantum Information
January–June 2011 Statistics
July–December 2010 Geometric, Combinatorial and Computational Group Theory
January–April 2010 Number Theory as Experimental and Applied Science
August–December 2009 Mathematical Problems in Imaging Science
2008–2009 Joint CRM-PIMS Program: Challenges and Perspectives in Probability
2008–2009 Probabilistic Methods in Mathematical Physics
January–June 2008 Dynamical Systems and Evolution Equations
June–December 2007 Applied Dynamical Systems
January–June 2007 Recent Advances in Combinatorics
June–December 2006 Combinatorial Optimization
2005–2006 Analysis in Number Theory
2004–2005 The Mathematics of Stochastic and Multiscale Modelling
2003–2004 Geometric and Spectral Analysis
2002–2003 Mathematics in Computer Science
2001–2002 Groups and Geometry
2000–2001 Mathematical Methods in Biology and Medicine
1999–2000 Mathematical Physics
1998–1999 Number Theory and Arithmetic Geometry
1997–1998 Statistics
1996–1997 Combinatorics and Group Theory
1995–1996 Applied and Numerical Analysis
1994–1995 Geometry and Topology
1993–1994 Dynamical Systems and Applications
1992 Probability and Stochastic Control (special semester)
1991–1992 Automorphic Forms in Number Theory
1991 Operator Algebras (thematic semester)
1990 Nonlinear PDEs and Applications (concentration period)
1988 Shimura Varieties (special semester)
1987 Quantum Field Theory (special semester)
1987–1988 Fractals: Theory and Application
1987 Structural Rigidity (special semester)

THE AISENSTADT CHAIR

The 2015–2016 Aisenstadt Chairholders

Nikita Nekrasov, a Professor at the Simons Center for Geometry and Physics (Stony Brook), is regarded as one of the leading experts on mathematical aspects of quantum field theory. Nekrasov received his Ph.D. in 1996 from Princeton University, where he studied under the supervision of David Gross. He then joined the Society of Fellows at Harvard University as a Junior Fellow, after which he spent two years as a Dicke Fellow at Princeton University. Nekrasov joined the faculty of the Institut des Hautes Études Scientifiques in Bures-sur-Yvette, France, before moving in 2013 to his current position at the Simons Center. Nekrasov's work has been honoured by several awards, including the Jacques Herbrand Prize, the Herman Weyl Prize, and the Compositio Prize. Nekrasov gave five lectures (one general lecture and four technical ones) at the CRM, during the week of September 14-18, 2015. For a description of these lectures and his work, we refer the reader to the Spring 2016 edition of Le Bulletin du CRM.

The Aisenstadt Chair was endowed by Montréal philanthropist Dr. André Aisenstadt. Each year one or more distinguished mathematicians are invited to spend at least one week (ideally one or two months) at the CRM. During his or her stay a Chairholder delivers a series of lectures on a specialized topic and is also invited to prepare a monograph. At the request of Dr. Aisenstadt, the first lecture given by an Aisenstadt Chairholder should be accessible to a wide audience. Generally speaking the research fields of the Chairholders are closely related to the CRM thematic program for the current year.

Bertrand Eynard is a member of the Institut de Physique Théorique at CEA Saclay. A leading innovator in a number of currently active fields of mathematical physics (including random matrices, conformal field theory, quantum gravity, string theory, graphical enumeration and combinatorics, random geometry and integrable systems), he has become known over the past decade as the driving force behind the exciting unifying development that goes under the name "topological recursion" (one of the two main topics of his Aisenstadt Chair lectures). He is recognized worldwide for his contributions and is often invited to speak at major international meetings: in particular he gave an invited talk at the 2014 ICM in Seoul, South Korea, and invited plenary talks at the series of biannual String-Math conferences (most recently, in Edmonton, 2014) and the Stat-Phys24 conference (Cairns, Australia, 2010). Eynard delivered three Aisenstadt Chair lectures on October 2, 9, and 23, respectively. For a description of these lectures and his work, we refer the reader to the Spring 2016 edition of Le Bulletin du CRM.

Nikita Nekrasov

Bertrand Eynard

Selim Esedoglu

Selim Esedoglu was the Aisenstadt Chairholder for the thematic semester on Computational Mathematics in Emerging Applications. Esedoglu is Professor of Mathematics at the University of Michigan (Ann Arbor) and received his Ph.D. from the Courant Institute under the supervision of Robert Kohn in 2000. After postdoctoral positions at the IMA (Minnesota) and UCLA, he joined the faculty at the University of Michigan. He has been the recipient of both a Sloan Foundation Fellowship and an NSF Early Career Award. Selim Esedoglu is an expert at using tools from the modern calculus of variations and nonlinear partial differential equations to develop state-of-the-art numerical methods for addressing contemporary problems in image processing and the material sciences. Esedoglu delivered three Aisenstadt Chair lectures on April 4 and 7, 2016. For a description of these lectures and his work, we refer the reader to the Fall 2016 edition of Le Bulletin du CRM.

Previous Aisenstadt Chairholders

Marc Kac, Eduardo Zarantonello, Robert Hermann, Marcos Moshinsky, Sybren de Groot, Donald Knuth, Jacques-Louis Lions, R. Tyrrell Rockafellar, Yuval Ne'eman, Gian-Carlo Rota, Laurent Schwartz, Gérard Debreu, Philip Holmes, Ronald Graham, Robert Langlands, Yuri Manin, Jerrold Marsden, Dan Voiculescu, James Arthur, Eugene B. Dynkin, David P. Ruelle, Robert Bryant, Blaine Lawson, Yves Meyer, Ioannis Karatzas, László Babai, Efim I. Zelmanov, Peter Hall, David Cox, Frans Oort, Joel S. Feldman, Roman Jackiw, Duong H. Phong, Michael S. Waterman, Arthur T. Winfree, Edward Frenkel, Laurent Lafforgue, George Lusztig, László Lovász, Endre Szemerédi, Peter Sarnak, Shing-Tung Yau, Thomas Yizhao Hou, Andrew J. Majda, Manjul Bhargava, K. Soundararajan, Terence Tao, Noga Alon, Paul Seymour, Richard Stanley, John J. Tyson, John Rinzel, Gerhard Huisken, Jean-Christophe Yoccoz, Wendelin Werner, Andrei Okounkov, Svante Janson, Craig Tracy, Stéphane Mallat, Claude Le Bris, Akshay Venkatesh, Alexander Razborov, Angus MacIntyre, Yuri Gurevich, Jamie Robins, Renato Renner, John Preskill, Richard M. Schoen, László Erdös, Elon Lindenstrauss, Fedor Bogomolov, Helmut Hofer, David Gabai, Gang Tian, Simon A. Levin, David Aldous, Martin Nowak, Masaki Kashiwara, Zeev Rudnick, Carl Pomerance, Sophie Morel, Pierre Colmez

SUMMER SCHOOLS

Séminaire de mathématiques supérieures 2015
Geometric and Computational Spectral Theory

June 15-26, 2015, CRM

sponsored by the CRM, the Fields Institute, the ISM, the MSRI, the CMS, PIMS, and the Université de Montréal

Organizers : Alexandre Girouard (Laval), Dmitry Jakobson (McGill), Michael Levitin (Reading), Nilima Nigam (Simon Fraser), Iosif Polterovich (Montréal), Frédéric Rochon (UQAM)

Each year the CRM organizes summer schools of the highest scientific calibre. They are attended by researchers from all over the world, postdoctoral fellows, and graduate students. Among these schools the Séminaire de mathématiques supérieures (SMS) is the oldest continuous activity of a mathematical nature to take place in Montreal: indeed the SMS was inaugurated in the 1960s.

At the beginning of the SMS, more than 50 years ago, the summer school was sponsored by NATO and organized by the Department of Mathematics and Statistics of the Université de Montréal. As time went by, the association between the CRM and the SMS became stronger and stronger. The SMS is not sponsored by NATO any more: its support comes from the CRM, the Fields Institute, PIMS, and the Mathematical Sciences Research Institute (MSRI) at Berkeley.

Here are the names and affiliations of the instructors and the course titles.

Gregory Berkolaiko (Texas A&M)
Interlacing Eigenvalue Inequalities and Counting Zeros of Graph Eigenfunctions

Dorin Bucur (Savoie Mont Blanc)
Shape Optimization and Spectral Inequalities

Bruno Colbois (Neuchâtel)
The Spectrum of the Laplacian: a Geometric Approach

Chen Grief (UBC)
Numerical Solution of Linear Eigenvalue Problems

Daniel Grieser (Oldenburg)
Asymptotics of Eigenvalues on Thin Things

Colin Guillarmou (École normale supérieure)
A Scattering Theory Approach for X-Ray Tomography

Bernard Helffer (Paris-Sud)
On Nodal Partitions and Minimal Spectral Partitions (An Introduction)

Guido Kanschat (Heidelberg)
Finite Element Approximation of Eigenvalue Problems

Richard Melrose (MIT)
Laplacians Degenerating at a Point and Gluing

Richard Schoen (Stanford)
The Spectral Geometry of the Dirichlet–Neumann Operator

Mikhail Sodin (Tel Aviv)
Random Nodal Portraits

Alexander Strohmaier (Loughborough)
Computation of Eigenvalues, Spectral Zeta Functions and Zeta-Determinants on Hyperbolic Surfaces

CRM–PIMS Summer School in Probability 2015

June 15-July 11, 2015, McGill University

sponsored by the CRM, PIMS, the MSRI, McGill University, the CRM Probability Laboratory, the ISM, and the NSF

Organizers : Louigi Addario-Berry (McGill), Louis-Pierre Arguin (Baruch College, CUNY), Martin T. Barlow (UBC), Edwin A. Perkins (UBC), Lea Popovic (Concordia)

This summer school consisted of two main courses (given by Alice Guionnet and Remco van der Hofstad, respectively) and three mini-courses.

Alice Guionnet (École normale supérieure de Lyon)
Random Matrices, Free Probability and the Enumeration of Maps

Remco van der Hofstad (TU Eindhoven)
High-Dimensional Percolation and Random Graphs

Louigi Addario-Berry (McGill)
Random Minimum Spanning Trees

Shankar Bhamidi (North Carolina)
Dynamic Random Network Models

Jonathan Mattingly (Duke)
Stabilization by Noise

Deep Learning Summer School 2015

August 3-12, 2015, CRM

sponsored by the CRM and the Canadian Institute for Advanced Research (CIFAR)

Organizers : Yoshua Bengio (Montréal), Yann LeCun (New York), Roland Memisevic (Montréal)

Yoshua Bengio (Montréal)
Theoretical Motivations for Representation Learning &
Deep Learning Generative Models from Auto-encoders

Phil Blunsom (Oxford)
From Language Modeling to Machine Translation
Memory, Reading, and Comprehension

Léon Bottou (Facebook)
Intro to Multi-layer Nets
Numerical Optimization and SGD, Structured Problems & Reasoning

Adam Coates (Stanford)
Speech Recognition with Deep Learning
Systems Issues and Distributed Training

Aaron Courville (Montréal)
Intro to Undirected Graphical Models
VAEs and Deep Generative Models for Vision

Ian Goodfellow (Google)
Structure of Optimization Problems
Adversarial Examples

Hugo Larochelle (Sherbrooke)
Neural Nets and Backprop
Directed Graphical Models and NADE

Honglak Lee (Michigan)
Stacks of RBMs
Convolutional Networks

Christopher Manning (Stanford)
NLP 101
NLP / Deep Learning

Roland Memisevic (Montréal)
Visual Features I, II

Ruslan Salakhutdinov (Carnegie Mellon)
Deep Boltzmann Machines
Multi-modal Models

Mark Schmidt (UBC)
Smooth, Finite, and Convex Optimization
Non-Smooth, Non-Finite, and Non-Convex Optimization

Richard Socher (Salesforce)
Recurrent Neural Networks
DMN for NLP

Graham Taylor (Guelph)
Learning Similarity
Modeling Human Motion, Pose Estimation and Tracking

Pascal Vincent (Montréal)
Intro to ML
Denoising and Contractive Auto-encoders, Manifold View

The CRM General Program

The general programme of the CRM funds a wide variety of scientific events, both on the premises of the CRM and elsewhere in Canada. Whether it be for specialized workshops attended by a small number of researchers or large meetings attended by hundreds of participants, the general programme promotes research in the mathematical sciences at all levels. The programme is quite flexible, allowing projects to be considered as they arise.

Apart from thematic program workshops and summer schools, the CRM organizes various activities that do not necessarily recur from year to year. These activities belong to the CRM General Program or the CRM Interdisciplinary and Industrial Program; they may also be sponsored by the CRM Laboratories. Note that groups of researchers may organize short thematic programs.

General Program: Activities Held at the CRM

Conference on Topology, Geometry and Dynamics In Honour of François Lalonde

August 31-September 4, 2015, CRM

Organizers: Octav Cornea (Montréal), Iosif Polterovich (Montréal), Leonid Polterovich (Tel Aviv)

This outstanding workshop demonstrated the great import of François Lalonde's contributions to symplectic topology and the development of mathematics (particularly during his two mandates as CRM director). The workshop attracted some of the top names in modern mathematics. We refer the reader to the Fall 2015 edition of Le Bulletin du CRM for a detailed description of the workshop lectures.

Workshop GRASTA–MAC 2015 7th workshop on GRAph Searching, Theory and Applications 5th workshop on Moving And Computing

October 19-23, 2015, Université de Montréal

sponsored by the Université de Montréal, the CRM, the CNRS, the Université Nice Sophia Antipolis and I3S

Organizers: Gena Hahn (Montréal), Nicolas Nisse (INRIA), Benjamin Seamone (Dawson College)

CRM–CANSSI Workshop on Statistical Inference for Complex Surveys with Missing Observations

October 25-26, 2015, Université de Montréal

sponsored by the CRM and CANSSI

Organizers: David Haziza (Montréal) and Changbao Wu (Waterloo)

24 heures de science (11th edition) "Les mathématiques au service de l'environnement"

May 6, 2016, Université de Montréal

sponsored by the CRM, CIRRELT, GERAD, the ncm$_2$, CIRANO, and the ISM

General Program: Activities Supported by the CRM Outside its Premises

CanaDAM 2015 : 5th Canadian Discrete and Algorithmic Mathematics Conference

June 1-4, 2015, University of Saskatchewan

sponsored by AARMS, the CRM, the Fields Institute, PIMS, the CMS, and the University of Saskatchewan

Program Committee: Jonathan Jedwab (Simon Fraser), Gary MacGillivray (Victoria), Charlie Colbourn (Arizona State), Anne Condon (UBC), Antoine Deza (McMaster), Marni Mishna (Simon Fraser), Mike Newman (Ottawa), Richard Nowakowski (Dalhousie), Ryan O'Donnell (Carnegie Mellon), Patric Östergård (Aalto), Martin Skutella (TU Berlin), Doug Stinson (Waterloo), Nick Wormald (Monash)

Executive Committee: Brett Stevens (Carleton), Gena Hahn (Montréal), Gary MacGillivray (Victoria), Joy Morris (Lethbridge), David Pike (Memorial), Frank Ruskey (Victoria)

Local Arrangements Committee: Chris Soteros, Michael Szafron, Mahshid Atapour, Richard Bowles, Murray Bremner, Mark Keil (Saskatchewan), and Joy Morris (Lethbridge)

2015 AARMS Workshop on Domain Decomposition Methods for PDEs

August 3-8, 2015, Dalhousie University

sponsored by AARMS, the Fields Institute, Memorial University, Dalhousie University, Saint Mary's University, NSERC, Springboard, and the CRM

Organizers: Ronald Haynes (Memorial), Hermann Brunner (Memorial), Scott MacLachlan (Memorial), David Iron (Dalhousie), Paul Muir (Saint Mary's)

59th Congress of the Association Mathématique du Québec Mathématiques & techniques s'arriment

October 16-17, 2015, Cégep Limoilou

sponsored by the SEECL, the Caisse Desjardins of Limoilou, L'Autre Zone, Les Presses de l'Université du Québec, Sobab, the CRM, the Brasserie générale, the CMS, INFODEV, and the CCDMD

INTRIQ Meeting The Emergence of Quantum Information A Conference in Honour of Gilles Brassard

November 2, 2015, Hôtel Château-Bromont

sponsored by the FRQNT, the Université de Montréal, the CRM, the Perimeter Institute, CIFAR, the Canada Excellence Research Chairs Program, and EPIQ

Organizers: Louis Salvail (Montréal), Claude Crépeau (McGill), David Poulin (Sherbrooke)

2015 CMS Winter Meeting

December 4-7, 2015, Hyatt Regency Hotel (Montréal)

sponsored by the CRM, PIMS, the Fields Institute, AARMS, Tourisme Montréal, and the ISM

