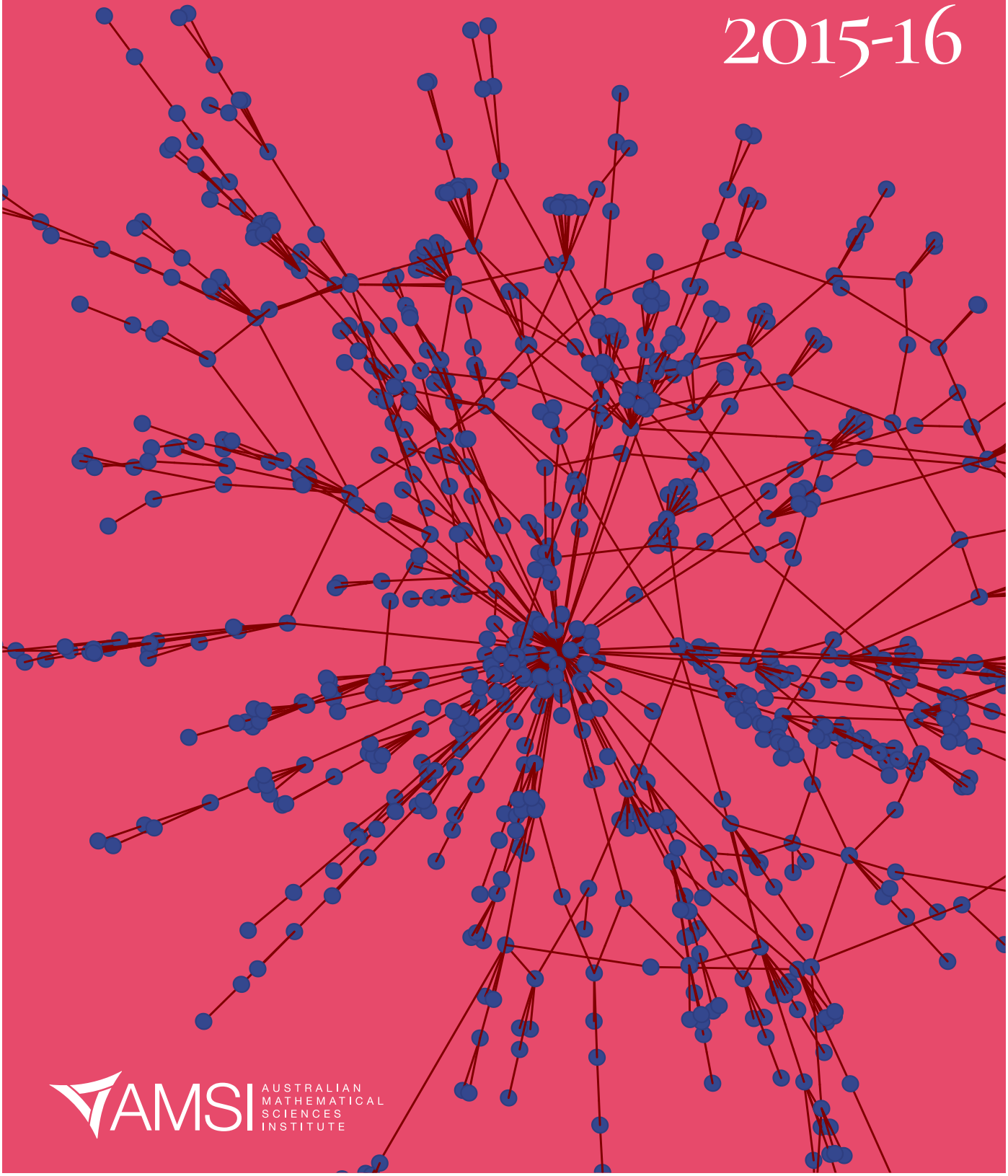
AUSTRALIAN MATHEMATICAL SCIENCES INSTITUTE

Research Report

2015-16



AMSI AUSTRALIAN MATHEMATICAL SCIENCES INSTITUTE

ABOUT AMSI

The Australian Mathematical Sciences Institute (AMSI) is a national collaborative venture of Australia's leading universities, professional societies and government agencies.

The central voice for the Australian mathematical sciences, AMSI drives a strong policy and advocacy agenda to radically improve the effective and efficient delivery of mathematical and statistical capability and capacity to education, research and industry.

AMSI delivers significant national programs to improve mathematical sciences outcomes within research, higher education, industry engagement and schools. Our activities include scientific workshops, distinguished visiting lectureships, short courses, PhD industry research internships, professional development for teachers, and industry liaison.

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Societies

Australian and New Zealand Industrial and Applied Mathematics
Australian Mathematical Society
Australian Mathematics Trust
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Funding bodies and sponsors

BHP Billiton Foundation (Choose Maths Project)
Australian Government Department of Education and Training

Front and back cover: A scale free network with exponent $\gamma<2$ by Professor Michael Small, School of Mathematics and Statistics, The University of Western Australia (See page 19)

Editorial team: Melissa Trudinger and Laura Watson
Design and layout: Michael Shaw

OPTIMISING THE MATHEMATICAL SCIENCES THROUGH COLLABORATION

As Australia's mathematical sciences peak body, AMSI works to enhance the discipline's national and global research impact. Between July 2015 and June 2016 the institute partnered with its members to deliver 16 workshops with over 670 participants. With four major research training events attended by 445 students and early career researchers AMSI has also continued its impact on emerging and early career research talent.

