

## Atlantic Association for Research in the Mathematical Sciences (AARMS)

*Submission to the Long Range Planning Committee, April 2012*

### Summary

Since its creation in 1996 AARMS has grown steadily into an organization which today could be referred to as Atlantic Canada's mathematical sciences institute. With an organizational structure that includes a Board of Directors, a Scientific Review Panel, an Executive Committee and specialist subcommittees, AARMS is able to provide a number of programs that contribute to mathematical sciences research regionally and nationally, and facilitate collaboration on an international scale.

AARMS programs support:

- Scientific workshops and conferences both regionally and nationally.
- Postdoctoral fellowships which attract excellent young researchers to Atlantic Canada, and assists in recruiting and retaining junior faculty.
- Collaborative research groups program designed to develop and sustain national and international collaborations.
- An annual 4-week international graduate summer school which provides advanced courses in pure and applied mathematics.
- Outreach activities for disseminating mathematical knowledge in schools and the community.

A long range plan for funding mathematical sciences research in Canada ought to ensure an equitable distribution of funding to the Atlantic region. At present the national funding AARMS' receives through CRM, Fields and PIMS represent 1% of their combined operating budgets (or 3% of their combined MRS grants). In comparison, the Atlantic region constitutes 7% of Canada's population, and has areas of international strength in the mathematical sciences which deserve proportionate national funding.

This document contains an exposition of AARMS' strengths, and makes the case for substantial future growth provided sufficient national funding is forthcoming.

## Atlantic Association for Research in the Mathematical Sciences (AARMS)

AARMS is a research institute that was founded in 1996 by mathematicians at Dalhousie University (Dal), Memorial University of Newfoundland (MUN) and the University of New Brunswick (UNB). Since its inception AARMS has provided a voice, structure and resources for the mathematical sciences community in the Atlantic region. This has strengthened research and graduate studies, helped universities be more competitive in recruiting and retaining faculty, and raised the profile of the mathematical sciences in the region.

In its first stage (1996-1999) AARMS was modestly supported by participating universities and by occasional conference grants from one or more of Fields, CRM or PIMS. In 2002, during the Directorship of Herman Brunner (2000-2005), AARMS secured its first continuing annual funding. This consisted of \$30,000 each from Dal, MUN and UNB, and \$30,000 each from the three institutes (CRM, FIELDS and PIMS), an arrangement that has continued to the present. Pursuant to the agreement among the three universities and the three Institutes, a Board of Directors was established and a Scientific Review Panel appointed. A set of policy and procedures documents was developed by the Board. The subsequent Directors, Jonathan Borwein (2006-2007) and Viqar Husain (2008-2011) were appointed through formal search processes.

Since 2007 all of the smaller universities in the region with degree programs in the mathematical sciences became affiliated with AARMS, while Dal, MUN and UNB remain the principal sponsoring universities.

In 2009 AARMS successfully applied for support of its activities from the provincial governments of New Brunswick and Nova Scotia for a period of five years, at \$50,000 each per year. This permitted AARMS to significantly expand the number and range of its activities: In 2010 a Collaborative Research Group program was initiated, and the number of postdoctoral fellowships were doubled to steady of state of 7-8.

**Table 1: Affiliated Universities**

<i>Dalhousie</i>	<i>UNB</i>
<i>MUN</i>	<i>Acadia</i>
<i>Cape Breton</i>	<i>Mt. Allison (MtA)</i>
<i>St. Mary's (SMU)</i>	<i>St. Francis Xavier (StFX)</i>
<i>U. de Moncton (UdeM)</i>	<i>UPEI</i>

## Activities

AARMS funds the following activities:

- Research workshops and conferences.
- Collaborative research groups.
- Postdoctoral fellowships.

- Annual Summer School offering advanced courses for students from across the region and abroad.
- Instructional workshops for graduate students.
- Outreach and enrichment programs for students and teachers in provincial schools.

Each of these is described in detail below with respect to their impact on the research programs of mathematical sciences faculty in the region, HQP training, and public awareness.