Scientific Director: Louigi Addario-Berry (McGill)

Scientific Committee: James Colliander (UBC & PIMS), Henri Darmon (McGill), Lisa Jeffrey (Toronto), Yu-Ru Liu (Waterloo), Nilima Nigam (Simon Fraser), Christiane Rousseau (Montréal), Bruce Shepherd (McGill)

SUMM 2016: Seminars in Undergraduate Mathematics in Montreal

January 8-10, 2016, Université du Québec à Montréal

sponsored by the CRM, the ISM, the CMS, Maplesoft, and four Montreal universities (Concordia, McGill, the Université de Montréal, and UQAM, including the mathematics departements and the student associations of these universities)

Organizers: Alexis Langlois-Rémillard (Montréal), Antoine Giard (Montréal), Erick Schulz (McGill), Fabrice Nonez (Polytechnique Montréal), Jida Hussami (Concordia), Joey Litalien (McGill), Renaud Raquépas (McGill)

Book Signing Event Mathematics Without Apologies Michael Harris (Paris-Diderot & Columbia)

February 11, 2016, Concordia University

Molecules and Laser Fields An Honorary André Bandrauk Symposium

May 4-7, 2016, Hôtel Chéribourg (Magog)

Organizers: Catherine Lefebvre (INRS-ÉMT), François Légaré (INRS-ÉMT), Maria Bandrauk, Tung Nguyen-Dang (Université Laval)

XIXth Colloque panquébécois des étudiants de l'ISM

May 13-15, 2016, Université du Québec à Montréal

Organizers: Fils Geasino Fotso (UQAM), Kasia Jankiewicz (McGill), Nadia Lafrenière (UQAM), Mélodie Lapointe (UQAM)

2016 Student Conference of the Statistical Society of Canada

May 28, 2016, Brock University

sponsored by the Fields Institute, CANSSI, the CMS, Brock University, the CRM, Groupe Roche, and the Biostatistics Group of the SSC

Organizer: Thuva Vanniyasingam (McMaster University)

International Conference on Image and Signal Processing (ICISP 2016)

May 30-June 1, 2016,
Université du Québec à Trois-Rivières

sponsored by EURASIP, the IAPR, the Université de Caen Basse-Normandie, the UQTR, Ibn Zohr University, the Union of UQTR Professors, and the CRM

Organizers: Fathallah Nouboud (UQTR), Alain Chalifour (UQTR), Jean Meunier (Montréal)

Doppler Institute–CRM Workshop on the Occasion of the 80th Birthdays of Jiří Patera and Pavel Winternitz

May 30-June 3, 2016, Vila Lanna (Czech Republic)

sponsored by the Doppler Institute and the CRM

Organizers: Libor Šnobl (UT Prague), Goce Chadzitaskos (UT Prague), Sarah Post (Hawaii at Mānoa), Luc Vinet (Montréal), Miroslav Znojil (NIP, CAS)

Interdisciplinary and Industrial Program

The CRM has been organizing Industrial Problem Solving Workshops (IPSWs) since 2007. In 2014 the three Canadian mathematics research institutes (the CRM, the Fields Institute, and PIMS) were awarded an NSERC grant in order to develop their industrial collaborations. This grant is called "Institutes Innovation Platform" (IIP). The IIP has allowed the CRM to hire a Partnerships Development Officer (Dr. Stéphane Rouillon) and organize more IPSWs. The CRM has also decided to organize another kind of workshops, called Networking Industrial Events (organized by Stéphane Rouillon). A Networking Industrial Event lasts for one day and includes presentations of industrial problems, as well as presentations by CRM laboratories and exchanges between mathematicians and industrial partners. Here is a list of the workshops that took place in 2015-2016.

Networking Industrial Event (organized with IVADO) Big Data

June 8, 2015, Polytechnique Montréal

Sixth Montreal Industrial Problem Solving Workshop

August 17-21, 2015, CRM

sponsored by NSERC

Organizers: Charles Audet (Polytechnique Montréal), Huaxiong Huang (York), Odile Marcotte (CRM and UQAM), Nilima Nigam (Simon Fraser), Stéphane Rouillon (CRM)

Team Coordinators: Charles Audet, Sean Bohun (UOIT), Odile Marcotte, Perouz Taslakian (McGill), Maciej Augustyniak (Montréal), José Urquiza (Laval)

Participating Companies: National Bank of Canada, Bombardier, Genia Photonics, Plotly, Pratt & Whitney Canada, Rio Tinto

Networking Industrial Event Photonics

October 5, 2015, CRM

Networking Industrial Event Medical Imaging

February 8, 2016, CRM

Seventh Montreal Industrial Problem Solving Workshop

May 16-20, 2016, CRM

sponsored by NSERC and CANSSI

Organizers: Thierry Duchesne (Laval), Odile Marcotte (CRM and UQAM), Stéphane Rouillon (CRM)

Team Coordinators: Louis Doray (Montréal), Thierry Duchesne, Jean-François Plante (HEC Montréal), Jean-François Quessy (UQTR), Bruno Rémillard (HEC Montréal)

Participating Companies: National Bank of Canada, Caisse de dépôt et placement du Québec, Desjardins General Insurance Group, The Co-operators

Activities Organized by the CRM Laboratories

The CRM activities described so far (thematic program, general program, interdisciplinary program) are organized to a large extent by mathematicians who belong to at least one laboratory of the CRM. The CRM members, however, also organize activities that are proposed and supported by the laboratories themselves. Here are the activities organized by the laboratories in 2015-2016.

The Joint 2015 CAMBAM–MBI–NIMBioS Summer School Nonlinear Dynamics in Biological Systems

June 1-22, 2015, McGill University

sponsored by CAMBAM

Organizers: Anmar Khadra (McGill), Santiago Schnell (Michigan)

Statistics and Biostatistics Colloquium

June 10-11, 2015, Université de Sherbrooke

sponsored by the Statistics Laboratory

Organizer: Éric Marchand (Sherbrooke)

Workshop Noncommutative Geometry and Spectral Invariants

June 29-July 3, 2015, Université du Québec à Montréal

sponsored by the ANR, CIRGET, the CRM, the Fields Institute, NSERC, the NRF (Korea), and the UMI 3457 (at the CRM)

Organizers: George Elliott (Toronto), Thierry Giordano (Ottawa), Masoud Khalkhali (Western), Victor Nistor (Metz), Raphaël Ponge (UN Seoul), Frédéric Rochon (UQAM)

Workshop Lévy Processes and their Applications in Ruin Theory

October 8, 2015, Université du Québec à Montréal

sponsored by Quantact

Organizers: Hélène Cossette (Laval), David Landriault (Waterloo), Étienne Marceau (Laval), Jean-François Renaud (UQAM)

2015 Montreal–Toronto Workshops in Number Theory

October 10-11, 2015, CRM

sponsored by CICMA

Organizers: Eyal Goren (McGill), Stephen Kudla (Toronto)

5th Workshop of Graduate Students in Actuarial Sciences and Financial Mathematics

November 20, 2015, Université Laval

sponsored by Quantact

Organizers: Manuel Morales (Montréal), José Garrido (Concordia), Alexandre Roch (UQAM), Geneviève Gauthier (HEC Montréal), Ghislain Léveillé (Laval)

CRM Nirenberg Lectures in Geometric Analysis Gunther Uhlmann (Washington)

March 18, 21, and 22, 2016, CRM

sponsored by the Analysis Laboratory

Organizers: Iosif Polterovich (Montréal), Alina Stancu (Concordia), Dmitry Jakobson (McGill), Pengfei Guan (McGill)

Workshop Rare DNA Variants, Analysis of Family Studies

May 27, 2016, CRM

sponsored by the Statistics Laboratory

Organizers: Alexandre Bureau (Laval), Aurélie Labbe (McGill)

"GRANDES CONFÉRENCES" DU CRM & COLLOQUIUM

Four lectures were delivered at the Université de Montréal in 2015–2016: "L'art et la science des systèmes à trop d'inconnues" (The Art and Science of Systems Involving Too Many Unknowns) by Emmanuel Candès (October 29, 2015); "Counting from Infinity, Yitang Zhang and the Twin Prime Conjecture" (November 19, 2015); "Systèmes et contrôle: enjeux et réussites" by Enrique Zuazua (January 29, 2016); and "Why Conservation Biology Needs Mathematics" by Stephanie Peacock (May 6, 2016). The reader will find below summaries inspired in part by texts published in Le Bulletin du CRM (and authored by Christiane Rousseau, Christian Genest, and David A. Stephens). Each of the lectures was attended by hundreds of participants of various ages. Receptions held after the lectures allowed members of the audience to ask questions, renew old acquaintances, and meet other attendees interested in science. The "Grandes Conférences" program is under the stewardship of Christiane Rousseau and Yvan Saint-Aubin, both full professors in the Department of Mathematics and Statistics at the Université de Montréal.

In 2006 the CRM launched the "Grandes Conférences" lecture series in order to fulfill the expectations of a public wishing to understand important developments in the mathematical sciences. The "Grandes Conférences" feature outstanding lecturers whose presentations convey the power and beauty of mathematical research to a wide audience.

L'art et la science des systèmes à trop d'inconnues

Emmanuel Candès (Stanford University)

On October 29, 2015, a public lecture on *The Art and Science of Systems Involving Too Many Unknowns* was given at the CRM by Professor Emmanuel Candès, holder of the Barnum–Simons Chair in Mathematics and Statistics at Stanford University. Born in Paris, France, where he received most of his education, Professor Candès has consistently earned high acclaim for his groundbreaking contributions to compressed sensing, an area of research and emerging technology that largely grew out of his joint work with Justin Romberg and Terence Tao over the past 15 years.

Compressed sensing is a signal processing technique for efficiently acquiring and reconstructing a signal by solving underdetermined linear systems of equations. In his hour-long presentation, Professor Candès motivated and illustrated some of his research on the subject by drawing mainly from diagnostic medicine, with an emphasis on magnetic resonance imaging, where the need for fast and high-quality image reconstruction is paramount. He stressed, however, that compressed sensing finds applications in many other areas, including circuit design, optics, photography, holography, and facial recognition. As a further illustration of this general methodology, he discussed the 2006–2009 Netflix Prize open competition, whose ultimate goal was to predict user ratings for films as accurately as possible, based only on previous ratings and without any other information about the users or the films.

Compressed sensing is based on the principle that, through optimization, the sparsity of a signal can be exploited to recover it from far fewer observations than prescribed by the famous Nyquist–Shannon theorem. In the canonical two-dimensional imaging example, measurements y are made at various locations in the spectral domain, the required image f lies in the spatial domain, and the two objects are related through an identity where K (the Fourier Kernel) appears. The main challenge is to reconstruct f at as high a resolution as possible, given that only a sketch of the Fourier transform is available. Minimizing data collection in the spectral domain is relevant in practice, for example in the context of magnetic resonance imaging (where taking measurements is potentially time consuming and invasive or unpleasant for the patient).

Emmanuel Candès

Professor Candès explained that under a discrete approximation, the problem of reconstructing an image f from indirect measurements reduces, for a known matrix, to the solution of a linear system of equations $y = Ax$ given by the discrete (inverse) Fourier transform of the observed data. This system is underdetermined when m is smaller than n, i.e., when data collection has low resolution. A unique solution, however, can be found if one imposes that x has as many zero entries as possible, provided that the measurement matrix A satisfies minimal conditions, in particular if it contains a sufficient amount of "randomness" and "incoherence." In practice, the search for the sparse (or compressed) solution is computationally intractable, as it is an NP-hard problem. Luckily, it turns out that under broad and realistic conditions, equivalent sparse solutions can be obtained by imposing $L1$ constraints instead, thereby converting the optimization problem into a convex programming issue. As Professor Candès showed, the resulting sparse reconstruction is extremely effective.

In the last third of his talk, Professor Candès went on to demonstrate how these principles could be generalized to other forms of underdetermined systems using alternative constrained solutions and low-rank decompositions. The unifying theme was again the framing of a mathematically and computationally intractable problem in a tractable, convex optimization setting. The "Grande Conférence" by Professor Candès attracted a large audience and aroused much interest among mathematicians, statisticians, and the general public. A video of his talk (in French) can be found at http://www.crm.math.ca/Candes/; a related lecture (in English) given by Professor Candès at the 2014 International Congress of Mathematicians in Seoul, South Korea, is available on YouTube (http://www.youtube.com/watch?v=W-b4aDGsbJk).

Counting from Infinity, Yitang Zhang and the Twin Prime Conjecture

On November 19, 2015, the film *Counting from Infinity, Yitang Zhang and the Twin Prime Conjecture* was shown in a large lecture room of the Jean-Coutu pavilion at the Université de Montréal. The director who made that film, George Csicsery, is well known for his films on some famous mathematicians (among other films). A public question-and-answer session took place after the film: Professor Andrew Granville (from the Université de Montréal) and Professor K. Soundararajan (from Stanford University) were available to answer the questions of the audience. The film dealt with a very famous conjecture in number theory, which has a connection with the CRM. Here is the story.

In April 2013, a lecturer at the University of New Hampshire (Yitang Zhang) submitted a paper to the *Annals of Mathematics*. Within weeks, word spread: a little-known mathematician, with no permanent job, working in complete isolation, had made an important breakthrough towards solving the Twin Prime Conjecture. This conjecture states that there are infinitely many pairs of contiguous odd prime numbers, like 3 and 5, 5 and 7, 11 and 13, 17 and 19, 29 and 31, etc. Yitang Zhang's techniques for bounding the gaps between primes soon led to rapid progress by the Polymath Group and a further innovation by James Maynard (a postdoctoral fellow at the CRM). *Counting from Infinity, Yitang Zhang and the Twin Prime Conjecture* is a study of Zhang's rise from obscurity as a disadvantaged youth to mathematical celebrity.

The story of quiet perseverance amidst adversity, and Zhang's preference for thinking and working in solitude, is interwoven with the history of the Twin Prime Conjecture as told by several mathematicians, many of whom have wrestled with this enormously challenging problem in number theory. Among them are Daniel Goldston, K. Soundararajan, Andrew Granville, Peter Sarnak, Enrico Bombieri, James Maynard, Nicholas Katz, David Eisenbud, Ken Ribet, and Terence Tao.

Systèmes et contrôle : enjeux et réussites

Enrique Zuazua (Universidad Autónoma de Madrid)

According to Professor Zuazua, who quoted Aristotle, the desire for automation has a long history: "If the shuttle would weave and the plectrum touch the lyre without a hand to guide them, chief workmen would not want servants, nor masters slaves." The first example of control that was presented, noise reduction, showed the difference between passive control and feedback loops. This was the beginning of Professor Zuazua's lecture on systems and control. Motivated by Leonhard Euler's quest for optimization principles, the lecture then made a detour through the calculus of variations in order to explain the laws of the universe. Examples were used to illustrate these ideas: the isoperimetric problem of Queen Dido, geodesics on surfaces, soap bubbles and Plateau's problem, Fermat's principle in optics, and optimal transportation. The lecturer presented two completely different methods for finding the numerical value of a minimum: the gradient method and the Monte Carlo method. The former is efficient when the function or functional to minimize is sufficiently regular, whereas a Monte Carlo method is preferred when the structure of the functional is very complex.

The core of the lecture was on controllability: the cybernetics introduced by Ampère in the 19th century and described by Norbert Wiener as the *science of control and communication in animals and machines*, which anticipated that in the future machines would be expected to imitate humans. The statement was illustrated using the example of a robot's arm. In the example the robotic arm has only three fingers opposed to the thumb, because every additional finger adds a great deal of complexity to its design. Another question addressed in the lecture was: "Is it possible to control the state of n components with only m controls when n is much larger than m?" Kálmán's theorem (1958) gives necessary and sufficient conditions for this to be possible. For example, in a car, one has multiple degrees of freedom: the position of the car's centre of gravity, its orientation, and the orientation of the driving wheels. Yet only two controls are needed to make the car move: the steering wheel and the forward movement, as shown in many videos of highly skilled drivers.

Enrique Zuazua also described the mathematics involved in the optimal design of an aircraft, which includes fluid mechanics, used to simulate the airflow along the body of an aircraft, and optimization of the form using successive iterations for minimizing the functional cost. He explained the importance of the viscosity term in the Navier–Stokes equation (it allows the birds to fly!) and discussed the great challenges posed to mathematicians by the resolution of these equations. The lecture ended with a reflection on future perspectives and a discussion of the numerous applications of control theory to mechanics, medicine, electronics, chemistry, economics, and finance. The networks that surround us are more complex and distributed than ever, and thus pose new challenges to mathematicians. New tools are needed: combinatorics and graph theory, data mining and big data, and statistical learning; algorithms of ever increasing sophistication continue to emerge.