Increasing Australia's global mathematical sciences impact also remains a priority, including through sponsorship of lecture tours and international expert visits.

Our deep and productive relationship with the Australian Mathematical Society and its ANZIAM division has been renewed and expanded, delivering benefit through the joint workshop funding program, AMSI's Summer School, the Society's Early Career Workshops and our shared support for the Heidelberg Laureate Forum.

In April 2016, the Australian Government announced a four-year continuation of our co-funding arrangements. The new *Securing Australia's Mathematical Workforce* project will see our research training programs augmented with a new annual event, AMSI Optimise. University researchers will be engaging with private sector end users, government agency specialists and commercial mathematical sciences companies to build strategic capacity in this vital area. This event will work in conjunction with our PhD research internship program, AMSI Intern, to build collaborations around the most current research and the most current commercial and agency challenges.

16 workshops with over **670** participants

4 major research training events attended by **445** students & early career researchers

Female participation remains one of the biggest challenges facing the Australian mathematical sciences. AMSI has partnered with BHP Billiton Foundation to actively address female student engagement through its Choose Maths project. It is of considerable concern that the number of women attending our workshops remains significantly lower than their university workforce representation would indicate. Over the next year we are working with the Women In Maths Special Interest Group of the Australian Mathematical Society and the new Science in Australia Gender Equity (SAGE) initiative of the Australian Academy of Science to build a detailed picture of key drivers behind this trend and how they may be addressed. You can read more about AMSI's engagement with women on page 62 of this report.

The sudden passing of Laureate Professor Jonathan Borwein in August this year was a shock felt across the Australian and global mathematical communities. Jon was the chair of AMSI's Scientific Advisory Committee and one of the Institute's most notable and strongest champions. The strength of our research program is a testament to his commitment and vitality. At a personal level I deeply miss his wit and wisdom.

Please read on and be inspired by the vibrancy of the Australian Mathematical Sciences.

Professor Geoff Prince
Director

Remembering Jon Borwein

It was with a great sense of loss and sadness that the AMSI Board, staff, and members marked the passing of Laureate Professor Jonathan Borwein FRSC, FAA, FAAAS, FAMS in August 2016.

Jon Borwein was a mathematician of astonishing range and versatility and a leader in every way. He will be long remembered for his contribution to the institute as a passionate and inspiring leader and voice for research.

A highly respected ambassador for the Australian Mathematical Sciences, he held a range of leadership roles including, President of the Canadian Mathematical Society and Editor in Chief of the Journal of the Australian Mathematical Society. An ISI highly cited scientist, his work in mathematics and computing, including optimisation, computational number theory and classical functional analysis was widely published.

Jon's interests spanned pure mathematics (analysis), applied mathematics (optimisation), computational mathematics (numerical and computational analysis), and high performance computing. He also had a long-running interest in the number pi and its computation, and was considered one of the world's experts on the irrational number.

Jon moved to Australia in 2008 to take up a position as Laureate Professor in the University of Newcastle's School of Mathematical and Physical Sciences and Director of CARMA, the Priority Research Centre in Computer Assisted Research Mathematics and its Applications. Two years later he became the chair of AMSI's Scientific Advisory Committee, going on to hold roles as a member of AMSI's Research and Higher Education Committee and as an observer on AMSI's Board. His deep international leadership experience, coupled with his great generosity of spirit, has been of extraordinary value to the mathematical sciences in Australia and to AMSI in particular.

He authored over a dozen books and over 400 refereed articles. He was a co-founder (1995) of a software company MathResources, consulting and producing interactive software primarily for school and university mathematics. And he mentored 30 graduate students and 42 post-doctoral scholars.

Jon's legacy to mathematics, both in Australia and internationally, is considerable. The world has lost a remarkable mathematician and AMSI one of its greatest champions.

Professor Geoff Prince
AMSI Director

Laura Watson
Media and Communications

I have known Jon Borwein for many years, since I too was active in the Canadian Mathematical Society to which Jon provided vision in many capacities. Over several decades, he held numerous CMS Executive and Board appointments, also serving as a CMS delegate to the American Mathematical Society Council (2000–2002), as the Governor at Large of the Mathematical Association of America (2005–2007) and as the Chair of the CMS International Affairs Committee (2004–2005).

Jon was always ready to help with strategic thinking about the long-term future of the CMS and how it could serve and support the mathematical sciences. He carried this attitude and approach with him to AMSI on his move to Australia, working tirelessly to ensure high quality outcomes for all involved.

Professor Lynn Batten
Research Chair in Mathematics
Deakin University

Jon was a mathematician with a major international reputation in a number of branches of mathematics ranging from pure mathematics to applied and computational mathematics. A wonderful asset to the Australian mathematical community.