## Structure

AARMS is governed by a Board of Directors whose membership includes mathematical scientists, senior university administrators and private sector executives. Major research activities (requesting support in excess of \$5,000) and postdoctoral applications are assessed by the Scientific Review Panel; other activities are assessed by the Executive Committee. The Executive Committee is composed of the Director and other mathematical scientists from affiliated universities. It oversees AARMS' day to day operations.

**Table 2: Board of Directors (2007-08)**

<i>Hermann Brunner</i>	Board Chair, MUN	<i>David Iron</i>	Dalhousie
<i>Mark Abrahams</i>	Science Dean, MUN	<i>Gregory Kealey</i>	VPR, UNB
<i>Alejandro Adem</i>	PIMS & UBC	<i>Sherry Mantyka</i>	MUN
<i>Jacques Allard</i>	U. de Moncton	<i>Paul Muir</i>	Saint Mary's
<i>Edward Bierstone</i>	Fields	<i>Peter Russell</i>	CRM
<i>Russell Boyd</i>	Dalhousie	<i>Katherine Schultz</i>	VP (R & D) UPEI
<i>David Bremner</i>	UNB	<i>Xiaoqiang Zhao</i>	Dep. Director, MUN
<i>Hugh Chipman</i>	Acadia	<i>Ke Hua Zhou</i>	NBIMC
<i>Viqar Husain</i>	Director, UNB		

## Relationship with CRM, FIELDS and PIMS

There continues to be a cooperative and supportive relationship between AARMS and the three institutes. This is apparent from both the funding provided to AARMS by the institutes, and the service offered by their Directors on the AARMS Board and Scientific Review Panel. This has helped to maintain at AARMS a scientific and operational quality comparable to that at the other institutes.

The funding arrangement in place since 2002 was undertaken by the three institutes for two reasons. It was a means of partially fulfilling their national mandates to support mathematical sciences research across Canada. It also provided resources to enable the mathematical sciences community in the Atlantic region to develop a research organization that could eventually apply to NSERC for direct funding. The Directors of PIMS, Fields and CRM visited St. John's, Halifax and Fredericton in 2002 to meet with senior administrators at the region's three main research universities about the proposed arrangement.

The expectation that AARMS would apply to NSERC, several years hence, was an explicit part of the discussions between the Directors and the university administrators.

**Table 3: Scientific Review Panel**

<i>Xiaoqiang Zhao</i>	Chair, MUN	<i>Franklin Mendivil</i>	Acadia
<i>Yuri Bahturin</i>	MUN	<i>Matthias Neufang</i>	Fields
<i>Richard Charron</i>	PanGeo Subsea Inc.	<i>Peter Russell</i>	CRM
<i>Lisa Jeffrey</i>	Toronto	<i>Hugh Thomas</i>	UNB
<i>Leah Keshet</i>	UBC & PIMS	<i>Mary Williams</i>	NRC
<i>Dan Kucerovsky</i>	UNB		

The \$90,000 total annual support AARMS has been receiving from the institutes, which is approximately 1% of their combined annual operating budgets (or 3% of their combined MRS grants), is well appreciated and has been essential to its development. However, AARMS has reached a stage of development and activity in which this level of national support is seriously inadequate. Also, AARMS has no assurances from the institutes that the current funding arrangement will continue beyond 2012.

Experience in western Canada during the early to mid 1990s demonstrated that national institutes based in particular regions of the country (at that time in Ontario and Quebec) cannot bring full scientific benefits to a different region. In particular, only the prospect of direct NSERC grant support brings commitments from universities to increase their support for mathematical sciences research, and commitments from provincial governments for matching support. In turn, such commitments enable significant expansion of outreach activities by mathematicians to industry, to schools and to scientists in a wide range of mathematically intensive disciplines. The creation of PIMS, and its support by NSERC, has led to substantial benefits for western Canada. Atlantic Canada is the only remaining region not enjoying comparable support.

### Research Activities

AARMS has been devoting much of its resources to strengthening the stronger research areas in the region. The venture has been successful, and several groups are now in a position to productively exploit an increase in support at an international level. More recently, AARMS has been reaching out to scientists in a wide range of mathematically intensive disciplines such as theoretical physics, oceanography, and other applied mathematics disciplines. This experience has demonstrated considerable scope for expanding these efforts.