Why Conservation Biology Needs Mathematics

Stephanie Peacock (University of Alberta)

Within the framework of the "24 heures de science" (see the section of this report on the other activities of the CRM), Stephanie Peacock delivered a lecture on the usefulness of mathematics in conservation biology. The phrase "conservation biology" tends to conjure up images of field research in remote locations and weathered-looking scientists searching for endangered species. But chalkboards, computers, and – yes – mathematics are important tools for the modern-day conservation biologist. Ecological data are often patchy and riddled with error, making it difficult to draw conclusions about the factors driving change in wildlife populations and the environment. Mathematical models can describe the mechanisms that may underlie patterns in ecological data and increase our power to test alternative hypotheses, predict future change, and evaluate the potential outcomes of different management scenarios. In an age where government and industry demand quantitative evidence before action, mathematics may be the key to conservation.


Enrique Zuazua


Stephanie Peacock

Le Colloque des sciences mathématiques du Québec

The CRM, in association with the Institut des sciences mathématiques (ISM), organizes a series of lectures held during the academic year. The lectures are actually survey talks by world-renowned mathematicians and statisticians on various subjects of current interest. In 2015–2016, the organizers were Henri Darmon (McGill University), Iosif Polterovich (Université de Montréal), Yvan Saint-Aubin (Université de Montréal), Alina Stancu (Concordia University), and David Stephens (McGill University) for the lectures taking place in Montreal; Alexandre Girouard and Jean-Philippe Lessard (both from the Université Laval) for the lectures taking place in Quebec City; and Éric Marchand (Université de Sherbrooke) for the lectures taking place in Sherbrooke.

September 25, 2015, UQAM
Dmitri Vassiliev (University College London)
Analysis of First-Order Systems of PDEs on Manifolds without Boundary

October 9, 2015, UQAM
Hugh Thomas (UQAM)
Coxeter Groups and Quiver Representations

October 19, 2015, Université de Montréal
Emmanuel Giroux (ENS Lyon & UMI-CRM)
Holomorphic Functions, Convexity and Transversality

October 23, 2015, UQAM
John Harnad (Concordia University)
Weighted Hurwitz Numbers: Classical and Quantum

October 30, 2015, Université de Montréal
Emmanuel Candès (Stanford University)
A Knockoff Filter for Controlling the False Discovery Rate

November 6, 2015, UQAM
Piotr Przytycki (McGill University)
Walls in random groups

November 13, 2015, Université de Montréal
Alexander Fribergh (Université de Montréal)
Random walks in random environments

November 20, 2015, UQAM
Lia Bronsard (McMaster University)
Sur l'étude des singularités dans des modèles mathématiques de cristaux liquides

November 26, 2016, McGill
Richard Cook (University of Waterloo)
Inference Regarding Within-Family Association in Disease Onset Times under Biased Sampling Schemes

November 27, 2015, Université de Montréal
Stéphane Jaffard
(Université Paris-Est-Créteil-Val-de-Marne)
Measuring Irregularities in Data: Can Fractals Help to Classify Van Gogh Paintings?

December 10, 2015, Université de Montréal
Nicolai Meinshausen (ETH Zürich)
Causal Discovery with Confidence Using Invariance Principles

January 22, 2016, UQAM
Andrea Lodi (Polytechnique Montréal)
Big Data & Mixed-Integer (Nonlinear) Programming

January 29, 2016, Université de Montréal
Jérôme Vétois (McGill University)
Stability and Instability for Nonlinear Elliptic PDE with Slight Variations to the Data

February 5, 2016, UQAM
Tadashi Tokieda (University of Cambridge)
Chain Reactions

February 12, 2016, Université de Montréal
Dorin Bucur (Université Savoie-Mont-Blanc)
Optimal Shapes and Isoperimetric Inequalities for Spectral Functionals

February 26, 2016, Université de Montréal
Dmitry Khavinson (University of South Florida)
The Fundamental Theorem of Algebra, Complex Analysis and... Astrophysics

March 10, 2016, McGill
Gennady Samorodnitsky (Cornell University)
Ridges and Valleys in the High Excursion Sets of Gaussian Random Fields

March 17, 2016, Université Laval
Vern Paulsen (University of Waterloo)
Quantum Chromatic Numbers and the Conjectures of Connes and Tsirelson

April 1st, 2016, Université de Montréal
Malabika Pramanik (UBC)
Needles, Bushes, Hairbrushes and Polynomials

April 8, 2016, Université de Montréal
Nathanael Berestycki (University of Cambridge)
The Dimer Model: Universality and Conformal Invariance

April 14, 2016, Université Laval
Philippe Rigollet (MIT)
The Statistical Price for Computational Efficiency

April 14, 2016, Université de Sherbrooke
Andrew L. Rukhin (National Institute of Standards)
Statistical Estimation Problems in Meta-Analysis

April 15, 2016, Université de Montréal
Ovidiu Savin (Columbia University)
Elliptic PDEs in Two Dimensions

May 20, 2016, Université de Montréal
Gérard Ben Arous (Courant Institute, NYU)
Complexité des fonctions d'un grand nombre de variables : de la physique statistique aux algorithmes d'apprentissage profond

LABORATORIES

The CRM laboratories act as focal points for local research in mathematics and participate actively in the scientific programming of the CRM. Members of the laboratories organize thematic years or semesters, coordinate activities and seminars sponsored by the laboratories themselves, and train graduate students and postdoctoral fellows. The laboratories involve members from many universities and therefore greatly facilitate collaboration between researchers in Quebec.

THE MOST IMPORTANT CHARACTERISTIC OF THE CRM IS PERHAPS ITS DUAL STRUCTURE; IT IS A COLLABORATIVE AND THEMATIC RESOURCE AS WELL AS A DYNAMIC COMBINATION OF THIRTEEN RESEARCH LABORATORIES. THESE FEATURES SET IT APART FROM SIMILAR INTERNATIONAL INSTITUTES IN THAT THE CRM COMBINES THE CLASSICAL RESEARCH MODEL WITH THE ORGANIZATION OF THEMATIC PROGRAMS WITHIN AN INSTITUTIONAL MODEL. AS SUCH, THE CRM BENEFITS FROM THE INVOLVEMENT OF APPOINTED MEMBERS AS WELL AS THE PARTICIPATION OF A LARGE NUMER OF TOP-NOTCH INTERNATIONAL RESEARCHERS IN ITS ACTIVITIES.

Mathematical Analysis

At the same time classical and central to modern mathematics, analysis involves the study of continuous systems, from dynamical systems to solutions of partial differential equations and spectra of operators. The laboratory includes regular and associate members working at more than ten different universities in Canada, the United Kingdom, France, and Austria. The members of the laboratory work in the following areas: harmonic analysis, complex analysis, several complex variables, potential theory, functional analysis, Banach algebras, microlocal analysis, analysis on manifolds, nonsmooth analysis, spectral theory, partial differential equations, geometric analysis, ergodic theory and dynamical systems, control theory, mathematical physics, probability, nonlinear analysis, nonlinear differential equations, topological methods in differential equations, fluid dynamics, and turbulence.

The laboratory members organize (on their own or with other laboratories) several seminars that take place regularly in Montreal universities, at the Université Laval, and at the Université de Sherbrooke.

Highlights

In June 2015 three members of the laboratory (A. Girouard, D. Jakobson, and I. Polterovich) organized the Séminaire de mathématiques supérieures on geometric and computational spectral theory (mentioned in the section on the summer schools of the CRM). Raphaël Ponge (Seoul National University) visited the laboratory and co-organized the Workshop on Noncommutative Geometry and Spectral Invariants in honour of Georges Skandalis (see the CIRGET report below). Among the other researchers who visited the Mathematical Analysis Laboratory in 2015–2016 let us mention A. Panati (Toulon), D. Ueltchi (Warwick), A. Shirikyan (Cergy-Pontoise), C. Bénéteau and K. Khavinson (University of South Florida), Y. Pautrat (Paris-Sud), C.-A. Pillet (Toulon), L. Bruneau (Cergy-Pontoise), T. Benoist (Toulouse), and L. Baratchart (INRIA Sophia Antipolis). Note that some researchers who were postdoctoral fellows in the laboratory have accepted tenure-track positions: Y. Canzani (UNC Chapel Hill), A. Hassannezhad (University of Bristol), Y. Bonthonneau (CNRS), S. Eswarathasan (Cardiff University), and D. Kinzebulatov (Université Laval).

Dmitry Jacobson

The Nirenberg Lectures in Geometric Analysis are the most prestigious event organized by the laboratory (see the section on the other activities of the CRM). In March 2016 Gunther Uhlmann (University of Washington) gave lectures on the following topics: transformation optics and scientific proposals to achieve invisibility; determining the sound speed or index of refraction of a medium by measuring the travel times of waves going through the medium; inverse problems for the Einstein equation with a time-depending metric on a 4-dimensional globally hyperbolic Lorentzian manifold.

Students and postdoctoral fellows

In 2015–2016 the members of the Mathematical Analysis Laboratory supervised 32 M.Sc. students, 26 Ph.D. students, and 12 postdoctoral fellows.

Director

Dmitry Jakobson (McGill)

Regular members

Marlène Frigon, Paul M. Gauthier, Iosif Polterovich, Christiane Rousseau, Dana Schlomiuk (Montréal)

Stephen W. Drury, Vojkan Jakšić, Ivo Klemes, Paul Koosis, John A. Toth, Jérôme Vétois (McGill)

Abraham Boyarsky, Galia Dafni, Pawel Góra, Alexey Kokotov, Alexander Shnirelman, Alina Stancu, Ron J. Stern (Concordia)

Line Baribeau, Alexandre Girouard, Frédéric Gourdeau, Javad Mashreghi, Thomas J. Ransford, Jérémie Rostand (Laval)

Tomasz Kaczinski (Sherbrooke)

Dominic Rochon (UQTR)

Vadim Kaimanovich (Ottawa)

Richard Fournier (Dawson College)

Francis H. Clarke (Université Claude Bernard)

Robert Seiringer (IST Austria)

Associate members

Octav Cornea, Richard Duncan, Samuel Zaidman (Montréal)

Kohur Gowrisankaran, Pengfei Guan, Niky Kamran (McGill)

John Harnad, Dmitry Korotkin (Concordia)

Nilima Nigam (Simon Fraser)

Yiannis Petridis (University College, London)

CAMBAM
Centre for Applied Mathematics in Bioscience and Medicine

The mission of CAMBAM is to be a leading institution in the application of mathematics to address challenges in bioscience and medicine through partnerships with industry, government, and other stakeholders in society. CAMBAM meets its objectives by promoting and fostering research, teaching, and training in applications of quantitative biology at all levels, ranging from the molecular/genetic through single-cell and whole-organ physiology and biology to population dynamics and broader ecological questions, on time scales from the present to the evolutionary; by honing the talents of students at all levels through unique training opportunities in academic and non-academic settings; and by conducting applied research of the highest scientific rigour, meeting existing industry and societal demands in clinical and public health settings

CAMBAM organizes two seminar series. The first series, called Cutting Edge Lecture Series, is geared towards the general public and consists of one lecture per month, delivered at the Redpath Museum of McGill University. Each lecture draws more than 80 persons. The second series is attended by CAMBAM members: it consists of lectures delivered by CAMBAM researchers and invited researchers, who present their work.

Highlights

In the summer of 2015 CAMBAM was the host of the *Nonlinear Dynamics in Biological Systems International Summer School*. This summer school took place at McGill University on June 1-12, 2015, and was co-organized by Anmar Khadra (CAMBAM and McGill) and Santiago Schnell (Computational Medicine & Bioinformatics, University of Michigan), with the participation of the Mathematical Biosciences Institute (MBI, Ohio State University) and the National Institute for Mathematical and Biological Synthesis (NIMBioS, University of Tennessee). The school welcomed 41 participants. In the summer of 2016 CAMBAM was a partner in the organization of a summer school entitled *Mathematical Modeling of Infectious Disease Spread*, held at Ohio State University. CAMBAM also organized a session on mathematical biology within the Winter Meeting of the Canadian Mathematical Society. Finally CAMBAM held its annual meeting on May 31, 2016, in order to publicize the research of its members through 17 presentations by its student members.

Students and postdoctoral fellows

In 2015–2016 the CAMBAM members supervised or cosupervised 15 M.Sc. students, 23 Ph.D. students, and 5 postdoctoral fellows.

Codirectors

Erik Cook and Frédéric Guichard (McGill)

Regular members

Jacques Bélair, Alain Vinet (Montréal)

Pedro Peres-Neto (UQAM)

Mathieu Blanchette, David L. Buckeridge, Maurice Chacron, Vamsy Chodavarapu, Kathleen Cullen, Paul François, Gregor Fussman, Leon Glass, Michael Guevara, Anthony R. Humphries, Anmar Khadra, Svetlana V. Komarova, Brian Leung, Michael C. Mackey, Jacek Majewski, Sam Musallam, Christopher Pack (McGill)

André Longtin (Ottawa)

Associate members

Fahima Nekka (Montréal)

Juli Atherton (UQAM)

Lea Popovic (Concordia)

Claire de Mazancourt, Michel Loreau (Station d'Écologie Expérimentale du CNRS à Moulis)

Moisés Santillán Zerón (Cinvestav)

Vincent Lemaire (Pfizer)

CICMA
Centre interuniversitaire en calcul mathématique algébrique

CICMA includes researchers working in number theory, group theory, and algebraic geometry. Algebraic geometry is a broad discipline having close links with diverse fields from arithmetic to theoretical physics. Eyal Goren and Adrian Iovita are leaders in the application of techniques from algebraic geometry to problems arising in number theory, especially Shimura varieties and p-adic cohomology theories. John McKay is one of the instigators of the mooshine program, which ties together in a surprising way certain notions in the theory of modular forms, arithmetic geometry, and theoretical physics.

Number theory has developed over the last decades following two major trends: on one hand algebraic number theory, including such themes as the study of special values of L-functions attached to arithmetic objects, which originates in the work of Gauss and Dirichlet and leads to the modern conjectures of Deligne, Beilinson, and Bloch-Kato. Another theme of algebraic number theory, originating in the Langlands program, postulates a close link between arithmetic L-functions and automorphic representations.

On the other hand analytic number theory addresses deep and subtle questions concerning the distribution of primes. It makes use of mathematical analysis techniques, especially functions of several complex variables and spectral theory. Number theory in all its different flavours is particularly well represented in the laboratory, with Darmon, Goren, Iovita, and Kassaei on the arithmetic and automorphic side, and David, Granville, Kisilevsky, Koukoulopoulos, and Lalín on the more analytic side of the subject.

The members of CICMA organize the Analytic Number Theory Seminar and the Québec-Vermont Number Theory Seminar.

Highlights

The work of Matomäki and Radziwill on multiplicative functions in short intervals was rewarded by the SASTRA Ramanujan Prize, a very prestigious international prize awarded each year to a young researcher in number theory. Indeed, among the 14 researchers who were awarded this prize, two went on to win a Fields Medal and at least another one will win a Fields Medal. Radziwill's work featured in presentations made by mathematicians during the Séminaire Bourbaki and in a plenary talk within an AMS conference. Work by Andreatta, Iovita, and Pilloni on p-adic families of Siegel modular forms continues to have a major impact and has just resulted in the proof of Coleman's conjectures on the spectral halo, leading to a notion of p-adic modular form that looks very promising. Work by Andreatta, Goren, Howard, and Madapusi Pera on the conjecture of Bruinier-Kudla-Yang is generating a lot of interest, especially because of its applicability to the André-Oort conjecture. Antonio Lei's work was rewarded by many invitations to prestigious international conferences, in particular the Clay workshop held in Oxford on the Birch and Swinnerton-Dyer conjecture.

Matilde Lalín is pursuing her work on the Mahler measure of elliptic curves. In collaboration with Ramamonjisoa, she succeeded in expressing a value of an elliptic curve L function as the value of the regulator at a non-torsion point. Lalín has also continued her work on the number of points of a manifold on a finite field: particularly, in collaboration with Bucur, Cojocaru, and Pierce, she has estimated the number of points of bounded height on a cyclic cover of the projective space on a finite field. Dimitris Koukoulopoulos continues to work in analytic number theory and his joint results with Chantal David (on the statistics of elliptic curves on a finite field) have unified and conceptualized this research area and allow one to compute statistics that cannot be studied

through traditional methods. These results are presented in an article to be published in *Mathematische Annalen*. In another article Koukoulopoulos studies the anatomical structure of the Selberg sieve weights: these weights have played a crucial role in the proof of Maynard's results on the bounded gaps between consecutive primes. In Chantal David's work in collaboration with Bettin and Delaunay, she proved new results on the root number of families of elliptic curves: in particular she proved that any rational number comprised between -1 and 1 is the average root number of a non-isotrivial family of elliptic curves on $\mathbb{Q}$.