Jon was a staunch supporter of AMSI with an invariably positive and constructive approach to any issues facing the Institute. He made an enormous contribution in chairing the critical Scientific Advisory Committee at a time when the idea of the National Research Centre was taking shape.

Jon was a delightful and engaging colleague with interesting views on a wide range of topics, mathematical and many others.

Dr Ron Sandland AM FTSE
Chair, AMSI Board

CONTENTS

AMSI Milestones

2002

AMSI established. Prof. Garth Gaudry appointed Director (Victorian government $1m)

2003

Centre for Excellence for Mathematics and Statistics of Complex Systems (MASCOS) established (Australian government $10.9m)

2004

International Centre of Excellence for Education in Mathematics (ICE-EM) established (Australian government $7.8m)

2005

AMSI Awards 100th Vacation Research Scholarship

2006

National Strategic Review of the Mathematical Sciences in Australia (Academy of Science)

2007

AMSI Research Training programs expanded (Australian government $2m)

2008

AMSI sponsors 100th Scientific Workshop

AMSI wins National Innovation Award for Science Innovation

2009

AMSI Intern established

The improving Mathematics in Schools (TIMES) project (Australian government $2m)

2010

AMSI Intern expanded (Australian government $1.7m)

2011

2nd edition of ICE-EM Mathematics textbooks published

2012

AMSI delivers 10th Annual AMSI Summer and Winter Schools

National Maths for the Future Forum: *Keep Australia competitive*

Research Training programs expanded (Australian government $2m)

2013

AMSI sponsors 150th Scientific Workshop

International Year of Mathematics of Planet Earth Australia led by AMSI

2014

AMSI Intern expanded (AMSI member co-investment $6.7m)

2015

Choose Maths launched to increase female participation (BHP Billiton Foundation $22m)

500th Vacation Research Scholarship awarded

10th Annual AMSI Lecture Tour held

Advanced Collaborative Environment (ACE) Network launched to replace the AMSI Access Grid Network

AMSI Intern partnerships with eight universities in Victoria and NSW to expand internship program

2016

Almost 1200 mathematicians attend AMSI-sponsored workshops and research training events (2015-16)

$2m grant for AMSI research training programs

Academy of Sciences launches The Mathematical Sciences in Australia: A Vision for 2025

AMSI places 160th intern

AMSI sponsors 200th Scientific Workshop

ABOUT **AMSI RESEARCH**

AMSI Research has been supporting the advancement and communication of fundamental and applied mathematical sciences knowledge for almost 15 years.

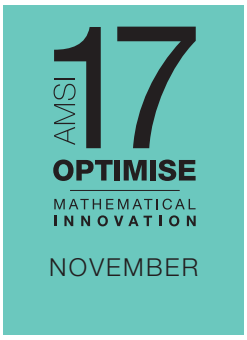
Building critical links between universities, government agencies and industry, our programs foster cross-disciplinary collaboration and industry experience to grow mathematical sciences capability and equip Australia as a STEM leader for the future.

Our research training schools, scholarships and graduate courses have enhanced learning outcomes and networking opportunities for students and early career researchers, helping grow the supply of emerging mathematical talent to support public and private sector innovation.

Disclaimer

Important

The following research workshop and event reports are not intended to be a comprehensive overview of research activities and events within the Australian mathematical sciences. These reports are developed in collaboration with event partners and may include views or recommendations from third parties that do not necessarily reflect those of the Australian Mathematical Sciences Institute. Links to event websites and contact information provided are not intended as endorsements of views or information but are provided for the convenience



$2 MILLION BOOST FROM AUSTRALIAN GOVERNMENT FOR AMSI'S RESEARCH AND HIGHER EDUCATION PROGRAMS

The Australian Mathematical Sciences Institute received a $2 million boost to its research and higher education programs in April from the Department of Education and Training.

The investment will allow AMSI to closely engage with the federal government's National Science and Innovation Agenda (NISA) to strengthen Australia's mathematical capability. In addition to building on the success of AMSI's current flagship events and scholarship programs, the funding means that AMSI can expand the program though new initiatives.

"The key to AMSI's success is its position as the national peak body with access to both academic and industry networks AMSI is uniquely placed to secure Australia's mathematical workforce into the 21st Century."

Launching in 2017, a new annual research training event AMSI Optimise will strengthen mathematical optimisation research engagement and its applications across industry. Modelled on the successful AMSI BioInfoSummer, the event will comprise of a three-day industry-research symposium with expert and end user talks, computer workshops, collaboration showcases and challenge sessions. The symposium will be followed by a two-day research workshop. The event will provide research training in this vital area along with a platform for collaboration, especially through PhD internships.

With a need to prepare students for private sector and cross-discipline research opportunities, AMSI will strengthen industry pathways by linking its key events such as BioInfoSummer and AMSI Optimise to industry placement opportunities to foster work readiness. Retention of senior undergraduate students, in particular women and indigenous students will also be a priority.

The key to AMSI's success, according to Professor Geoff Prince, is its position as the national peak body with access to both academic and industry networks.