AARMS has been supporting research workshops and conferences, many of them with significant international participation. These meetings have aided researchers in Atlantic Canada to develop and maintain national and international collaborations. Table 4 shows the number of meetings during each of the past five years. The number in each year is partly

a function of the level of funding warranted, and the level granted, for each meeting (for instance, the international Hopf algebras meeting at UNB in 2008 received substantially more AARMS support than most other meetings on the recommendation of the SRP).

Table 5 shows the number of participants in AARMS activities in the past four years, together with the percentage of national and international attendees. The dramatic rise in 2010, due in part to the influx of provincial funding, gives a clear indication of the potential of the mathematical sciences community in the Atlantic region.

**Table 4: Number of Conferences/Workshops**

<i>2004</i>	<i>2005</i>	<i>2006</i>	<i>2007</i>	<i>2008</i>	<i>2009</i>	<i>2010</i>
<i>12</i>	<i>7</i>	<i>9</i>	<i>16</i>	<i>9</i>	<i>10</i>	<i>15</i>

**Table 5: Participation in AARMS activities**

(P = # of participants, N/I = National/International, R = Regional)

<i>Year</i>	<i>P</i>	<i>R %</i>	<i>N/I %</i>
<i>2007</i>	<i>643</i>	<i>33</i>	<i>67</i>
<i>2008</i>	<i>276</i>	<i>65</i>	<i>35</i>
<i>2009</i>	<i>631</i>	<i>64</i>	<i>36</i>
<i>2010</i>	<i>1249</i>	<i>53</i>	<i>47</i>

Two of the groups have formal structures within their host universities. They are the Atlantic Algebra Centre at MUN (Yuri Bahturin, coordinator) and the Centre for Research in Non-commutative Geometry and Topology at UNB (Colin Ingalls, director; Bahram Rangipour, assistant director). The category theory group is centred at Dalhousie University, with active members at Mount Allison and SMU. The group in general relativity and quantum gravity is centred mainly at UNB and Dal, with other members at MUN and St. Francis Xavier. These four groups have been active at an international level for periods varying from one to three decades.

### Main Research Areas

*Atlantic Algebra Center AAC* (MUN) The main objective of the AAC is the promotion of research and study in Algebra and its applications at participating universities of Atlantic Canada. AAC has been funded by AARMS and MUN. Algebra has been a strong point in the Department of Mathematics and Statistics at MUN for a couple of decades. The algebraists at MUN maintain strong ties with their research colleagues at various universities in Canada and throughout the world. Its Advisory Committee includes Yuri Manin (Max Planck Institute and Northwestern University), Sudarshan Sehgal (University of Alberta), and Efim Zelmanov (UC-San Diego). AAC is currently managed by Yuri Bahturin (Coordinator), Edgar Goodaire, and Mike Parmenter. Core members of AAC include Eddy Campbell, Mikhail Kochetov and Yiqiang Zhou. AAC plans include Algebra mini courses

by prominent scholars (2 to 3 times a year), an annual workshop, colloquia and seminar talks, and exchange visits of research colleagues in Atlantic Canada. AAC supports the research of active graduate students in Algebra and recent Ph D graduates of participating universities. AAC also organizes Algebra competitions among the students of MUN and other universities of Atlantic Canada and participates in events promoting mathematics in this part of Canada and beyond.

In 2009 AAC hosted the annual Combinatorial Algebra Meets Algebraic Combinatorics conference. The first four meetings in this series were held at Ontario universities, but the host sites moved to Atlantic Canada for fifth and sixth meetings, at the initiative of researchers at Dal, UNB and MUN.

*Category Theory* (Dal, MtA, SMU, StFX) Category Theory in Atlantic Canada began with the pioneering work of F.W. Lawvere and his group at Dal in the years 1969-71. The towering scientific achievement of that short period was the discovery and study of elementary toposes. Bob Pare, who had been part of Lawvere's group, was hired after Lawvere left and he soon attracted a number of graduate students. With Schumacher of Acadia, Pare started ATCAT, the Atlantic Category Theory Seminar in 1972. ATCAT has met ever since then and is the longest running research seminar in the region, and one of the largest. Faculty category theorists in the seminar number 4 from Dal, 2 from St. Mary's, 1 from Acadia, 1 from Mount Allison and 1 from StFX on a regular basis, with additional faculty from other universities participating occasionally. Graduate students, postdoctoral fellows, visitors and other interested faculty also participate.