Students and postdoctoral fellows

In 2015–2016 the members of CICMA supervised or cosupervised two undergraduate students, 24 M.Sc. students, 41 Ph.D. students, and 28 postdoctoral fellows.

Director

Henri Darmon (McGill)

Regular members

Andrew Granville, Dimitris Koukoulopoulos, Matilde Lalín (Montréal)

Eyal Z. Goren, John Labute, Michael Makkai, Maksym Radziwill, Peter Russell (McGill)

Chris J. Cummins, Chantal David, David Ford, Adrian Iovita, Hershy Kisilevsky, John McKay, Francisco Thaine (Concordia)

Hugo Chapdelaine, Jean-Marie De Koninck, Antonio Lei, Claude Levesque (Laval)

Damien Roy (Ottawa)

M. Ram Murty (Queen's)

David S. Dummit (Vermont)

Associate members

Daniel Fiorilli, Abdellah Sebbar (Ottawa)

Payman L. Kassaei (King's College, London)

Henri Darmon

CIRGET
Centre interuniversitaire de recherches en géométrie et topologie

Topology and differential geometry are fundamental disciplines of mathematics whose richness and vitality, evident throughout history, reflect a deep link to our experience of the universe. They are a focal point of modern mathematics and indeed several domains of mathematics have recently shown a strong trend towards a geometrization of ideas and methods: two cases in point are mathematical physics and number theory.

CIRGET, based at UQAM, is composed of regular and associate members and a large number of postdoctoral fellows and graduate students working in this broad field. The main themes to be pursued in the coming years include the topological classification of 3-dimensional manifolds; the quantization of Hitchin systems and the geometric Langlands program; the classification of special Kähler metrics; the study of symplectic invariants, especially in dimension 4; nonlinear partial differential equations in Riemannian geometry, convex geometry, and general relativity; and Hamiltonian dynamical systems. Two further domains are represented within CIRGET: algebraic geometry (through Steven Lu's and Peter Russell's work) and geometric group theory (through Daniel Wise's work).

The members of CIRGET organize several seminars in geometry and topology, symplectic topology, and geometric group theory, as well as the CIRGET Junior Seminar.

Highlights

Thanks to the CNRS–CRM UMI agreement, CIRGET hosted three professors from France during the year: Baptiste Chantraine (Nantes), Christophe Mourougane (Rennes), and Dan Popovici (Toulouse). Liam Watson (Glasgow) also spent the fall semester at the centre. It was therefore a year of lively scientific exchanges. Frédéric Rochon (UQAM), Raphaël Ponge (Seoul National University), George Elliott (University of Toronto), Thierry Giordano (University of Ottawa), Masoud Khalkhali (Western University), and Victor Nistor (Metz) organized a workshop on Noncommutative Geometry and Spectral Invariants at UQAM from June 29 to July 3, 2015, in honour of Georges Skandalis. The workshop brought together approximately 60 participants.

Octav Cornea (Montréal), Iosif Polterovich (Montréal), and Leonid Polterovich (Tel Aviv) organized the Lalondefest, a conference on topology, geometry and dynamical systems in honour of François Lalonde, CIRGET's founder. The conference attracted 90 participants, including many of his former graduate students and postdoctoral fellows. Finally, Adam Clay, Mark Powell, and Piotr Przytycki organized a session on Low-dimensional Topology and Geometric Group Theory at the Winter Meeting of the Canadian Mathematical Society held in Montreal.

Students and postdoctoral fellows

In 2015–2016 the members of CIRGET supervised or cosupervised one undergraduate student, 19 M.Sc. students, 35 Ph.D. students, and 17 postdoctoral fellows.

Director

Steven Boyer (UQAM)

Regular members

Abraham Broer, Octav Cornea, François Lalonde, Iosif Polterovich (Montréal)

Vestislav Apostolov, Olivier Collin, André Joyal, Steven Lu, Mark Powell, Frédéric Rochon (UQAM)

Pengfei Guan, Jacques Hurtubise, Niky Kamran, Mikaël Pichot, Piotr Przytycki, Peter Russell, Johannes Walcher, Daniel T. Wise (McGill)

Virginie Charette (Sherbrooke)

Associate members

Dmitry Jakobson, John A. Toth (McGill)

Syed Twareque Ali, John Harnad (Concordia)

Clément Hyvrier (Cégep de Saint-Laurent)

GIREF
Groupe Interdisciplinaire de Recherche en Éléments Finis

The recent advances in computer hardware and software allow researchers to model and simulate physical phenomena whose complexity is unheard of. These problems are characterized by nonlinear laws, non-differentiable friction laws, large-deformation geometries, complex solid-solid or fluid-solid interactions, problems in multiphysics, etc. Such problems can be found everywhere in industrial environments, especially in the design and fabrication of high-technology products. Hence the members of GIREF (an acronym that means "Interdisciplinary Research Group in Finite Element Methods") aim to develop original numerical methods for solving cutting-edge industrial problems in nonlinear mechanics. Their work concerns pure mathematics, computer science, software engineering, and engineering. The GIREF members propose general methods that can be used for diverse industrial applications.

GIREF organizes a regular seminar on the research areas of its members.

Highlights

The members of GIREF continue to be active in numerical modelling and simulation and to apply these techniques to all kinds of concrete problems. In May 2016 J. Urquiza, J. Deteix, and A. Fortin, in collaboration with A. Garon and M. Fernandez (INRIA), organized a workshop entitled *Applications and New Frontiers for the Finite Element Method*, within the thematic semester on computational mathematics. This workshop took place at the Université Laval and was attended by around thirty researchers. D. Pelletier and A. Garon, both professors at Polytechnique Montréal, obtained a significant grant entitled *NSERC-CREATE Training Program in Simulation-Based Engineering Science* (with the participation of A. Fortin and several other researchers). The goal of this grant is to improve the training of students in all the aspects of numerical modelling and simulation. Finally let us mention that Jean-Philippe Lessard was awarded the CAIMS/PIMS Early Career Award. This prize is given in recognition of the exceptional contributions of a researcher at the beginning of his career.

Students and postdoctoral fellows

In 2015–2016 the members of GIREF supervised or cosupervised one undergraduate student, 11 M.Sc. students, 14 Ph.D. students, and two postdoctoral fellows.

Director

André Fortin (Laval)

Deputy Director

André Garon (Polytechnique Montréal)

Regular members

Jean Deteix, Nicolas Doyon, Michel Fortin, Robert Guénette, Jean-Philippe Lessard, René Therrien, José Urquiza (Laval)

Associate members

Michel Delfour (Montréal)

Alain Cloutier, Marie-Laure Dano, Claire Deschênes, Guy Dumas, Khader Khadraoui, Hassan Manouzi, Mathieu Olivier, Jean-Loup Robert, Seyed Mohammad Taghavi (Laval)

Stéphane Étienne, François Guibault, Dominique Pelletier (Polytechnique Montréal)

Marie-Isabelle Farinas (UQAC)

Yves Secrétan (INRS-ETE)

Yves Bourgault (Ottawa)

Pietro-Luciano Buono (UOIT)

Mohamed Farhloul, Sophie Léger (Moncton)

Youssef Belhamadia (American University of Sharjah)

Jean-François Hétu (CNRC-IMI)

LaCIM
Laboratoire de combinatoire et d'informatique mathématique

LaCIM is a research centre gathering researchers in mathematics and mathematical computer science working in algebraic combinatorics, discrete mathematics, and the mathematical aspects of computer science. LaCIM was founded in 1989 and includes regular members, postdoctoral researchers, and associate researchers. The regular members of LaCIM supervise, on their own or with collaborators, Ph.D. and M.Sc. students and summer interns (who are undergraduate students). The research interests of LaCIM members have broadened considerably since 1989: it is considered as one of the main research groups worldwide in algebraic combinatorics, enumerative combinatorics, and word combinatorics. Some LaCIM researchers work in bioinformatics and analysis of algorithms. The laboratory welcomes many visitors and researchers who are leaders in the subjects studied at LaCIM. The laboratory also maintains numerous collaborations with most of the great centres in combinatorics, especially centres in France, the United States, and Canada. The combinatorics and mathematical computer science seminar takes place each Friday at LaCIM, from September to June.

Highlights

The members of LaCIM organized or co-organized seven conferences in 2015-2016: Words 2015 (Kiel, Germany, 2015); the session on algebraic combinatorics at the Winter Meeting of the Canadian Mathematical Society (Montreal, December 2015); a colloquium in honour of Marcel-Paul Schützenberger (Bordeaux, 2016); GASCom, a conference on random and exhaustive generation of combinatorial structures (La Marana, Corsica, 2016); DGCI 2016, a conference on discrete geometry for computer imagery (Nantes, 2016); Algebraic Combinatorics and Group Actions (Herstmonceux Castle, United Kingdom, 2016); and Developments in Language Theory 2016 (Montreal, 2016).

Students and postdoctoral fellows

In 2015–2016 the members of LaCIM supervised or cosupervised 28 M.Sc. students, 26 Ph.D. students, and 8 postdoctoral fellows.

Director
Srečko Brlek (UQAM)

Regular members
Sylvie Hamel (Montréal)

Anne Bergeron, François Bergeron, Alexandre Blondin Massé, Christophe Hohlweg, Gilbert Labelle, Vladimir Makarenkov, Christophe Reutenauer, Franco Saliola, Hugh Thomas (UQAM)

Ibrahim Assem, Thomas Brüstle, Shiping Liu (Sherbrooke)

Benoît Larose (Champlain Regional College)

Cédric Chauve, Marni Mishna (Simon Fraser)

Associate members
Timothy Walsh (UQAM)

Nantel Bergeron (York)

Applied Mathematics

The Applied Mathematics Laboratory is a research network of around 20 applied mathematicians, engineers, computer scientists, and chemists, based in Montreal. The laboratory exists primarily to stimulate research and collaboration in the applied mathematical research areas of its members by fostering discussion and the creation of ideas through conferences, workshops, and seminars, and the furtherance of research through its visitors' program and the appointment of talented postdoctoral fellows. The laboratory is also very concerned with the training of young researchers and supports travel and conference attendance of its postdoctoral fellows.

The research interests of the laboratory members are quite diverse although there are a number of common threads that make interchange and collaboration both possible and fruitful. Active areas of research represented within the laboratory include, for example, the application of dynamical systems theory to complex phenomena, high-dimensional chaos, and biology. There is also an interest in numerical linear algebra and its applications, including the design, analysis, and implementation of effective computer algorithms. Amongst the membership one will also find expertise in numerical simulation, applied dynamical systems, quantum chemistry, turbulence, combustion, biomechanics, numerical methods in fluid mechanics and electromagnetism, hp-finite element methods, molecular dynamics, control, optimization, preconditioners, and large-scale eigenvalue problems.

Highlights
In 2015–2016 the activities of the Applied Mathematics Laboratory were focused on the thematic semester on computational mathematics in emerging applications (see the section on the CRM thematic program). The director of the laboratory, Adam Oberman, was awarded a Simons Fellowship in Mathematics for the year 2016–2017. The laboratory continued to give a strong support to research assistants, postdoctoral fellows, and graduate students: we would like to mention Ruan Yanlong, Andy Wan, Xin Yang Lu, Gabriel Martine LaBoissonière, Hwi Lee, Tiago Salvador, Chris Finlay, Rebecca Carrington, and Tyler Cassidy.

Students and postdoctoral fellows
In 2015–2016 the members of the Applied Mathematics Laboratory supervised or cosupervised 17 M.Sc. students, 30 Ph.D. students, and 7 postdoctoral fellows.

Director
Adam Oberman (McGill)

Regular members
Jacques Bélair, Robert G. Owens (Montréal)

Peter Bartello, Peter Edwin Caines, Xiao-Wen Chang, Rustum Choksi, Antony R. Humphries, Jean-Christophe Nave, Bruce Shepherd, Gantumur Tsogtgerel, Adrian Vetta (McGill)

Eusebius J. Doedel (Concordia)

André D. Bandrauk (Sherbrooke)

Emmanuel Lorin (Carleton)

Associate members
Sherwin A. Maslowe, Jian-Jun Xu (McGill)

Jean-Philippe Lessard (Laval)

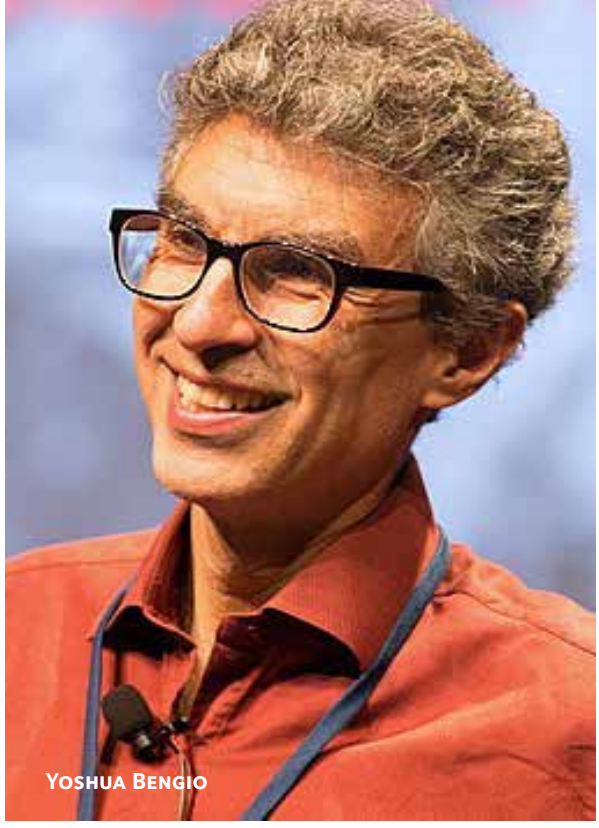
MILA
Montreal Institute for Learning Algorithms

MILA was founded by Professor Yoshua Bengio (Department of computer science and operations research, Université de Montréal). It includes around ten professors, almost 100 students, and around ten full-time employees (i.e., an Executive Director, a Team Lead in Software Infrastructure, six programmers, a financial agent, and an office coordination technician). The members of MILA have developed an impressive expertise in deep (discriminating or generative) networks and their applications in computer vision, speech modelling, and natural language processing. MILA has gained worldwide recognition for its numerous breakthroughs in the field of deep learning algorithms and their applications to many concrete problems (including, among others, the modelling of natural language, automatic translation, object recognition, generative models with structured output, and natural language recognition). The mission of MILA is to gather researchers in deep learning, to propose a platform for collaboration and student supervision, to pool human resources and computational clusters, and to facilitate technological transfer to companies wishing to benefit from machine learning algorithms.

The MILA seminars usually take place on Friday at the Université de Montréal. The seminars are given by MILA students or renowned researchers from other institutions or companies. The lecturers present their most recent discoveries. Each year MILA welcomes more than thirty invited lecturers.

Highlights

Many deep learning breakthroughs (popularized by the media) arose from work carried out by MILA, on its own or in collaboration with other researchers or centres: let us mention important contributions to unsupervised pre-training (level by level), supervised deep rectifier networks, generative neural networks, the theory of recursive networks, the automatic tuning of hyperparameters, automatic translation, and the theoretical analysis of neural networks. Since 2007 MILA has been organizing several events, such as the deep learning workshops within the ICLM and NIPS conferences. In 2016 three MILA members (I. Goodfellow, Y. Bengio, and A. Courville) published a modern textbook on deep learning. Recently MILA was at the heart of a historic award of 93 million dollars by the Canadian Government. This grant aims to make Montreal a world centre in data science. Finally a magazine popularizing science (La Recherche) included Yoshua Bengio's work in the list of the ten discoveries that changed science in 2015.



Yoshua Bengio

Students and postdoctoral fellows

In 2015–2016 the members of MILA supervised or cosupervised 24 interns, 22 M.Sc. students, 42 Ph.D. students, and 6 postdoctoral fellows.

Director

Yoshua Bengio (Montréal)

Regular members

Aaron Courville, Simon Lacoste-Julien, Roland Memisevic, Pascal Vincent (Montréal)

Christopher Pal (Polytechnique Montréal)

Laurent Charlin (HEC Montréal)

Doina Precup, Joëlle Pineau (McGill)

Mathematical Physics

The mathematical physics group is one of the oldest and most active at the CRM. It consists of around twenty regular members, around ten local associate members (all full-time faculty members at one of the participating universities), and close to ten external associate members working permanently at universities and research laboratories in Europe, the U.S., or Mexico. The group carries out research in many of the most active areas of mathematical physics: coherent nonlinear systems in fluids, optics, and plasmas; classical and quantum integrable systems; the spectral theory of random matrices; percolation phenomena; conformal field theory; quantum statistical mechanics; spectral and scattering theory of random Schrödinger operators; quasi-crystals; relativity; spectral transform methods; foundational questions in quantization; asymptotics of eigenstates; coherent states; wavelets; supersymmetry; the symmetry analysis of PDEs and difference equations; representation theory of Lie groups and quantum groups; and the mathematical structure of classical and quantum field theories.