Research Workshops 1

1 RESEARCH WORKSHOPS OVERVIEW

Australia's premier sustained workshop program, AMSI Research builds mathematical research collaboration through its internationally recognised program of scientific workshops.

From July 2015 to June 2016 AMSI sponsored 16 workshops and conferences around Australia through the Scientific Workshops Program, encompassing a range of mathematical sciences and attracting 670 participants from academia, industry and government. Additional support, including travel grant funding, was also provided for several events and conferences outside of this stream.

AMSI sponsored 16 workshops and conferences and sponsored 68 speakers to attend workshops

Of the speakers 84% were international

35% of workshop participants were international visitors

Female mathematicians made up 14% of the participants, 19% postgraduate students, 11% were early career researchers

More than 30 students and researchers received travel funding to attend AMSI-sponsored research events

Research Workshops

1.01 THE MATHEMATICS OF CONFORMAL FIELD THEORY

Mathematical Sciences Institute, The Australian National University, 13–17 July 2015

An exploration of conformal field theory and its influence on pure mathematics and mathematical physics, this workshop provided an important platform to uncover new avenues for research collaboration and foster engagement of student and emerging research leaders.

Conformal field theory is a fundamental part of modern mathematical physics. It was initially developed to further the study of statistical lattice models and string theory, but its richness has also led to an unexpectedly large number of connections to pure mathematics. In particular, its (partial) axiomatisations have led to several new mathematical structures including vertex algebras, conformal nets and modular tensor categories.

This conference fostered communication and collaboration between pure mathematicians and mathematical physicists working across conformal field theory and related disciplines. In addition to conformal field theory, vertex algebras and conformal nets, seminars addressed such diverse topics as binary codes, cellular algebras, conformal loop ensembles, coset constructions, fusion, higher spin string theory, non-semisimple module categories, quantum and mock modular forms, categorical modular invariance, q-series identities, quantum groups and Nichols algebras, Schramm-Loewner evolution, sigma models, statistical lattice models, subfactors, and W-algebras.

Importantly, this event was successful in its aim of facilitating communication between the mathematical science and mathematical physics communities. The expanse and calibre of the mathematical topics covered resulted in an accurate impression of the important open field problems useful for students and early career researchers alike. With a strong international presence including invited speakers and conference participants, provided a fantastic opportunity for networking and collaboration.

While domestic participation was somewhat lower than expected, international participation was high, due in part to the calibre of the invited speakers. Attendance by postgraduate students and other early career researchers was also higher than anticipated.

Overall, this conference has done much to cement Australia's place as an international centre for the study of mathematical conformal field theory.

"The Mathematics of Conformal Field Theory was, far and away, the best conference I have attended. The content was coherent yet diverse enough to attract a wide variety of researchers, and the ordering and grouping of speakers created a nice flow to the proceedings. I only wish that all conferences would be as useful to me!"

Organisers

Prof. Peter Bouwknegt, The Australian National University
Asst. Prof. Thomas Creutzig, University of Alberta
Prof. Charles Doran, University of Alberta
Prof. Alexander Molev, The University of Sydney
Dr David Ridout, The University of Melbourne
Dr Simon Wood, The Australian National University

Special Presenters

Prof. Jürgen Fuchs, Karlstad University, Sweden
Research interests: conformal field theory
Prof. Matthias Gaberdiel, ETH Zürich, Switzerland
Research interests: string theory, conformal field theory
Assoc. Prof. Terry Gannon, University of Alberta, Canada
Research interests: conformal field theory, algebra, number theory, and mathematical physics
Prof. Geoff Mason, University of California, Santa Cruz, USA
Research interests: conformal field theory
Prof. Paul Pearce, The University of Melbourne
Research interests: integrable systems, mathematical physics, statistical mechanics, exact solutions of lattice models, critical phenomena (phase transitions), and conformal/quantum field theory
Prof. Ingo Runkel, University of Hamburg, Germany
Research interests: algebra and higher structures, mathematical physics, topological and conformal field theories.
Prof. Hubert Saleur, CEA Saclay, France; University of Southern California, USA
Research interests: conformal field theory, quantum field theories, statistical mechanics, non-perturbative effects, transport out of equilibrium, and AdS/CFT correspondence
Prof. Alexei Semikhatov, Lebedev Physical Institute, Moscow, Russia
Research interests: conformal field theory, abstract algebra, and algebra

MathSciNet Classification

81T40, 17B69, 81R10

Web Links

http://maths.anu.edu.au/events/mathematics-conformal-field-theory

Other Sponsors

Pacific Institute for the Mathematical Sciences (PIMS)

Key Contact

Dr David Ridout, The University of Melbourne, **david.ridout@unimelb.edu.au**

1.02 BAXTER 2015: EXACTLY SOLVED MODELS AND BEYOND

Palm Cove, Queensland, 19–25 July 2015

Bringing together an outstanding group of international and Australian researchers, this conference highlighted the contributions of Professor Rodney Baxter on the field of exactly solved models in statistical mechanics and its impact on theoretical physics and mathematics.