At international CT conferences the number of Canadian participants is only exceeded by participants of the host country. Among the Canadian contingent ATCAT participants dominate. At the Calais meeting in June of 2008 there were 7 from ATCAT, of whom 5 (3 faculty, a pdf, and a graduate student) were from Dal. Many postdoctoral fellows and graduate students have attended and continue to attend ATCAT. It has also incubated successful careers in such cognate disciplines as Torsion Theories and Hopf Algebras. In 1995 ATCAT member R. Rosebrugh (Mount Allison) founded the electronic journal, *Theory and Applications of Categories*, of which he has been one of the managing editors throughout. He has also served as moderator of an electronic CT bulletin board since the late 1980s. These publications have helped ATCAT become an international centre of CT research.

Current areas of work by the ongoing members of ATCAT include Double Categories (Dawson, Pare, and Pronk), ERA sketches for Database Design (Rosebrugh), Quantum Programming Languages (Selinger) and Cartesian and Monoidal Bicategories (Wood).

*General Relativity and Quantum Gravity* (Dal, MUN, UNB, StFX) There are at present 6 faculty members (Booth, Coley, Husain, Gegenberg, Milson, Van Den Hoogen) at four institutions in the region with 4 PDFs and several graduate students. The group is visible internationally and is comparable in size to that at UBC and Alberta combined. The researchers in the group work in a number of areas in classical general relativity, and on

approaches to formulating a theory of quantum gravity. A wide range of mathematical disciplines, pure and applied, are utilized in the group's research, including geometry, group theory, dynamical systems, numerical methods, and quantum theory.

The groups at Dal and StFX work mainly in classical general relativity studying symmetry properties of spacetimes that have become of interest in string theory, and the dynamical properties of cosmologies including brane-world models. At UNB there is more focus on quantum gravitational issues with studies underway on the quantum effects on gravitational collapse. Numerical simulations have already yielded interesting modifications of the Choptuik scaling properties, which are known to break down at sufficiently high matter densities. The group at MUN also studies black holes but with more emphasis on classical properties of dynamical horizons. This diversity leads to productive exchanges of ideas at the annual Atlantic General Relativity meetings which feature an external plenary speaker. In 2008 this was Bei-Lok Hu of the University of Maryland. This group has had 9 PDFs in the past 5 years, 2 of whom were supported by AARMS.

*Non-Commutative Geometry and Topology* (UNB) This group is an officially recognized Research Center at UNB. It has 9 faculty members, 6 at UNB (Gegenberg, Husain, Ingalls, Kucerovsky, Rangipour, Stoica) and 1 each at Dal (Taylor), UPEI (MacDonald) and Lakehead (Dean). The members of the group conduct research on a number of projects including KK-theory and extensions, the classification program for nuclear  $C^*$ -algebras, Hopf algebras, non-commutative geometry, non-commutative algebraic geometry, and applications to physical theory, as well as other aspects of operator theory. It has been working at an international level for several years.

The Centre has mounted several well-attended workshops and conferences in the last several years, and has had an AARMS funded PDF. In 2008 two of its members (Kucerovsky and Rangipour) co-organized (with Fields medalist Connes, Hajac and Khalkhali) the first Canadian Hopf-Algebra conference in which 14 experts from North America and Europe gave talks. In 2008 four members of the Centre (Ingalls, Gegenberg, Husain and Kucerovsky) organized a Noncommutative Geometry Workshop in which series of talks were given by Artin (MIT), Lapidus (UC) and Balachandran (Syracuse). The Center also hosted and organized or co-organized an operator algebra and index theory workshop (2000), the Canadian Operator Algebra Symposium (2003), a functional analysis and operator theory symposium (2004), and a minicourse on operator algebras (2006).