The laboratory organizes a regular mathematical physics seminar, held in general at the CRM on Tuesday afternoon.

Highlights

The year 2015–2016, for the Mathematical Physics Laboratory, was naturally focused on the thematic program on the AdS/CFT correspondence, holography, and integrability, already discussed in a section of this report. This program attracted to the CRM more than 300 leaders in diverse areas of mathematical physics and constituted the first major joint program between the CRM and the Perimeter Institute for Theoretical Physics. Indeed two researchers from the Perimeter Institute (Pedro Vieira and Freddie Cachazo) organized workshops or were members of the scientific committee. Note also that many participants visited the Mathematical Physics Laboratory for short or medium periods.

Laboratory members continued to receive worldwide recognition for their work, to organize workshops or conferences, and to give invited lectures. We give here a few examples. Marco Bertola was an invited lecturer at the *Moduli, Integrability and Dynamics* workshop, at the Mittag-Leffler Institute (Sweden, May 30–June 3, 2016). John Harnad was an invited lecturer within the program on statistical mechanics, integrability, and combinatorics organized by the Galileo Galilei Institute (Arcetri, Florence); he visited this institute from May 3 to July 11, 2015. Robert Brandenberger was one of the organizers of the *Workshop on Double Field Theory* that took place at ETH Zürich on January 20–22, 2016. Robert Brandenberger was also elected Fellow of the Royal Society of Canada in 2015. He was awarded a Simons Fellowship in Theoretical Physics in 2015 and became a Senior Fellow at the ETH Institute for Theoretical Studies for the August 2015–July 2016 period.

Students and postdoctoral fellows

In 2015–2016 the members of the Mathematical Physics Laboratory supervised or cosupervised 8 undergraduate students, 17 M.Sc. students, 33 Ph.D. students, and 13 postdoctoral fellows.

Director

John Harnad (Concordia)

Regular members

Véronique Hussin, Manu B. Paranjape, Jiří Patera, Yvan Saint-Aubin, Luc Vinet, Pavel Winternitz (Montréal)

Robert Brandenberger, Keshav Dasgupta, Jacques Hurtubise, Alexander Maloney (McGill)

Syed Twareque Ali, Marco Bertola, Richard L. Hall, Dmitry Korotkin (Concordia)

Pierre Mathieu (Laval)

Vasilisa Shramchenko (Sherbrooke)

Alfred Michel Grundland (UQTR)

Johannes Walcher (Heidelberg)

Associate members

Alexander J. Hariton, François Lalonde, Igor Loutsenko (Montréal)

Dmitry Jakobson, Vojkan Jakšić, Niky Kamran, John A. Toth (McGill)

Chris J. Cummins, Alexander Shnirelman (Concordia)

Stéphane Durand (Cégep Édouard-Montpetit)

Robert Conte, Bertrand Eynard (CEA-Saclay)

Jean-Pierre Gazeau (Paris Diderot)

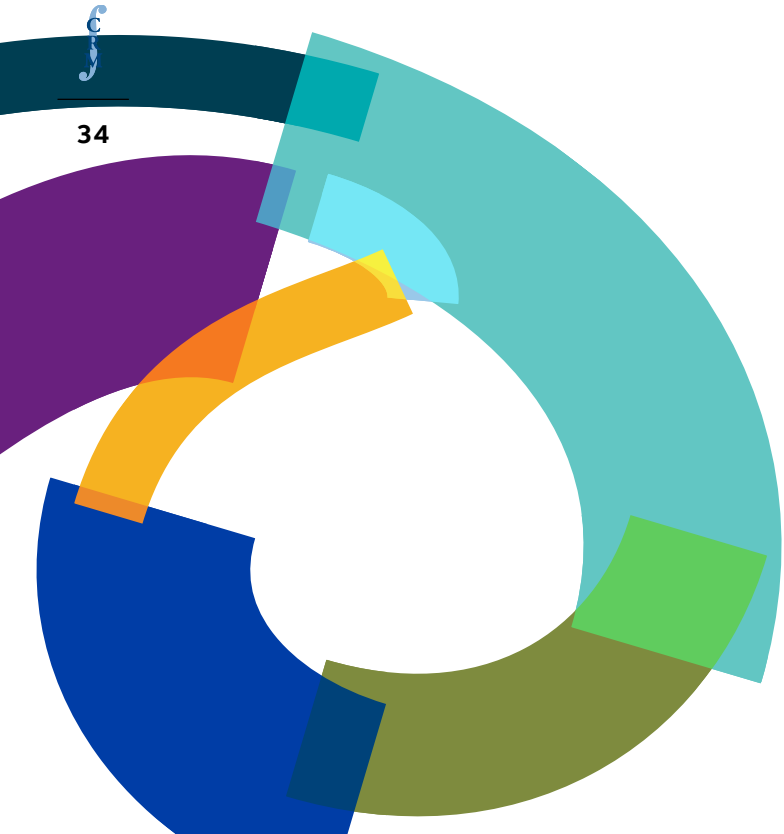
Alexander R. Its (IUPUI)

Decio Levi (Roma Tre)

Robert Seiringer (IST Austria)

Alexander Turbiner (UNAM, Mexico)

Peter Zograf (Steklov Institute, Saint Petersburg)



PhysNum

Applied mathematics now plays an important role in the biomedical field and especially the neurosciences. The research activity at PhysNum ("Numerical Physics") has two main themes: pharmacometrics and brain imaging. In particular Jean-Marc Lina and Habib Benali study the multimodal imaging of the spinal cord, Lina and Christophe Grova the multiresolution and multimodal imaging in magneto/electrophysiology, and Benali and Maxime Descoteaux models of the anatomical and functional connectivity of the brain. Grova also studies neurovascular models in epilepsy and Lina studies sparse representations, inverse problems, brain wave synchronization, and scale-invariant processes in electrophysiology.

Fahima Nekka and her team conduct research in pharmacometrics, a discipline whose goal is to interpret and describe pharmacological phenomena in a quantitative manner, so as to support rational therapeutic decisions and improvement of patient health. They have developed a whole framework of probabilistic pharmacometrics in which different sources of variability and the nonlinearity of the system are accounted for. The team is working on compliance metrics and ranking and on direct and inverse problems related to patient drug behaviour and the therapeutic effect of drugs. It is designing tools that shed new light on drug development and evaluation, revisiting classical concepts in pharmacology and developing models for drug interactions.

Highlights

Karim Jerbi and Frédéric Lesage were awarded Canada Research Chairs in 2015 and 2016, respectively. In 2014 Fahima Nekka had already obtained an NSERC Industrial Research Chair in Pharmacometrics. Christophe Grova is the director of The Multimodal Functional Imaging Laboratory at Concordia University; he is also a professor in the Department of physics of Concordia and an adjunct professor at McGill University. Jean-Marc Lina is affiliated with several research centres, particularly the Center for Advanced Research in Sleep Medicine (Hôpital du Sacré-Coeur de Montréal). In 2016 he published articles on the prediction of epileptic seizures and high-frequency oscillations in electroencephalography.

Students and postdoctoral fellows

In 2015–2016 the PhysNum members supervised or cosupervised 19 M.Sc. students, 30 Ph.D. students, and 8 postdoctoral fellows.

Director

Jean-Marc Lina (ÉTS)

Regular members

Karim Jerbi, Fahima Nekka (Montréal)

Frédéric Lesage (Polytechnique Montréal)

Habib Benali, Christophe Grova (Concordia)

Maxime Descoteaux (Sherbrooke)

Alain Arnéodo (Laboratoire de physique, ENS Lyon)

Montréal Probability Group

In 2014 the CRM ratified the creation of a new CRM laboratory in probability: the Montréal Probability Group. The research interests of the group span theoretical and applied, continuous and discrete probability. One important stream of research within the laboratory is the development and analysis of probabilistic models for physical, biological, statistical, and computational systems. The creation of this laboratory highlights the quality of probability research in the Montréal region and the recent influx of researchers in this area.

Highlights

In July 2015 Louigi Addario-Berry became Deputy Director, Scientific Programs of the CRM. He was awarded the Coxeter-James Prize of the Canadian Mathematical Society in April 2016, in recognition of his exceptional contributions to mathematical research. In June 2015 the laboratory co-organized the CRM–PIMS Summer School in Probability, which took place at McGill (see the section of the present report on the summer schools of the CRM). More than 80 students registered for the Summer School and took part in it: they were coming from Canada, the United States, Mexico, Europe, Japan, China, India, Australia, and South America. Members of the Probability Laboratory organized three sessions within the CMS Winter Meeting (December 2015): a session on measure-valued diffusions (with 6 speakers), a session on probability and statistical mechanics (with 14 speakers), and a session on stochastic partial differential equations (with 7 speakers). During the Winter Meeting the laboratory also organized a joint session with CAMBAM on "Bridging the Gap between Mathematical Approaches and Biological Problems" (with 17 speakers). Finally we mention that the Probability Laboratory and the Mathematical Physics Laboratory jointly welcomed a fellow, Janosch Ortmann, who was awarded the prestigious CRM–ISM postdoctoral fellowship in July 2015.

The laboratory members organize a regular probability seminar.

Students and postdoctoral fellows

In 2015–2016 the members of the Montréal Probability Group supervised or cosupervised 10 M.Sc. students, 20 Ph.D. students, and 4 postdoctoral fellows.

Director

Lea Popovic (Concordia)

Regular members

Alexander Fribergh, Sabin Lessard (Montréal)

Louigi Addario-Berry, Linan Chen, Luc Devroye, Bruce A. Reed (McGill)

Wei Sun, Xiaowen Zhou (Concordia)

Donald A. Dawson (Carleton)

Louis-Pierre Arguin (Baruch College, CUNY)

Associate members

Andrew Granville (Montréal)

Dmitry Jakobson, Vojkan Jakšić (McGill)

Marco Bertola (Concordia)

Quantact Actuarial and Financial Mathematics Laboratory

Quantact is the name of the CRM Laboratory of Actuarial and Financial Mathematics, i.e., the area of mathematics concerned with problems in insurance and finance. The Laboratory members develop and use probabilistic and statistical methods to analyze issues having a financial impact on society. Quantact gathers professors from UQAM, Concordia University, the Université Laval, and the Université de Montréal.

The research interests of Quantact members include FADR insurance, actuarial statistics, actuarial finance, and mathematical finance, as well as the mathematics of risk and ruin theory. Here are a few of the themes studied by Quantact members: pricing and provisioning in FADR insurance; solvency of financial institutions; financial innovation in insurance (pricing and covering of variable annuities and market-linked insurance products); the modelling of longevity risk and mortality and its impacts on life insurance and pension schemes; the quantification of the impact of natural disasters and other extreme events; dependency models; measures of risk; models for the frequency and severity of disasters; stochastic control of risk processes and stochastic optimization; and the statistical analysis of big data in insurance.

Highlights

During the second year of Quantact as a CRM laboratory (2015–2016), its members organized regular seminars in actuarial and financial mathematics (in the member universities), a seminar for graduate students (at the Université Laval), and a thematic day on ruin theory (at UQAM). The laboratory also helped organize a session on financial mathematics during the CMS Winter Meeting (December 2015). Quantact welcomed a new member (Anne Mackay, a professor at UQAM) on June 1, 2016.

Students and postdoctoral fellows

In 2015–2016 the members of Quantact supervised or cosupervised 4 undergraduate students, 30 M.Sc. students, 16 Ph.D. students, and 3 postdoctoral fellows.

Director

Jean-François Renaud (UQAM)

Regular members

Maciej Augustyniak, Manuel Morales (Montréal)

Jean-Philippe Boucher, Mathieu Boudreault, Arthur Charpentier, Mathieu Pigeon, Alexandre Roch (UQAM)

Patrice Gaillardetz, José Garrido, Cody Hyndman, Mélina Mailhot (Concordia)

Hélène Cossette, Étienne Marceau (Laval)

Chantal Labbé (HEC Montréal)

Statistics

Statistical methods and reasoning play an important role in the advancement of knowledge. Be it through surveys from sampling, the measure of socio-economic indicators, clinical trials to compare various biomedical treatments, or the study of the survival of an animal population in ecology, statistical methodology can be found everywhere in the sciences. Recently statistics has undergone a revolution in its techniques and approaches. This revolution has been driven by the need to analyze very large data sets and data with more complex structure, and by the advent of powerful computers. Statistical methodology is now addressing problems whose structure is very complex, such as the analysis of brain images or genome data, and new methodology (such as data mining) is being developed for large data sets. The computational aspect of statistics is thus becoming more and more important, but of course mathematics continues to be the foundation of statistics.

Statistics has many application areas and in particular the laboratory includes several researchers in biostatistics. One of the aims of the laboratory is to structure the Québec statistical community so that it can participate in the revolution mentioned above at a time when an important renewal of academic personnel is taking place. This structure allows the Québec community to participate in Canada-wide programs organized by the three Canadian mathematics institutes, as well as the newly created Canadian Statistical Sciences Institute (CANSSI). The laboratory is formed of

the leaders of the Québec school of statistics, who work on topics such as statistical learning and neural networks, survey sampling, analysis of functional data, statistical analysis of images, dependence structures, Bayesian analysis, analysis of time series and financial data, and resampling methods.

The members of the Statistics Laboratory organize four regular seminars: the Statistics Seminars at McGill, Laval, and Sherbrooke, respectively, and the Biostatistics Seminar at the Université de Montréal.

Highlights

Several laboratory members organized or coorganized major scientific meetings at the CRM, including: the meeting *Statistical Causal Inference and Applications to Genetics* in the summer of 2016 (Erica Moodie, David Stephens); the *CRM–CANSSI Workshop on Statistical Inference for Complex Surveys with Missing Observations* in October 2015 (David Haziza); and the workshop on *Rare DNA Variants, Analysis of Family Studies* in May 2016 (Aurélie Labbe). Many members of the laboratory were honoured or accepted important positions: these honours or positions are a testimony to their competence and the wide recognition of their contributions on the world scene. For example Christian Genest became a member of the Royal Society of Canada and editor-in-chief of the *Journal of Multivariate Analysis*; Christian Léger was appointed Chair of the Program Committee for the *Joint Statistical Meetings 2018*; David Haziza was elected Fellow of the American Statistical Association; and Louis-Paul Rivest was named a member of the National Statistics Council of Statistics Canada. Finally Yoshua Bengio published the book *Deep Learning* (MIT Press) and an article in the *Scientific American*; his work on artificial intelligence and statistical learning was cited or featured in many interviews (The Economist, Le Monde, Radio Télévision Suisse, National Public Radio, Radio-Canada, Bloomberg Technology News, Canadian Business, La Recherche, etc.).

Students and postdoctoral fellows

In 2015–2016 the members of the Statistics Laboratory supervised or cosupervised 115 M.Sc. students, 100 Ph.D. students, and 17 postdoctoral fellows.

Director

Éric Marchand (Sherbrooke)

Regular members

Jean-François Angers, Mylène Bédard, Yoshua Bengio, Martin Bilodeau, Pierre Duchesne, David Haziza, Pierre Lafaye de Micheaux, Christian Léger, Alejandro Murua, François Perron, Mireille Schnitzer (Montréal)

Juli Atherton, Sorana Froda, Simon Guillotte, Fabrice Larribe, Geneviève Lefebvre, Brenda MacGibbon, Karim Oualkacha (UQAM)

Masoud Asgharian, Abbas Khalili, Aurélie Labbe, Erica E. M. Moodie, Johanna Nešlehová, Robert W. Platt, James O. Ramsay, Russell Steele, David A. Stephens, David B. Wolfson (McGill)

Yogendra P. Chaubey, Arusharka Sen (Concordia)

Belkacem Abdous, Anne-Sophie Charest, Thierry Duchesne, Lajmi Lakhal Chaieb, Louis-Paul Rivest (Laval)

Taoufik Bouezmarni, Éric Marchand, Sévérien Nkurunziza (Sherbrooke)

Debbie J. Dupuis, Bruno Rémillard (HEC Montréal)

Associate members

Vahid Partovi Nia (Polytechnique Montréal)

Fateh Chebana (INRS-ETE)

Nadia Ghazzali (UQTR)

The CRM Prizes

The 2016 CRM–Fields–PIMS Prize Awarded to Daniel Wise

Each year the CRM awards four prizes (among the eight important national prizes in the mathematical sciences): the CRM–Fields–PIMS Prize (awarded jointly by the three Canadian mathematics institutes); the André Aisenstadt Prize, awarded by the CRM to a rising young Canadian star selected by the CRM International Scientific Advisory Committee; the Theoretical Physics Prize awarded jointly by the CRM and the Canadian Association of Physicists; and the CRM–SSC Prize, awarded jointly by the CRM and the Statistical Society of Canada to a researcher at the beginning of his or her career.