Baxter 2015: Exactly Solved Models and Beyond celebrated the research contribution of Professor Rodney Baxter in honour of his 75th birthday. In particular, the event highlighted his pioneering contributions to exactly solved models in statistical mechanics and crucial developments within theoretical physics and mathematics.

Attended by many leading Statistical Mechanics, Mathematical Physics and Mathematics researchers, the meeting featured a stellar plenary speaker line-up, including Professor Stanislav Smirnov (2010 Field Medallist), Professor Ludvig Faddeev (Heineman, Dirac, Poincare & Shaw Prize; past President of the IMU), Professor Michio Jimbo (Heineman & Wigner Medal), Professor George Andrews (past President of the AMS) and Australia's own Professor Nalini Joshi (Laureate Fellow). The scientific program contained an engaging mix of state-of-the-art research and historical talks on the development of the field of solvable models in Statistical Mechanics and Quantum Field Theory (Andrews & Faddeev).

Topics included exactly solvable models in statistical mechanics, quantum integrable systems, conformal field theory, physical combinatorics, lattice models, and representation theory. The intensive program also allowed ample opportunity for individual discussions and collaborations to take place.

The organisers made notable efforts of inviting female researchers and students, with nearly all women working in the area of exactly solvable lattice models participating the conference, including Professors Nalini Joshi, Angela Foerster, Helen Au-Yang, Milena Radnovic, and others.

"This was a splendid international conference. The scientific standard of the speakers was exceptional, as might be expected from the colleagues of Rodney Baxter, and the lively discussions after most talks was indicative of the level of interest they elicited. Altogether, this was a conference that all participants will fondly remember for a long time."

Professor Tony Guttmann

Organisers

Prof. Vladimir Bazhanov, The Australian National University
Prof. Murray Batchelor, The Australian National University
Gary Bosnjak, The Australian National University
Prof. Xi-Wen Guan, Wuhan Institute of Physics and Mathematics, China
Prof. Vladimir Mangazeev, The Australian National University
Prof. Aleks Owczarek, The University of Melbourne
Prof. Paul Pearce, The University of Melbourne
Prof. Reinout Quispel, La Trobe University
Dr Sergey Sergeev, The Australian National University
Prof. Ole Warnaar, The University of Queensland

Special Presenters

Prof. George Andrews, Pennsylvania State University, USA
Research interests: number theory, q-series, special functions, and combinatorics, integer partitions
Prof. Ludwig Faddeev, St. Petersburg branch of Steklov Institute of Mathematics, Russian Academy of Sciences
Research interests: mathematical physics and mathematical problems of quantum field theory
Prof. Michio Jimbo, Rykkyo University, Tokyo, Japan
Research interests: integrable quantum systems, representation theory
Prof. Nalini Joshi, The University of Sydney
Research interests: nonlinear differential and difference equations, and integrable systems
Prof. Barry McCoy, The State University of New York at Stony Brook, USA
Research interests: statistical mechanics, lattice spin systems, quantum groups
Prof. Stanislav Smirnov, University of Geneva
Research interests: complex analysis, dynamical systems, probability theory

MathSciNet Classification

82B20, 82B23, 16T25

Web Links

http://baxter2015.anu.edu.au

Other Sponsors

AustMS, ANU College of Physical and Mathematical Sciences, Asia-Pacific Centre for Theoretical Physics Mathematical Sciences Institute at The Australian National University, Research School of Physics and Engineering, The Australian National University, The University of Canberra, Wuhan Institute for Physics and Mathematics, China, ACEMS

Key Contact

Prof. Vladimir Bazhanov, The Australian National University, **vladimir.bazhanov@anu.edu.au**

1.03 WORKSHOP ON GEOMETRIC QUANTISATION

The University of Adelaide, 27–31 July 2015

This workshop on geometric quantisation provided fertile ground for exploring new research directions in the field and highlighted its relevance to many other areas in both mathematics and physics.

An increasingly active area since before the 1980s, geometric quantisation has links to physics, symplectic geometry, representation theory, index theory, and differential geometry and geometric analysis in general. In addition to its relevance as a field on its own, it acts as a focal point for the interaction between all of these areas, which has yielded far-reaching and powerful results.

This workshop included a number of world-leaders in geometric quantisation experts, including Professors Michèle Vergne, Weiping Zhang, Eckhard Meinrenken and Nigel Higson. This exceptional concentration of expertise in geometry and analysis was a great opportunity for anyone working in these areas to exchange ideas with some of the world's top mathematicians.

Typical for the area, topics discussed ranged from those directly motivated by physics to more fundamentally mathematical topics. This reflects geometric quantisation's influence on many areas in mathematics and physics. The common theme of geometric quantisation helped to focus the presentations into a coherent workshop, and meant people from different areas were able to learn from each other's talks.

The program was structured to maximise opportunity for discussion and foster collaboration. This model proved successful in facilitating engagement during most breaks and after talk sessions, with junior participants getting advice from their senior colleagues, and the senior participants combining their expertise to explore new research directions. Many participants left the workshop with new ideas and projects. This is the most important outcome of any workshop, and in that sense it was a complete success.