Since autumn 2007, the Center has been co-organizing non-commutative geometry meetings at the Fields Institute (4 have been held to date). Operator algebraist, Dean (Lakehead) has recently become affiliated with the Center, and intends to spend summers in Fredericton for the next several years. Discussions are in progress on a partnership agreement between the Centre and the Non-commutative Geometry Independent Research Unit of the Mathematical Institute of the Polish Academy of Sciences. Such an agreement would fit into the Seventh Framework Program of the European Union, which is eligible for a grant from the Marie Curie action program for Geometry and Symmetry of Quantum

Spaces.

In recent years, AARMS has been facilitating the development of additional groups in branches of mathematics where research strength is distributed over several of the region's universities. One of these is in mathematical modeling and differential equations, involving researchers at Dal, Acadia, SMU, UNB and MUN. Another is in combinatorics, graph theory and optimization, with active researchers at almost all of the AARMS universities. AARMS has also been facilitating the development of research collaboration in statistics (researchers at Dal, MUN, UNB, Acadia and UdeM) and in theoretical computer science (researchers at Acadia, Dal, MUN and UNB).

*Modeling, PDEs and Scientific Computation* (Dal, UNB, MUN, Acadia, SMU) The researchers in these areas number over 30 and are at present less cohesive than the other groups simply because of the diversity of areas represented. These include areas such as ocean current modeling, numerical relativity, Monte Carlo simulations, data mining, mathematical biology, and traditional numerical analysis. There is an annual AARMS funded numerical analysis meeting that has been running since 2002 and brings together members of this diverse group. With the collaborations in place with researchers in other parts of Canada and the USA, this meeting has the potential, with additional funding, to become an international event.

The strengths at UNB are in mathematical biology and in high performance computing. Faculty members Wang and Watmough have ongoing collaborations with researchers at Alberta, UBC and York, as well as with members of the UNB Biology department. Two faculty researchers in computer science (Aubanel and Bhavsar) specialize in high performance computing with applications in physics and bioinformatics. The areas of strength at Dal, MUN and SMU are in differential equations, numerical analysis and modeling (Iron, Janssen, Leon, Muir, Thompson; Kocabiyik, Sadov, Zhao; Chipman, Haynes), and others in condensed matter theory and oceanography in other physical science departments at Dal and MUN.

*Combinatorics, Graph Theory, & Optimization* (Acadia, Dal, MUN, MtA, StFX, SMU, UNB, UPEI) There is a substantial community of researchers in combinatorics in the Atlantic Provinces, more than 30 faculty members. Topics of interest include graph theory (including applications to network security), algebraic combinatorics, optimization, and design theory. AARMS has provided substantial support for meetings organized by this group. An annual East Coast Combinatorics meeting has been held since 2005, drawing participation from the region and beyond.

AARMS has also funded the Atlantic Optimization Days (Fredericton, October 2006) and a meeting on Algebraic Combinatorics and Combinatorial Algebra (Halifax, January 2008), the fifth in an annual series which had previously all been held in central Canada. The sixth was held in January 2009 at MUN, again with the support of AARMS. This meeting series is international in scope, drawing participants from Canada, the United States, and Europe.

Since 2003 AARMS has been providing partial support for postdoctoral fellows. Although on a small scale (a total of 9 AARMS PDFs during the past six years, due to AARMS' limited resources), this program has been very successful: talented fellows were selected by the AARMS SRP and each worked productively with his/her supervisor. Each has gone on to university faculty or other research positions.

Recently, AARMS has begun supporting intensive mini courses/workshops for training graduate students. In 2006 a mini course in operator algebras was held by the Centre at UNB and in the past 3 years several mini courses in algebra were held by the Centre at MUN. In 2007 the first of what is planned to be an annual or biennial workshop in high performance computing was held at Acadia.

Since 2002, AARMS has run an annual month-long summer school for graduate students. The summer school has significantly strengthened graduate education in the region. During this time, the number and quality of graduate students in mathematical sciences at UNB, Dal and MUN has increased.

### **Collaborative Research Groups**

AARMS plans to use a substantial portion of any increase in its total budget to further develop collaborative research groups, to assist them in reaching their full potential at an international level. Collaborative groups would be invited apply for multi-year grants.

CRG funds could be used for research conferences or workshops, visits of one to several weeks by collaborators, expenses in maintaining international collaborations, or intensive mini courses or training workshops for graduate students.