Dani Wise is widely recognized as one of the top geometric group theorists in the world. His fundamental research contributions lie at the core of what is widely considered to be the most important development in geometry and topology since Perelman's celebrated proof of the Poincaré Conjecture, namely the proof of Thurston's virtually fibered conjecture for hyperbolic three-manifolds. His work has also been central to the resolution of major open problems such as Waldhausen's virtual Haken conjecture and Baumslag's famous 1968 conjecture stating that every one-relator group with torsion is residually finite. Over the past 40 years, the works of Thurston and Waldhausen have been central to the development of 3-manifold topology and hyperbolic geometry. The work of Wise followed a totally different direction, which he developed with exceptional insight and virtuosity over more than 15 years, leading to the spectacular results mentioned above.

The profound impact and originality of Wise's work have been recognized through major awards, most notably the Veblen Prize of the American Mathematical Society, which he shared in 2013 with Ian Agol (Berkeley). He delivered an invited address at the 2014 International Congress of Mathematicians in Seoul and was elected a Fellow of the Royal Society of Canada, also in 2014. Dani Wise received his Ph.D. from Princeton in 1996. After having held postdoctoral positions at Berkeley and Cornell, he joined the mathematics department at McGill in 2001, where he is now James McGill Professor.

Daniel Wise

The CRM–Fields–PIMS Prize

This prize was established in 1994 as the CRM–Fields Prize to recognize exceptional research in the mathematical sciences. In 2005 PIMS became an equal partner in the awarding of the prize and its name was changed to the CRM–Fields–PIMS Prize. A committee appointed by the three institutes chooses the recipient. The previous recipients of the prize are H.S.M. (Donald) Coxeter (1995), George A. Elliott (1996), James Arthur (1997), Robert V. Moody (1998), Stephen A. Cook (1999), Israel Michael Sigal (2000), William T. Tutte (2001), John B. Friedlander (2002), John McKay (2003), Edwin Perkins (2003), Donald A. Dawson (2004), David Boyd (2005), Nicole Tomczak-Jaegermann (2006), Joel S. Feldman (2007), Allan Borodin (2008), Martin Barlow (2009), Gordon Slade (2010), Marc Lewis (2011), Stevo Todorcevic (2012), Bruce Reed (2013), Niky Kamran (2014), and Kai Behrend (2015).

The 2016 André Aisenstadt Prize Awarded to Anne Broadbent

Dr. Broadbent earned her Ph.D. from the Université de Montréal in 2008, under the joint supervision of Alain Tapp and Gilles Brassard. Her doctoral thesis (entitled *Quantum nonlocality, cryptography and complexity*) was distinguished by multiple prizes, including an NSERC Doctoral Prize by the Natural Sciences and Engineering Research Council of Canada. She went on to win the prestigious John Charles Polanyi Prize in Physics in 2010. Dr. Broadbent continued her research at the Institute for Quantum Computing (University of Waterloo), first as an NSERC Postdoctoral Fellow and then as a CIFAR (Canadian Institute for Advanced Research) Global Scholar from 2011 to 2013. In January 2014 Dr. Broadbent joined the Department of Mathematics and Statistics at the University of Ottawa, where she holds the University Research Chair in Quantum Information.

Dr. Broadbent is a leader in the field of quantum information and cryptography. In 2009 she and her co-authors introduced the concept of blind quantum computation – roughly, this means using quantum properties to permit third parties to perform extensive computations on data without jeopardizing the secrecy of the data. These highly-cited papers launched new important research directions in quantum information processing, including her current groundbreaking work on quantum homomorphic encryption. Other significant contributions she has made to this field include characterizing quantum one-time programs and presenting a novel automated technique for parallelizing quantum circuits.

Anne Broadbent

The André Aisenstadt Prize

Created in 1991, the André Aisenstadt Mathematics Prize is intended to recognize and reward research achievements in pure and applied mathematics by talented young Canadian mathematicians. This prize consists of a $3,000 award and a medal. The recipient is chosen by the International Scientific Advisory Committee of the CRM. At the time of consideration, candidates must be Canadian citizens or permanent residents of Canada and no more than seven years from their Ph.D. The mathematician who is awarded this prize is invited to give a lecture at the CRM and present a summary of his or her work for publication in the Bulletin du CRM. The previous recipients of the André Aisenstadt Prize are Niky Kamran (1992), Ian Putnam (1993), Michael Ward (1995), Nigel Higson (1995), Adrian S. Lewis (1996), Lisa Jeffrey (1997), Henri Darmon (1997), Boris Khesin (1998), John Toth (1999), Changfeng Gui (2000), Eckhard Meinrenken (2001), Jinyi Chen (2002), Alexander Brudnyi (2003), Vinayak Vatsal (2004), Ravi Vakil (2005), Iosif Polterovich (2006), Tai-Peng Tsai (2006), Alexander E. Holroyd (2007), Gregory G. Smith (2007), József Solymosi (2008), Jonathan Taylor (2008), Valentin Blomer (2009), Omer Angel (2010), Joel Kamnitzer (2011), Marco Gualtieri (2012), Young-Heon Kim (2012), Spyros Alexakis (2013), Sabin Cautis (2014), and Louis-Pierre Arguin (2015).

The 2016 ACP–CRM Prize Awarded to Freddy Cachazo

The 2016 CAP–CRM Prize in Theoretical and Mathematical Physics was awarded to Freddy Cachazo (Perimeter Institute), for introducing elegant new mathematical ideas and methods that have led to unexpected insights in the way scattering amplitudes are calculated in Supersymmetric Yang-Mills Theory. Inspired in part by twistor-string theory, the Cachazo–Svrcek–Witten (CSW) and Britto–Cachazo–Feng–Witten (BCFW) recursion relations revolutionized the field, making it possible to perform previously impossible calculations analytically in a few lines using explicit integral formulae. These results turned out to be in remarkable correspondence with structures explored concurrently by mathematicians for completely different purposes, establishing a suggestive link with the modern theory of integrable systems.

Dr. Freddy Cachazo is a theoretical physicist who has made outstanding contributions to the field of mathematical physics, many of which are widely characterized as breakthroughs. With collaborators, Cachazo has creatively drawn upon a variety of elegant mathematical ideas to develop entirely new methods for studying scattering processes in gauge theories and gravity. Cachazo's contributions to quantum field theory range from applications of geometric engineering (in string theory) to understanding mysterious dualities relating theories in different dimensions to novel techniques to compute scattering amplitudes in Quantum Chromodynamics (and its generalizations). The latter has brought relatively new mathematics into physics, such as the positive Grassmannian and its combinatorial structure, the positroid.

Freddy Cachazo

Beyond providing deep new insights into the structure of quantum field theory, these new methods have had a major impact on high-energy physics, as evidenced by the fact that the Britto–Cachazo–Feng–Witten (BCFW) technique has already been incorporated into the newest edition of the celebrated textbook, "Quantum Field Theory in a Nutshell," by Anthony Zee (2010), and into the new textbook, "Quantum Field Theory and the Standard Model," by Matthew D. Schwartz (2015). The physical and mathematical principles underlying Cachazo's research are profound. Cachazo's 60 papers since 2001 have attracted over 7,500 citations, attesting to the enormous influence of his new insights. Besides being of utility to huge accelerator experiments, Cachazo's works will have enduring and far-reaching impact in the search for a simpler, unified description of nature's physical laws and its connection to mathematics.

The ACP–CRM Prize

The Centre de recherches mathématiques (CRM) and the Canadian Association of Physicists (CAP) created in 1995, on the occasion of the 50th anniversary of the CAP, a joint prize in recognition of exceptional achievements in theoretical and mathematical physics. The prize consists of a $3,000 award and a medal. The previous recipients of the ACP–CRM Prize are Werner Israel (1995), William G. Unruh (1996), Ian Affleck (1997), J. Richard Bond (1998), David J. Rowe (1999), Gordon W. Semenoff (2000), André-Marie Tremblay (2001), Pavel Winternitz (2002), Matthew Choptuik (2003), Jiří Patera (2004), Robert Myers (2005), John Harnad (2006), Joel S. Feldman (2007), Richard Cleve (2008), Hong Guo (2009), Clifford Burgess (2010), Robert Brandenberger (2011), Luc Vinet (2013), Mark Van Raamsdonk (2014), and Charles Gale (2015).

The 2016 CRM–SSC Prize Awarded to Radu Craiu

Radu Craiu grew up in Bucharest, Romania, where he received his B.Sc. and M.Sc. degrees in mathematics. After a brief stay in Paris, where he developed both statistical knowledge and conversational French under the supervision of Christian Robert, Craiu enrolled in the Ph.D. program of the Statistics Department at the University of Chicago. Five years later, in 2001, he completed his doctoral dissertation, "Multivalent Framework for Approximate and Exact Sampling and Resampling," under the direction of Xiao-Li Meng: it included research about antithetic coupling schemes for Markov Chain Monte Carlo (MCMC) algorithms that was later published in the *Annals of Statistics*. Upon graduation Craiu accepted a position at the University of Toronto, where he has been a professor of statistics ever since. Craiu has published several dozen research papers, in such leading journals as *Annals of Statistics*, *Journal of the American Statistical Association*, *Annals of Applied Statistics*, *Journal of Computational and Graphical Statistics*, *Statistics and Computing*, *Biometrika*, and more. The breadth of Craiu's research is striking: he has published papers on statistical computation, MCMC methodology, copula applications, competing risk models, and statistical genetics (in collaboration with Lei Sun).

To take just one area of Craiu's research profile, consider his work on MCMC algorithms. After his doctoral dissertation work on antithetic coupling, Craiu developed regional adaptive algorithms to improve MCMC performance, provided new foundations for such "adaptive" MCMC algorithms, applied concepts from copula theory to improve the choice of MCMC proposal distributions, and developed new ways for "multiple-try" algorithms to improve their "learning" from their previously rejected proposal states. Most recently Craiu suggested a certain novel condition for validating adaptive MCMC algorithms, which after much effort led to a deep and lengthy and influential six-author mathematical paper developing both probabilistic analysis and computational methodology in that context. Craiu's publications on various other statistical topics have been similarly impressive.

The CRM–SSC Prize

The SSC, founded in 1977, is dedicated to the promotion of excellence in statistical research and practice. The prestigious CRM–SSC Prize is given each year to a Canadian statistician in recognition of outstanding contributions to the discipline during the recipient's first 15 years after earning a doctorate. The previous recipients of the CRM–SSC Prize are Christian Genest (1999), Robert J. Tibshirani (2000), Colleen D. Cutler (2001), Larry A. Wasserman (2002), Charmaine B. Dean (2003), Randy Sitter (2004), Jiahua Chen (2005), Jeffrey Rosenthal (2006), Richard Cook (2007), Paul Gustafson (2008), Hugh Chipman (2009), Grace Y. Yi (2010), Edward Susko (2011), Changbao Wu (2012), Derek Bingham (2013), Fang Yao (2014), and Matías Salibián-Barrera (2015).

Radu Craiu

EDUCATION

A substantial part of the CRM activities are carried out in collaboration with the Institut des sciences mathématiques (ISM), which was created in 1991 and has eight partners: Bishop's University, Concordia University, McGill University, Université de Montréal, UQAM, UQTR, Université de Sherbrooke, and Université Laval. The ISM is financed by its partners and the Québec Ministry of Education. The ISM mission consists of: coordinating and harmonizing the mathematics graduate programs of Québec universities; fostering excellence in training; supporting research through scholarships and prizes; and stimulating the interest of young people for the mathematical sciences, in particular through the dissemination of mathematical knowledge among teachers, young people, and the general public. In 2015–2016 the director of the ISM was Professor **Alina Stancu** (Concordia University).

The mandate of the CRM is to foster the development of research in the mathematical sciences at all levels. For the CRM the training of young researchers, the promotion of mathematical research, and the development of mathematics teaching are very important endeavours. This is why the CRM supports (financially and otherwise) many activities and programs in the area of mathematical education and training.

CRM–ISM Postdoctoral Fellowships

The CRM-ISM Postdoctoral Fellowships allow promising young researchers to devote most of their time to their research work. These postdoctoral fellows are chosen in a rigorous and very competitive manner: only one applicant out of 40 is selected. The postdoctoral fellows play a crucial role in our universities, by collaborating with mature researchers, bringing new ideas from other great centres of mathematical research, and organizing working groups on cutting-edge topics.

2015–2016 Postdoctoral Fellows

Here is the list of fellows, along with the institution and year of their Ph.D. We also give their research areas and the names of the mathematicians who supervised them at the CRM. Note that the first four fellows work in diverse fields not necessarily related to the 2015–2016 thematic program, while the last three are associated with this thematic program.

Yannick Bonthonneau
Ph.D.: Université Paris-Sud (2015)
Supervisors: Dmitry Jakobson (McGill), Pengfei Guan (McGill), Iosif Polterovich (Montréal), John Toth (McGill), and Frédéric Rochon (UQAM)
Research area: mathematical analysis, geometry and topology

Jeffrey Galkowski
Ph.D.: University of California, Berkeley (2015)
Supervisors: Dmitry Jakobson (McGill), Iosif Polterovich (Montréal), and John Toth (McGill)
Research area: mathematical analysis

Janosch Ortmann
Ph.D.: University of Warwick (2012)
Supervisors: Louigi Addario-Berry (McGill), Marco Bertola (Concordia), John Harnad (Concordia), and Lea Popovic (Concordia)
Research area: mathematical physics, probability

ALINA STANCU

Michelle Carey
Ph.D.: University of Limerick (2012)
Supervisors: Christian Genest (McGill) and James Ramsay (McGill)
Research area: statistics

Henry D. Maxwell
Ph.D.: Durham University (2015)
Supervisors: Robert Brandenberger (McGill), Keshav Dasgupta (McGill), and Alexander Maloney (McGill)
Research area: mathematical physics

Fedor Soloviev
Ph.D.: New York University (2010)
Supervisors: John Harnad (Concordia), Jacques Hurtubise (McGill), Dmitry Jakobson (McGill), and Dmitry Korotkin (Concordia)
Research area: mathematical physics

Xi Yang Lu
Ph.D.: Scuola Normale Superiore, Pisa (2013)
Supervisors: Rustum Choksi (McGill) and Adam Oberman (McGill)
Research area: applied mathematics

Undergraduate Summer Scholarships

In collaboration with the CRM and ISM professors, the ISM awards summer scholarships to promising undergraduates who want to do research during the summer and plan to study mathematics at the graduate level. These undergraduates are supervised by postdoctoral fellows, who in general are supervising students for the first time. The reader will find below the list of the undergraduate scholars for the summer of 2015.

Brahim Abdenbi (Concordia)
Scholarship co-financed by Alina Stancu
Supervisor: Boaz Slomka
Topic: *Convexity Theory in Models of the Hyperbolic Space*

David Ayotte (Laval)
Scholarship co-financed by Antonio Lei
Supervisor: Antonio Lei
Topic: *Les coefficients des polynômes caractéristiques des variétés abéliennes*

Étienne Bilocq (McGill)
Scholarship co-financed by Niky Kamran
Supervisor: Tarcisio Castro
Topic: *Differential Geometry*

Éric-Olivier Bossé (Montréal)
Scholarship co-financed by Luc Vinet
Supervisor: Vincent Genest
Topic: *Solution exacte d'un modèle quantique avec un cœur dur*

Jacob Courtemanche (Bishop's)
Supervisors: Trevor Jones and Brad Willms
Topic: *Parameter Fitting for Solutions to Autonomous Systems of ODEs*

Antoine Giard (Montréal)
Scholarship co-financed by Matilde Lalín
Supervisor: Detchat Samart
Topic: *Generalized Mahler Measure: Bounds and Other Properties*

Julie Kienzle (Montréal)
Scholarship co-financed by Paul Gauthier
Supervisor: Myrto Manolaki
Topic: *Approximation d'une fonction f, définie sur un produit de n ensembles, par polynômes de n variables*

Raphaël-James Lebel (Laval)
Scholarship co-financed by Alexandre Girouard
Supervisor: Alexandre Girouard
Topic: *Modélisation du réseau de neurones de la corne dorsale par les équations d'Izhikevich*

Joëlle Matte (Montréal)
Schoarship co-financed by Henri Darmon
Supervisor: Daniel Disegni
Topic: *La notion de représentation « typique » ou aléatoire d'un groupe fini G*

Mathieu Nassif (Montréal)
Scholarship co-financed by Dimitris Koukoulopoulos
Supervisor: Dimitris Koukoulopoulos
Topic: *Bounded gaps between primes and other sequences*

Yann Ricaud (Laval)
Scholarship co-financed by Jean-Philippe Lessard
Supervisor: Jean-Philippe Lessard
Topic: *Sur une conjecture concernant l'existence d'une solution périodique d'une équation différentielle analytique par morceaux*

Nathaniel Sagman (McGill)
Scholarship co-financed by Galia Dafni
Supervisor: Almaz Butaev
Topic: *Discrete Fourier Analysis*

Maxime Tremblay (Laval)
Scholarship co-financed by Luc Vinet
Supervisor: Vincent Genest
Topic: *Les coefficients de Clebsch–Gordan de la superalgèbre quantique ospq(1,2) et les polynômes orthogonaux basiques*

Scientific Activities Jointly Organized or Supported by the CRM and the ISM

The CRM and the ISM jointly organize or support several scientific activities. Apart from the Séminaire de mathématiques supérieures, the Colloque des sciences mathématiques du Québec, and other activities mentioned elsewhere in this report, the CRM supported the "XIX^{e} Colloque panquébécois des étudiants de l'ISM," held at UQAM on May 13–16, 2016. The CRM and the ISM gave some financial support to the "59^{e} Congrès de l'Association mathématique du Québec" (Cégep Limoilou, October 17–18, 2015). The CRM and the ISM jointly oversee the *Annales mathématiques du Québec*, a journal that has been the international showcase of the Québec mathematical community for three decades.