Professor Michèle Vergne, one of the most famous female mathematicians of our time and inspiration to many women in mathematics was this year's most prominent guest. With women such as Michèle still a minority, the women in mathematics networking event on the first day of the workshop was dominated by lively discussion about the role of women in mathematics. Despite six female mathematicians receiving invitations to speak at this year's event, female attendance remains a key challenge, and organisers praised the considerable effort made to improve gender balance at this year's event.

"Thanks for organising an excellent workshop. I thought the blend of speakers, the number of talks per day and the overall atmosphere were excellent for exchange of information and collaboration."

Professor Diarmuid Crowley

Organisers

Dr Peter Hochs, The University of Adelaide
Dr Anthony Licata, The Australian National University
Prof. Mathai Varghese, The University of Adelaide
Dr Hang Wang, The University of Adelaide

Special Presenters

Prof. Maxim Braverman, Northeastern University, USA
Research interests: analysis on manifolds, index theory, analytic torsion, symplectic geometry
Dr Fei Han, National University of Singapore
Research interests: differential geometry, topology and mathematical physics
Assoc. Prof. Anthony Henderson, The University of Sydney
Research interests: geometric and combinatorial aspects of representation theory
Dr Rung-Tzung Huang, National Central University
Research interests: analysis on manifolds, global analysis, differential geometry, in particular, analytic torsion, eta invariant, index theorem
Prof. Nigel Higson, Pennsylvania State University, USA
Research interests: operator algebras and K-theory
Dr Yiannis Loizides, University of Toronto
Research interests: symplectic geometry
Prof. Eckhard Meinrenken, University of Toronto, Canada
Research interests: differential geometry, Lie theory, mathematical physics
Prof. Paul-Émile Paradan, Université Montpellier 2, France
Research interests: analysis, algebra, geometry and topology
Dr Romero Solha, Universidade Federal de Minas Gerais
Research interests: symplectic geometry, integrable systems, geometric quantisation, symplectic connections
Dr Yanli Song, University of Toronto
Research interests: noncommutative geometry, symplectic geometry, index theory, representation theory
Dr Jennifer Vaughan, University of Toronto
Research interests: symplectic geometry
Prof. Michèle Vergne, Institut de Mathématiques de Jussieu, France
Research interests: analysis and representation theory, geometry of numbers, Lie theory
Prof. Siye Wu, National Tsing Hua University, Taiwan
Research interests: differential geometry, mathematical physics
Prof. Weiping Zhang, Chern Institute of Mathematics, China
Research interests: geometry and analysis on manifolds

MathSciNet Classification

58F06, 53D50, 22E45

Web Links

www.iga.adelaide.edu.au/workshops/July2015/

Other Sponsors

Institute for Geometry and its Applications, The University of Adelaide, AustMS, Australian Research Council

Key Contact

Dr Peter Hochs, The University of Adelaide, **peter.hochs@adelaide.edu.au**

1.04 NUMBER THEORY DOWN UNDER 2015

The University of Newcastle, 18–19 September 2015

With a focus on the use of computational techniques for exact problem solving, this event stimulated robust discussion, opening avenues for national and international collaboration. Postgraduate students and early career researchers were given a platform to present their research through a poster session with prizes stimulating healthy competition. They additionally benefited from engagement with field leaders, new academic networks and representatives from defence as well as exposure to new areas of investigation.

Australia has a long history of leading investigation in the field of number theory. In the past this field was well represented through the works of Kurt Mahler and Alf van der Poorten and it has undergone resurgence in recent years with many permanent appointments and research positions. To take advantage of this, number theory conferences have been arranged over recent years to bring together domestic and international number theorists to share ideas, and to pursue collaborative work.

"A most enjoyable conference. Seven plenary talks, with many breaks for discussion, set a good pace."

"The organisers did a good job of ensuring that some people outside of academia attended. I liked meeting the people from Defence."

The 2015 conference focused on the theme "Can current computational techniques enable us to solve problems exactly?" and included presentations on Diophantine approximation, advances in analytic computation, Rogers-Ramanujan Identities and discussions on open problems in analytical and algebraic number theory.

A poster session created opportunities for postgraduate students and early career researchers to display and disseminate their work. The poster session was well attended and stimulated discussions surrounding research work displayed in the posters. Professor Wadim Zudilin presented the *NTDU Prize* for best poster to Angus McAndrew from Melbourne University for his poster *Differentiation of Siegel Modular Forms*.

The talks promoted a large and significant discussion and there was substantial interaction between researchers representing various subfields of number theory. The increase in participation from national and international universities as well as members from the Department of Defence ensured that number theoretic research will keep prospering and flourishing in Australia.