**Table 6: Faculty in main research areas**

<i>GROUP</i>	<i>FACULTY</i>
<i>Atlantic Algebra Center</i>	<i>8</i>
<i>Category Theory</i>	<i>9</i>
<i>General Relativity and Quantum Gravity</i>	<i>6</i>
<i>Modeling and PDEs</i>	<i>30</i>
<i>Non-Commutative Geometry and Topology</i>	<i>9</i>
<i>Combinatorics, Graph Theory &amp; Applications</i>	<i>35</i>

In the past five years the number of post-docs working in these areas is 35, of which 14 have been partially funded by AARMS PDFs.

### **Engagement and Increased Synergies**

Additional resources would enable AARMS to increase activities directed to engaging mathematical scientists in a wider range of NSERC disciplines than at present. They would also enable greater development of organizational synergies.

For the first several years, most AARMS-supported activities were in pure or applied mathematics. More recently, AARMS has been making substantial efforts to engage scientists in other mathematical or mathematically intensive disciplines. For example, beginning in 2005, an annual East Coast Combinatorics Conference has been held annually, involving computer scientists and operations researchers from various university departments, as well as members of mathematics departments, at a different location each year (UNB, UPEI, Mount Allison and St. Francis Xavier). In 2006, the first Atlantic Optimization Days conference was held at UNB, involving researchers from mathematics, computer science, business administration, engineering and forestry departments.

In recent years also, AARMS has also supported a number of conferences and workshops in statistics, in numerical analysis and in theoretical computer science. More meetings in these fields are being planned. AARMS supported an international statistics symposium at MUN in 2009.

AARMS has also developed synergies with several scientific organizations operating in the region. A High Performance Computing (HPC) Workshop, the first of its kind in Atlantic Canada, was initiated by AARMS and hosted by the Acadia Centre for Mathematical Modelling and Computation in summer 2007. It was co-funded by AARMS, the Atlantic Computational Excellence Network (ACEnet), MITACS, the regional NSERC office and the Dal D-Drive laboratory. This 6-day workshop trained researchers and graduate students in effective use of ACEnet's computing power. It culminated in a 2-day research event, covering large-scale weather modelling, statistical methods for the design and analysis of computer experiments, geophysical modelling, and other topics. Student participants presented posters on topics such as combinatorial methods in DNA sequencing, seismic profile modelling, and problems in number theory.

MITACS and AARMS have co-funded several research workshops. MITACS has also made annual financial contributions to the AARMS Summer School. David Bremner, Atlantic regional scientific director of MITACS, has co-organized several AARMS workshops and is a co-applicant in this MRS application.

Since its inception AARMS has been cooperating with the mathematics and statistics and computer science committees of the Atlantic Provinces Council on Science (APICS). For decades APICS has sponsored annual fall conferences, focused on undergraduates, that bring together faculty and students from all four provinces. From 1997 onwards, these meetings have been expanded in size and duration to include AARMS scientific workshops for faculty and graduate students. The APICS-AARMS meetings optimize organizing time and effort, as well as travel expenditures. To date AARMS research workshops have been hosted by every one of its universities.

With additional resources, AARMS could further develop existing research collaborations involving university mathematicians, statisticians and computer scientists with scientists employed at federal laboratories in the region that are focused on forestry, agriculture, fisheries, electronic commerce and oceanography. Existing research collaborations between

researchers in these central mathematical sciences and university researchers in social and health sciences could also be developed; this could bring more resources of CIHR and SSHRC into the region.

A substantial portion of AARMS' resources has been devoted to increasing the involvement of strong researchers at the smaller universities in the graduate programs at Dal, MUN and UNB. This has worked well in the central mathematical sciences; additional resources would allow expansion to other mathematically intensive disciplines.

Additional resources would enable AARMS to further develop natural synergies with federally funded institutes in central and western Canada, such as the Perimeter Institute, as well as CRM, Fields and PIMS. Greater national benefit would thereby be derived from these institutes' major theme programs, and specific research strengths in the Atlantic region would enhance strengths elsewhere in Canada.