Promotion of the Mathematical Sciences by the CRM and the ISM

The Accromαth magazine, whose editor-in-chief is André Ross, is produced by the ISM and its production costs are defrayed in part by the CRM. The magazine has two issues per year and is distributed free of charge in all Québec high schools and cégeps. The goal of Accromαth is to stimulate the high school and cégep teachers by providing them with material that is topical and up-to-date. Accromαth consists of articles on the most recent developments in mathematics and its applications, as well as articles on the history of mathematics or links between mathematics and the arts. Accromαth has been awarded several prizes (both for its contents and graphic design). The CRM and the ISM jointly support the "Sciences et mathématiques en action" program (created by Professor Jean-Marie De Koninck) and the "Association québécoise des jeux mathématiques."

Graduate Students Supervision

The CRM members supervise a large number of graduate students. We now give information on the students supervised by CRM members who graduated in 2015–2016. The name of the student is followed by the name of his or her supervisor (or names of his or her supervisors). Some names may be missing from this list, because we have only included those that have been brought to our attention.

Students who obtained their Ph.D. in 2015–2016

Maxime Abran (Frédéric Lesage)
Mahnoush Amiri (Frédéric Lesage)
Dylan Robert Attwell-Duvall (Eyal Z. Goren)
Dunarel Badescu (Vladimir Makarenkov)
Mohamed Belalia (Taoufik Bouezmarni)
Samuel Bélanger (Frédéric Lesage)
Jonathan Belletête (Yvan Saint-Aubin)
Laurence Boulanger (Vestislav Apostolov, François Lalonde)
Laurence Brunet (Erica E. M. Moodie)
Amy Wai Ling Jane Cheung Wooding (Eyal Z. Goren)
Morgan Craig (Fahima Nekka, Michael C. Mackey)
Yann Dauphin (Yoshua Bengio)
Alexandre Desfossés Foucault (Anne Bourlioux)
Dimitri Dias (Andrew Granville)
Kael Nicholas Dixon (Vestislav Apostolov, Niky Kamran)
Valéry Dongmo Jiongo (Pierre Duchesne, David Haziza)
Deshayne Fell (Robert W. Platt)
Élise Fortin (Robert W. Platt)
Gabriel Girard (Maxime Descoteaux, Kevin Whittingstall, Rachid Deriche)
Ethan K. Gough (Erica E. M. Moodie)
Claude Gravel (Gilles Brassard, Luc Devroye)
Genaro Hernández Mada (Adrian Iovita, Bruno Chiarellotto)
Lam Opal Huang (Aurélie Labbe)
Jonathan Jalbert (Jean-François Angers, Anne-Catherine Favre, Claude Bélisle)
Tarik Jari (Javad Mashreghi, Abdellatif Bourhim)
Aymen Jendoubi (André Fortin)
Dhaker Kroumi (Sabin Lessard)
Martin Leclerc (Lajmi Lakhal Chaieb)
Siyuan Lu (Pengfei Guan)
Annaliza McGillivray (David A. Stephens, Abbas Khalili)
Grégoire Mesnil (Yoshua Bengio, Pascal Vincent)
Gerard Ngueta (Belkacem Abdous)
Solomon Owerre (Manu B. Paranjape)
Eric J. Pedersen (Frédéric Guichard)
Maria Esther Perez Trejo (Robert W. Platt)
Jason K. C. Polák (Henri Darmon, Jayce Robert Getz)
Guillaume Poliquin (Iosif Polterovich)
Huygens Christian Ravelomanana (Steven Patrick Boyer, Olivier Collin)
Juan Ignacio Restrepo Lozano (Henri Darmon)
Guillaume Roy-Fortin (Iosif Polterovich)
Adam Schneider (Maurice Chacron, Kathleen Cullen)
Joseph François Tagne Tatsinkou (Pierre Duchesne, Pierre Lafaye de Micheaux)
Alexandra Tcheng (Jean-Christophe Nave)
Dave Touchette (Gilles Brassard, Alain Tapp)
Fodé Tounkara (Louis-Paul Rivest)
Rolina van Gaalen (David L. Buckeridge)
Raphaël Verge-Rebelo (Pavel Winternitz)

Accron

Évelyne Vinet (Robert W. Platt, Sasha Bernatsky)
Jinming Wen (Xiao-Wen Chang)
Yuting Wen (Louigi Addario-Berry)
Xiaohu Xie (Xiao-Wen Chang)
Li Yao (Yoshua Bengio)
Siamak Yousefi (Xiao-Wen Chang, Benoit Champagne)

Students who obtained their M.Sc. in 2015–2016

Manal Al-Zahrani (Chantal David)
Madeleine Anthonisen (Robert Brandenberger)
Lenin Arango Castillo (Sorana Froda)
Asma Bahamyirou (Éric Marchand)
Yariv Barsheshat (Vojkan Jakšić, Robert Seiringer)
Cédric Beaulac (Fabrice Larribe)
Marie-Ailan Beaulieu (Line Baribeau, Alexandre Girouard)
Corinne Belley (Dominique Pelletier)
Paule-Marjolaine Bodson-Clermont (Jean-François Angers)
Shant Boodaghians (Adrian Vetta)
Alexia Bouchard Saindon (Alain Vinet)
Laura Broley (Yvan Saint-Aubin)
Philippe Charron (Iosif Polterovich)
Antony Della Vecchia (Daniel T. Wise)
Myriam Demers (Dana Schlomiuk)
Alexandre Deschênes (Jean-François Angers)
Francis Desjardins (Jean-Philippe Lessard)
Daniele Dona (Adrian Iovita)
Guillaume Douville (Vasilisa Shramchenko, Ibrahim Assem)
Roland Jacks Ekila (Pierre Blanchet)
Marc-Antoine Fiset (Johannes Walcher)
Jean-François Forest-Desaulniers (Jean-Philippe Boucher, Mathieu Boudreault)
Steven Fortier (Taoufik Bouezmarni)
Mariem Fourati (Taoufik Bouezmarni)
Jean-François Gagnon (Christiane Rousseau)
Maxime Gélinas (Luc Bélair)
Julie Gendron (Virginie Charette)
Aram Gevorgyan (Thomas J. Ransford)
Pablo Gonzalez Ginestet (Robert W. Platt)
Isabelle Grenier (David A. Stephens, Abbas Khalili)
Vincent Grenier Gauthier (André Fortin, José Manuel Urquiza)
Hengameh Habibirad (David Haziza)
Ziad Hamze (Alain Vinet)
Eric Patrick Hanson (Vojkan Jakšić, Johannes Walcher)
Marion Henry (Ibrahim Assem)
Gabriel Herta (John A. Toth)
Wenjun Jiang (José Garrido)
Muhammad Khan (Adrian Vetta, Bruce Shepherd)
Marjorie Koffibié Gohou (Thierry Duchesne)
Elizabeth Krakow (Erica E. M. Moodie)
David Krueger (Yoshua Bengio, Roland Memisevic)
Cassandra Lafond (Pierre Blanchet)

Nadia Lafrenière (Srečko Brlek, Franco Valentino Saliola)
Annie Lapointe (Frédéric Lesage)
Marc-Élie Lapointe (Jean-François Angers)
Mathieu Lavoie (Javad Mashreghi, Jérémie Rostand)
Vincent Lavoie (Alain Cloutier)
Nicholas Leavitt (Louigi Addario-Berry)
Hwi Lee (Rustum Choksi)
Alexandre Leroux (Jean-François Angers)
Anick Lévesque-Gravel (Thomas J. Ransford)
Shang Wan Liu (Anmar Khadra)
Diouldé Mariko (Raluca M. Balan, Rafal Kulik)
Gabriel Martine LaBoissonière (Rustum Choksi)
Borislav Mavrin (Dmitry Korotkin)
Kevin McGregor (Aurélie Labbe)
Hamid Mesbah (Hugo Chapdelaine)
Vincent Méthot (Maxime Descoteaux)
Robin Milosz (Sylvie Hamel)
Tina Maria Mitre (Michael C. Mackey, Anmar Khadra)
Teerawat Monnor (Maurice Chacron)
Mondji Herbert Monwanou (Lajmi Lakhal Chaieb)
Spencer Moran (Anmar Khadra)
Vincent Morissette-Thomas (Taoufik Bouezmarni)
Maxime Murray (Jean-Philippe Lessard)
Yuliya Novytska (Dmitry Jakobson)
Jane Panangaden (Vojkan Jakšić)
Laurence Paquette (Frédéric Guichard)
Jeanseong Park (Raluca M. Balan, Ioana Schiopu-Kratina)
Siddhi Pathak (M. Ram Murty)
Matthew Pencer (Masoud Asgharian, Abbas Khalili)
Stéphanie Perron (Virginie Charette)
Mohammad Pezeshki (Yoshua Bengio, Aaron Courville)
Jean Milou Pierre (Khader Khadraoui)
Jerome Quintin (Robert Brandenberger)
Alice Remal (Christophe Hohlweg)
Simon Rioux (Thierry Duchesne)
José Manuel Rodríguez Caballero (Andrew Granville)
José Manuel Rodríguez Sotelo (Yoshua Bengio, Roland Memisevic)
Marjan Rashtchi (François Bergeron)
Kevin Rosamont (Jean-François Angers, Pierre Duchesne)
Arnaud Roussel (Jean-François Angers)
Maryam Sadat Tabatabaei Shafiei (Frédéric Lesage)
Wiam Serhan (Franco Valentino Saliola)
Samira Shirgir (Cody Hyndman)
Marie-Hélène Simard (Thierry Duchesne)
Samuel St-Jean (Maxime Descoteaux)
Étienne St-Onge (Maxime Descoteaux)
Yue Ru Sun (Sergey Norin)
Mylène Teasdale (Jean-François Angers)
Abdoulaye Thiam (Jean-Philippe Lessard)
Jérôme Tremblay (Srečko Brlek)
Pierre-Alexandre Veilleux (Étienne Marceau)
Galen Voysey (Eyal Z. Goren)
Nijun Wei (Pawel Góra, Abraham Boyarsky)
Xiao Dan Weng (David B. Wolfson)

Canadian Partnerships

On the Canadian scene the most important partnership of the CRM is the one with the two other Canadian mathematics institutes, i.e., the Fields Institute for Research in Mathematical Sciences (FI), based in Toronto, and the Pacific Institute for the Mathematical Sciences (PIMS) in the West. The three institutes coordinate their scientific activities (particularly their thematic programs) and have carried out several projects together, including the creation of networks such as Mitacs (see below) and the creation of the CRM-Fields-PIMS Prize. The three institutes also support some activities of the professional associations in the mathematical sciences and give some financial support to the Atlantic Association for Research in the Mathematical Sciences (AARMS), founded in 1996 to encourage and promote research in the mathematical sciences in the Atlantic provinces. The three institutes also support the Canadian Statistical Sciences Institute (CANSSI), whose aim is to develop statistical sciences in Canada through attracting new researchers to the field, increasing the points of contact among researchers nationally and internationally, and fostering collaborations with other disciplines and organizations. Finally the CRM is a partner of the Banff International Research Station (BIRS), which organizes workshops in mathematics all year round.

Although the CRM is primarily concerned with mathematical research and training taking place within Québec, its activities are part of a broad framework and it collaborates with many partners to fulfill its mission and ensure that the research carried out in Québec is of international calibre.

International Partnerships

The CRM members have many fruitful collaborations with French researchers, in particular those working at the Centre national de la recherche scientifique (CNRS), the Institut national de recherche en informatique et automatique (INRIA), and the Institut national de la santé et de la recherche médicale (INSERM). In March 2015 the CRM signed agreements with two prestigious French institutes: IHÉS (Institut des Hautes Études Scientifiques) and IHP (Institut Henri Poincaré). The CRM has signed a formal agreement with the ALGANT consortium (Algebra, Geometry, Number Theory) within the Erasmus Mundus network of the European Union. This agreement stimulates exchanges and joint supervision of graduate students. In 2010 the CRM and eleven other partners signed an agreement for the exchange of researchers with SISSA (International School for Advanced Studies, in English), a graduate studies university based in Trieste, Italy. The CRM also has two formal agreements with the Tata Institute of Fundamental Research (TIFR), a prestigious Indian institution: an agreement with the TIFR Centre for Applicable Mathematics (in Bangalore) and another with the TIFR centre in Mumbai. Finally we mention that the National Science Foundation (NSF) of the United States provides some financial support for almost every thematic program organized by the CRM.

The Unité Mixte Internationale (UMI) of the CNRS at the CRM


Emmanuel Giroux

A few years ago the Centre National de la Recherche Scientifique (CNRS) in France decided to create at the CRM a so-called UMI (i.e., a research unit outside of France). The official name of this UMI is "Centre de recherches mathématiques – UMI 3457" and it was inaugurated in October 2011. This UMI is extremely successful, thanks to the outstanding work of its first director, Laurent Habsieger, and its current director, Professor Emmanuel Giroux (CNRS Research Director). The UMI gives financial support to French researchers so that they can visit the CRM for long or short periods of time. It also supports visits to France by Québec researchers who spend a few weeks in France or are given temporary positions. The UMI also provides financial support for the organization of meetings and workshops, either directly or through the reimbursement of lecturers' expenses (for instance). In this manner the UMI supports the activities of the CRM thematic program and other activities.

When the President of France visited Québec in November 2014, the CNRS and the FRQNT signed an agreement providing for the financial support (by Québec) of Québec researchers visiting French laboratories (called "sites miroirs") for periods of two to six months. The Québec researchers in question must be affiliated with one of the three UMIs located in Québec universities. In particular this agreement allows members of the CRM to visit France in order to work with their French colleagues.

Academic Partners

The CRM has six academic partners: the Université de Montréal, McGill University, UQAM, Concordia University, the Université Laval, and the Université de Sherbrooke. The Department of Mathematics and Statistics of the University of Ottawa became a partner of the CRM in 2003. The CRM finances teaching releases so that University of Ottawa researchers can work in the CRM laboratories and take part in its scientific activities. The CRM also supports postdoctoral fellows at the University of Ottawa and finances the CRM–University of Ottawa Distinguished Lecture Series, which features talks by prominent mathematicians from Canada and abroad on topics at the forefront of mathematical research.

Collaborations with Research Networks

The CRM has created, on its own or with other institutes, research networks that promote collaborations in the mathematical sciences between universities and industry. In 1997 the CRM (whose director was Luc Vinet) created the Network for Computing and Mathematical Modeling (ncm2), a consortium of research centres in the Montréal area. The ncm2, which was funded by NSERC, was able to respond to the needs of industry in a wide variety of fields related to computing and mathematical modelling. At the present time it allows four research centres (the CRM, GERAD, CIRRELT, and CIRANO) to fund joint projects in the mathematical sciences.