Organisers

Dr Michael Coons, The University of Newcastle
Dr Mumtaz Hussain, The University of Newcastle
Dr Tim Trudgian, The Australian National University
Prof. Wadim Zudilin, The University of Newcastle

Special Presenters

Prof. Jon Borwein, Centre for Computer-Assisted Research Mathematics and its Applications (CARMA)
Research interests: computer assisted mathematical research, high performance computing, applied mathematics, functional and numerical analysis, data mining, discrete mathematics, dynamical systems, machine learning
Assoc. Prof. Shaun Cooper, Massey University, New Zealand
Research interests: number theory,
Prof. Karl Dilcher, Dalhousie University, Canada
Research interests: number theory (elementary, computational, analytic), Classical analysis (zeros of polynomials, inequalities), Bernoulli numbers and polynomials, and related sequences
Dr Alan Haynes, The University of York, England
Research interests: analytic number theory, Diophantine approximation, probability theory, dynamical systems, and ergodic theory
Prof. Mourad Ismail, The University of Central Florida, USA
Research interests: special functions and orthogonal polynomials, approximation theory, asymptotics and combinatorics
Prof. Sinai Robins, Brown University, USA
Research interests: discrete and computational geometry, number theory, and Combinatorics
Prof. Ole Warnaar, The University of Queensland
Research interests: algebraic combinatorics, basic and elliptic hypergeometric series, q-series and partition theory, representation theory, special functions

MathSciNet Classification

11F67, 11J13

Web Links

carma.newcastle.edu.au/meetings/ntdu3/

Other Sponsors

CARMA

Key Contact

Dr Mumtaz Hussain, The University of Newcastle,
Mumtaz.hussain@newcastle.edu.au

1.05 AMSI/AUSTMS WORKSHOP: GEOMETRY AND ANALYSIS

Flinders University, 25–27 September 2015

The third in AustMS and AMSI's annual joint workshop series, this event further strengthened Australia's reputation as leaders in pure mathematics and geometry and complex analysis. This event built on existing understanding to explore new areas of investigation and stimulate critical engagement and collaboration between established and emerging research leaders and students.

A satellite of the *Annual Meeting of the Australian Mathematical Society (AustMS)*, this event featured a series of international speakers including Professor Jorge Lauret. Several Australian participants also gave talks during the workshop. Topics included geometry of Riemannian and pseudo-Riemannian homogeneous spaces, geometric flows, parabolic and conformal geometry and complex geometry and CR-geometry.

Core outcomes included new directions for national and international collaboration and strengthening the international standing and reputation of Australian research in pure mathematics, particularly in geometry. Additionally it provided both students and established researchers with international exposure.

The workshop's world-class mathematical presentations also opened new avenues for joint research and collaboration. Informal and robust discussion sessions promoted networking providing a warm and friendly atmosphere for participating students who gained valuable experience of mathematical research.

Organisers worked with the Women in Mathematics Special Interest Group to increase female participation, bringing Professor Francine Meylan, from Fribourg University to Australia as one of the invited speakers.

"In my opinion, this series makes regular and extremely valuable contributions to the development of mathematics in Australia. Each time, the organisers manage to bring top-class international and domestic speakers to the meeting, and the 2015 conference was no exception."

Dr Artem Pulemotov

Organisers

Assoc. Prof. Grant Cairns, La Trobe University
Assoc. Prof. Vlad Ejov, Flinders University
Dr Yuri Nikolayevsky, La Trobe University
Assoc. Prof. Gerd Schmalz, The University of New England

Special Presenters

Prof. Dmitry Alekseevsky, The Institute for Information Transmission Problems, Russian Academy of Sciences, Moscow, Russia
Research interests: differential and Riemannian geometry, Lie groups, homogeneous spaces and geometric structures and mathematical physics
Assoc. Prof. Martin Kolář, Masaryk University, Czech Republic
Research interests: complex analysis of several variables, local geometry and CR invariants of real submanifolds in complex space, asymptotic properties of Bergman kernels, stochastic analysis, Bayesian methods
Prof. Jorge Lauret, Universidad Nacional de Córdoba, Argentine
Research interests: Einstein homogeneous manifolds, homogeneous Ricci flow and Ricci solitons, invariant geometric structures on (locally) homogeneous spaces and curvature flows
Prof. Francine Meylan, Université de Fribourg, Switzerland
Research interests: complex analysis and CR-geometry, CR automorphisms, meromorphic mappings, holomorphic mappings in Banach spaces
Prof. Jan Slovák, Masaryk University, Czech Republic
Research interests: theory of natural operators, applications of representational techniques of Lie groups and Lie algebras in differential geometry, and parabolic geometries

MathSciNet Classification

22E, 53C, 32V, 32M

Web Links

gygeom.com/2015/

Other Sponsors

AustMS, The University of New England, La Trobe University, Flinders University

Key Contact

Dr Yuri Nikolayevsky, La Trobe University, **y.nikolayevsky@latrobe.edu.au**

1.06 INTERNATIONAL WORKSHOPS ON COMPLEX SYSTEMS AND NETWORKS

Old Swan Brewery, Perth, 4–7 October 2015

Bringing together a cross-disciplinary selection of mathematicians, scientists and engineers, this workshop focused on applying developments in complex systems research to engineering problems.

Complex systems and networks have experienced an increase in prominence within the global scientific community over the past decade. While the underlying methodology has been familiar to mathematicians as a small component of graph theory for some time, it is only with the recent advent of data intensive sciences that practitioners from other sciences and engineering have been able to take advantage of these tools and extend them to a wide range of applications. The objective of this workshop was to bring together a wide cross-section of practitioners: academic mathematicians, scientists and engineers as well as practicing social scientists and engineering professionals. Meetings were held over three days, with

extensive discussion over formal workshops and social events.