### Summer School

The AARMS Summer School is unique in Canada - it is the only mathematical sciences summer school offering a range of advanced courses for graduate credit given by leading authorities in their specialties. Each year, four postgraduate courses are offered by professors from around the world recruited for the Summer School. The suite of courses changes from year to year. Tables 7 and 8 give a summary of the past four years.

Each student accepted is required to enrol in two of the four courses and pass an evaluation on the course material. Thus, students from Atlantic region universities are able to take courses not usually available at their home universities. They also have the opportunity to meet fellow postgraduate students from across Canada and around the world, because the AARMS Summer School has become an international destination. The Summer School was hosted by UNB in the years 2008, 2009 and 2010 (it was hosted at MUN and then Dal in the two previous three-year periods). It has moved to MUN again for the period 2011-2013.

The Summer School instructors are encouraged to develop their course notes for publication as monographs. The first in the series was published in the summer of 2008 by the American Mathematical Society. The subject matter of this monograph is the mathematical structure of the internet; its author is Anthony Bonato of Wilfred Laurier University and it is based on the AARMS Summer School course he gave at Dal in 2006.

**Table 7: Courses at the AARMS Summer School 2008-2009**

<i>2008</i>	<i>2009</i>
<i>Computational Methods for PDEs</i>	<i>Algebraic Topology</i>
<i>Mathematical Finance</i>	<i>Topological Combinatorics</i>
<i>Tropical Geometry</i>	<i>Quantum Computing</i>
<i>Representation Theory of Algebras</i>	<i>Cryptography and Data Security</i>

**Table 8: Courses at the AARMS Summer School 2010-2011**

<i>2010</i>	<i>2011</i>
<i>Non-commutative Geometry</i>	<i>Analysis &amp; Geometry of PDEs</i>
<i>Non-commutative Algebraic Geometry</i>	<i>Harmonic Analysis</i>
<i>Riemannian Geometry</i>	<i>Numerical solution of PDEs</i>
<i>Biostatistics</i>	<i>Mathematical Biology</i>

### Outreach Activities

Several faculty have ongoing outreach programs in their respective provinces. Of particular note are Nowakowski and Gupta (Dal), Mantyka (MUN), and Sankey, McLoughlin, D.Tingley and M. Tingley (UNB), who have been active for many years in designing and delivering programs for school students, teachers and the general public. AARMS has actively promoted these activities, and partially funded them. This funding has been rather small primarily due to the limited budget available to AARMS.

The following is a list of the activities currently ongoing in each province. These programs are designed to promote and develop mathematical thinking in students, engage high school teachers, and raise awareness of the mathematical sciences in the general public. AARMS intends to promote and expand these activities in both diversity and reach. It will facilitate regular inter-university collaboration and provide financial and logistical support. AARMS would fund all expansion of such activities with funds obtained from the provinces.

- High School Math Leagues in NS and NL.
- Math Contests in all Atlantic provinces for grades 7 through 12.
- Mathematics Learning Center in NL designed to facilitate school to University transition.
- Common Grade 12 exam project and question bank development in NB brings together math faculty and high school teachers annually.
- Math Circles in NS provide interactive exhibitions of mathematical ideas.
- Summer Math Camps in NB and NS.
- Math in the Mall: a presentation of mathematical exhibits for the general public.

### Industrial Workshops

Atlantic Canada has a diverse economic base that includes oil and gas production, petrochemicals, forest products, agri-food, fisheries and aquaculture, mining, manufacturing, transportation, shipbuilding, software development and electric power generation. While some industrial sectors are smaller than in other parts of Canada, others are large (for example the Irving oil refinery in Saint John is the largest in Canada, and plans have been announced by Irving to double its capacity). All four of the Atlantic Provinces are committed to expanding economic development through innovation and research. In their

published documents all four provinces explicitly recognize the importance of fostering collaboration amongst industry, researchers, government and education.

An AARMS Industrial Problem Groups program could provide the collaborative opportunities that our governments are attempting to foster, forming partnerships between the provinces, researchers and local industry. In addressing current industrial problems through application of the mathematical sciences AARMS will foster the growth of business, support the economic goals of the provinces and provide important opportunities for the training of HQP.

Successful industrial problems workshops have been mounted by PIMS and CRM, based on the Oxford model. AARMS intends to put into place a similar structure.