The three Canadian mathematics institutes (the CRM, the Fields Institute, and PIMS) launched the Mitacs network in 1999, thanks to a grant from the Canadian government. The objective of Mitacs, the only network of centres of excellence in the mathematical sciences, was to channel Canadian efforts in designing, applying, and commercializing new mathematical tools and methodologies within the framework of a world-class research program. Mitacs was extremely successful: in particular it has involved up to 300 researchers and 600 students in around 50 Canadian universities. In 2011 Mitacs broadened the scope of its activities and the "mathematics" section of Mitacs was taken over by the Mprime network (from 2011 to 2014). Since Mprime does not exist anymore, the creation and fostering of CRM/industry partnerships is now taking place within the framework of the Institutes Innovation Platform (IIP), a project of the three Canadian mathematics institutes funded by NSERC and mentioned elsewhere in this report.

Some CRM researchers take part in the activities of other networks, for instance Thierry Duchesne (who takes part in the Avahan-India AIDS Initiative), Gilles Brassard and Yoshua Bengio (who both take part in programs of the Canadian Institute for Advanced Research), and four PhysNum researchers (Maxime Descoteaux, Christophe Grova, Frédéric Lesage, and Jean-Marc Lina), who are members of the Québec Bio-imaging Network.

Collaborations with Professional Societies

The CRM and the other Canadian mathematics institutes give some financial support for the organization of the meetings of Canadian societies in the mathematical sciences. In particular, in 2015–2016, the CRM supported the 2015 Summer Meeting of the Canadian Mathematical Society (Charlottetown, June 5–8, 2015), the 2015 Winter Meeting of the CMS (Montreal, December 4–7, 2015), the 2015 Annual Meeting of the Statistical Society of Canada (Halifax, June 14–17, 2015), and the Joint Congress of the AMMCS and the Canadian Applied and Industrial Mathematics Society (Waterloo, Ontario, June 7–12, 2015).

Publications are an important component of the contribution of the CRM to the dissemination of research in the mathematical sciences. The CRM has two long-standing series published in collaboration with the American Mathematical Society (AMS): the *CRM Monograph Series* and the *CRM Proceedings* (formerly *CRM Proceedings and Lecture Notes*), included in *Contemporary Mathematics* since 2013. Springer publishes and distributes the *CRM Series in Mathematical Physics*, and a few titles from the CRM were included in its *Lecture Notes in Statistics* series. The first volumes of a new series (entitled *CRM Short Courses*) will appear in 2017. Although most of the books issued by the CRM are now to be found in these various series, the CRM also publishes and distributes, in French and in English, through *Les Publications du CRM*, monographs, proceedings, and lecture notes. In addition the CRM occasionally takes part in joint projects with various publishers and distributes preprints of articles written by its researchers.

The CRM publishes *Le Bulletin du CRM* twice a year. This newsletter, consisting of between 20 and 30 pages, includes news from the CRM and articles on its activities and the research of its members and prize winners.

2015–2016 Publications

CRM Monograph Series (AMS)

Philippe Poulin, *Leçons d'analyse classique : Exposition d'un cours fait par Paul Koosis à l'Université McGill*, Montréal, CRMM/36, 2015

CRM Proceedings (AMS)
subseries of Contemporary Mathematics

Javad Mashreghi, Emmanuel Fricain and William Ross (eds.), *Invariant Subspaces of the Shift Operator*, CONM/638, 2015

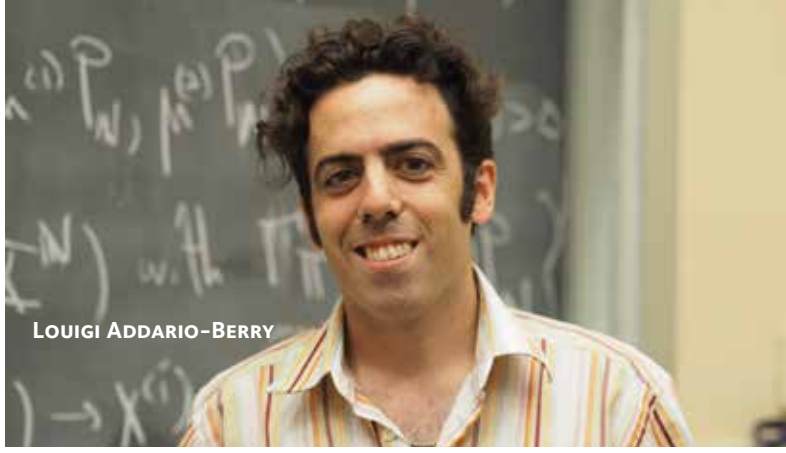
Alina C. Cojocaru, Chantal David and Francesco Pappalardi (eds), *SCHOLAR – a Scientific Celebration Highlighting Open Lines of Arithmetic Research*, CONM/655, 2016

Sergei Gukov, Mikhail Khovanov and Johannes Walcher (eds.), *Physics and Mathematics of Link Homology*, CONM/680, 2016

CRM Series in Mathematical Physics (Springer)

André D. Bandrauk, Emmanuel Lorin and Jerome V. Moloney (eds.), *Laser Filamentation – Mathematical Methods and Models*, 2016

GOVERNANCE & SCIENTIFIC GUIDANCE


Louigi Addario-Berry

The CRM structure consists of a Board of Directors, an Assembly of Members, an International Scientific Advisory Committee, a Local Scientific Committee, a Management Committee, and a Committee of Directors of Laboratories. Here are the members of these committees in 2015–2016 (except for the directors of laboratories, already mentioned in a previous section).

Board of Directors

The Board of Directors is composed of:

- The Director (ex officio);
- A member of the Management Committee nominated by the Board for a two-year mandate;
- Two regular CRM members nominated by the Assembly (each for a three-year mandate, normally renewable once);
- A Laboratory Director, nominated by the Committee of Directors of Laboratories for a two-year mandate, normally renewable once;
- The Chair of the International Scientific Advisory Committee;
- The Vice-Principal, Research, of each of the main partner universities of the CRM; and
- Additional members nominated by the Board of Directors, with or without voting rights, and coming from any relevant sector (business, industry, major Canadian or foreign research institutes, public sector).

In 2015–2016 the Board of Directors included Luc Vinet (Director of the CRM), Odile Marcotte (CRM Deputy Director, Partnerships), Christiane Rousseau and Jacques Bélair (both from the Université de Montréal), Steven Boyer (Director of CIRGET), Gérard Ben Arous (Chair of the International Scientific Advisory Committee), Marie-Josée Hébert (Vice-principal, Research, Université de Montréal), Graham Carr (Vice-principal, Research, Concordia University), Rosie Goldstein (Vice-principal, Research, McGill University), Catherine Mounier (Vice-principal, Research, UQAM), Edwin Bourget (Vice-principal, Research, Université Laval), Jacques Beauvais (Vice-principal, Research, Université de Sherbrooke), and Alina Stancu (Director of the ISM).

Louigi Addario-Berry (McGill) and Galia Dafni (Concordia), CRM Deputy Directors, were invited members of the Board of Directors.

International Scientific Advisory Committee

The International Scientific Advisory Committee (ISAC) consists of outstanding Canadian or foreign researchers who are either mathematicians or scientists with close links to the mathematical sciences. The main task of the Committee is to make recommendations on the general scientific orientations of the CRM and give advice on proposed scientific activities. In 2015–2016 this committee was chaired by Gérard Ben Arous (Courant Institute) and also included Lia Bronsard (McMaster), Ruth Charney (Brandeis), Stephen E. Fienberg (Carnegie Mellon), Edward Frenkel (Berkeley), Emmanuel Giroux (CNRS), Claude Le Bris (École des Ponts ParisTech), Dusa McDuff (Columbia), Robert Pego (Carnegie Mellon), Duong Phong (Columbia), Dana Randall (Georgia Institute of Technology), Nicolai Reshetikhin (Berkeley), Emmanuel Ullmo (Institut des Hautes Études Scientifiques), and Luc Vinet (Director of the CRM).

Marie-Josée Hébert (Vice-Principal, Research, Université de Montréal) was an ex officio member of ISAC. Louigi Addario-Berry, Galia Dafni, and Odile Marcotte (Deputy Directors of the CRM) were invited members of ISAC.

Local Scientific Committee

In 2015–2016 the Local Scientific Committee included Louigi Addario-Berry (McGill), Vestislav Apostolov (UQAM), Octav Cornea (Montréal), Jean-Philippe Lessard (Laval), Erica E. M. Moodie (McGill), Lea Popovic (Concordia), and Luc Vinet (Director of the CRM).

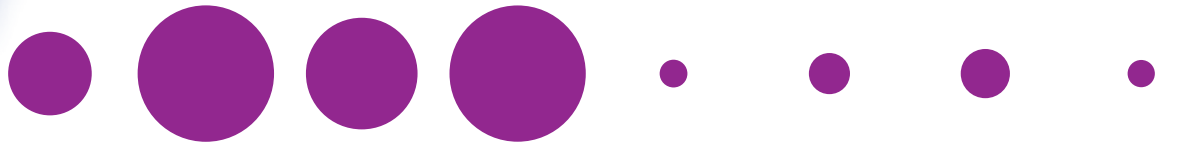
Management Committee

The Management Committee of the CRM consisted of Luc Vinet (Montréal), Director of the CRM, Louigi Addario-Berry (McGill), Deputy Director, Scientific Programming, Galia Dafni (Concordia), Deputy Director, Publications, and Odile Marcotte (UQAM and GERAD), Deputy Director, Partnerships.

THE CRM IN NUMBERS

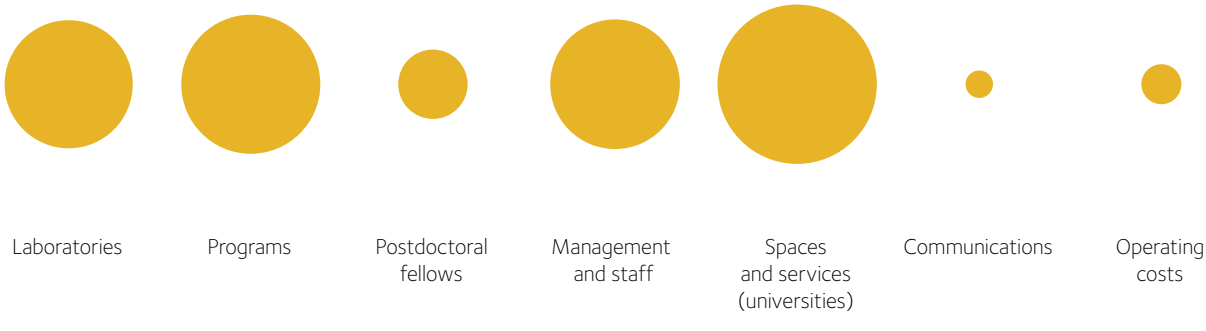
Sources of funding in 2015–2016
IN THOUSANDS OF $

FRQNT	**508**
NSERC	**1 353**
Universities (funding)	**906**
Universities (in-kind)	**1 350**
Endowments	**56**
Sales and registration fees	**123**
Other grants	**176**
Partner organizations	**54**
	4 525

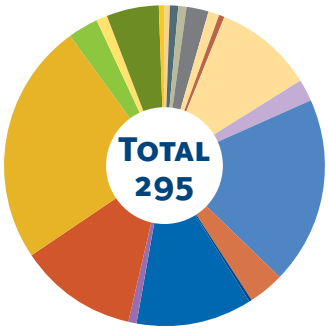


Use of funds
IN THOUSANDS OF $

Laboratoiries	**873**
Programs	**1 028**
Postdoctoral fellows	**256**
Management and staff	**893**
Spaces and services (universities)	**1 350**
Communications	**40**
Operating costs	**85**
	4 525

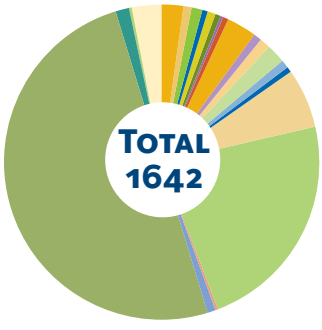


Affiliation of the regular and associate members (researchers) of the CRM and its laboratories



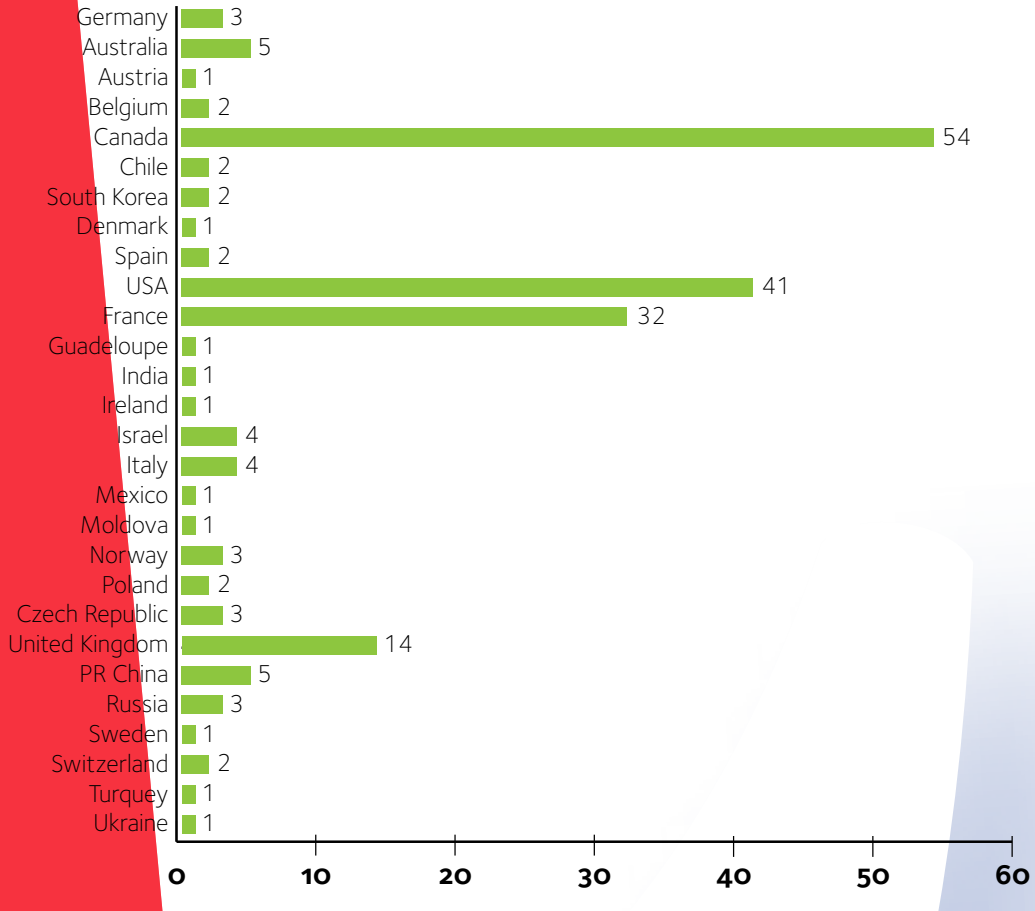
École de technologie supérieure	1
HEC Montréal	3
INRS (Québec)	2
Polytechnique Montréal	7
Québec, Cégeps	3
Carleton University	2
Concordia University	29
University of Ottawa	7
Université de Montréal	55
Université de Sherbrooke	11
Université du Québec à Chicoutimi	1
Université du Québec à Montréal	34
Université du Québec à Trois-Rivières	3
Université Laval	35
McGill University	72
Other, Canada	9
Other, USA	3
Other, Europe	16
Other, Industry	2

Country of origin of participants in CRM activities



Germany	46
Australia	8
Belgium	20
Canada	821
South Korea	13
Spain	6
USA	373
France	102
India	8
Israel	14
Italy	33
Japan	16
The Netherlands	16
United Kingdom	49
PR China	8
Russia	6
Sweden	8
Swizerland	14
Other, Africa	10
Other, Americas	17
Other, Asia	13
Other, Europe	41

Country of origin of visiting and postdoctoral researchers (193)



CRM Administrative and Support Staff

The Director's Office

Luc Vinet	Université de Montréal Director
Louigi Addario-Berry	McGill University Deputy Director – Scientific Programming
Galia Dafni	Concordia Deputy Director – Publications
Odile Marcotte	UQAM and GERAD Deputy Director – Parnerships

Administration

Vincent Masciotra	Head of Administration
Lucie Vincent	Secretary
Guillermo Martinez-Zalce	Research Laboratories Administrative Coordinator
Diane Brulé-De Filippis	Administrative Assistant
Wendy Barrientos	Administrative Assistant

Scientific Activities

Louis Pelletier	Coordinator
Louise Letendre	Administrative Assistant
Sakina Benhima	Project Manager

Computer Services

Daniel Ouimet	Systems Administrator
André Montpetit	Office Systems Manager (half-time)

Publications

André Montpetit	TeX expert (half-time)

Communications

Suzette Paradis	Communications Officer and Webmaster

Special Projects

Stéphane Rouillon	Partnerships Development Officer

CENTRE
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