Attracting a strong attendance, the program featured 20 speakers who led discussion on developments within complex systems and networks. As in previous years, the range of topics was vast including application domains—physics, engineering, mathematics, social networks, granular systems, electronic systems, robotics and guidance systems, and applications to business and innovation. Perth is the Australian resource industry hub and a particular focus this year was on problems of engineering for remote operations and the ways in which complex systems can contribute to better engineering practise—through reliability engineering, virtual networks and complex engineering systems. The audience was given wide range of problems from compressive sensing to synchronisation and dynamics of complex systems as well as application in the prediction of innovation and business success.

The workshop was a clear scientific success with lively exchange between world experts in the field and many students in attendance. Both the topics of discussion and the interaction among participants were excellent and have served to promote WA and Australia to the international complex systems community. Moreover, there are promising signs of new and ongoing collaboration among the participants and speakers.

Female attendance was boosted by the attendance of several high profile female speakers, acting as positive role models for the community. It was noted that a low level of interest and attendance from students based in the eastern states of Australia may have been due to the higher costs associated with the conference location.

"The IWCSN series was held the second time in Australia and this one at Perth, after Canberra in 2008, was another great success. I could see the remarkable progress gained by the Australian researchers, particularly by the strong team from UWA, on network science and engineering over the years. Needless to say, the riverfront conference venue was extremely nice and the program was very well organised."

Chair Professor Guanrong Chen

Organisers

Chair Prof. Guanrong (Ron) Chen, City University of Hong Kong
Prof. Michael Small, School of Mathematics and Statistics, The University of Western Australia
Chair Prof. CK Michael Tse, Hong Kong Polytechnic University

Special Presenters

Dr Stefano Boccaletti, National Institute of Applied Optics, Florence, Italy Italian Embassy, Israel (by Skype)
Research interests: condensed matter and quantum physics, statistical dynamics, biological systems, advanced instrumentation and techniques
Chair Prof. Guanrong Chen, City University of Hong Kong, Hong Kong
Research interests: nonlinear systems, control and dynamics, complex networks
Prof. Gary Froyland, The University of New South Wales
Research interests: dynamical systems, optimisation
Prof. Celso Grebogi, University of Aberdeen, UK
Research interests: dynamics of nonlinear and complex systems including chaotic dynamics, fractal geometry, systems biology, population dynamics, neurodynamics, fluid advection, relativistic quantum nonlinear dynamics, and nanosystems
Prof. Melinda Hodkiewicz, The University of Western Australia
Research interests: safety, asset system health and maintenance
Prof. Doctor Jürgen Kurths, Potsdam University, Germany
Research interests: nonlinear physics and complex systems sciences
Assoc. Prof. Kevin Judd, The University of Western Australia
Research interests: dynamical systems theory, optimisation and computer-aided teaching
Emer. Prof. Tony Lawrance, University of Warwick, UK
Research interests: statistical aspects of chaos and synchronised laser chaos communications, statistical modelling in financial time series, reversed chaotic and stochastic time series modelling, likelihood-based regression diagnostics and influence, engine mapping
Prof. Xiang Li, Fudan University, China
Research interests: theories and applications of complex adaptive networks, adaptive control and cognition of complex networking systems, and complexity and game in artificial life and financial networks
Dr Lewis Mitchell, The University of Adelaide
Research interests: data assimilation, computational social science, human dynamics and social networks, and the mathematics of weather and climate
Prof. Maciej Ogorzalek, Jagiellonian University, Poland
Research interests: biomedical signal processing, nonlinear circuits and systems, fractal techniques in engineering, circuits and systems design, future integrated circuits and systems, computational system biology
Dr Dion O'Neale, The University of Auckland, New Zealand
Research interests: complex systems and network science, network structures
Prof. Antoinette Tordesillas, The University of Melbourne
Research interests: homogenisation theory, interfacial continuum mechanics, mechanics of complex systems, mechanics of granular media
Prof. Ljiljana Trajkovic, Simon Fraser University, Canada
Research interests: communications networks, nonlinear circuits and systems
Chair Prof. Michael Tse, Hong Kong Polytechnic University, Hong Kong
Research interests: complex network applications, power electronics and nonlinear systems
Prof. Ba-Ngu Vo, Curtin University of Technology
Research interests: signal processing, systems theory and stochastic geometry
Prof. Xiaofan Wang, Shanghai Jiaotong University, China
Research interests: analysis and control of complex dynamical networks
Dr Chai Wah Wu, IBM T J Watson Research Center, USA
Research interests: foundations of nonlinear circuits and systems theory, dynamics in coupled networks of oscillators, synchronisation of chaos, application of chaos to information processing, distributed video streaming, digital halftoning, document and multimedia security, algebraic graph theory
Prof. Xinghuo Yu, RMIT University
Research interests: nonlinear and discontinuous control, complex and intelligent systems, and industrial information technologies

MathSciNet Classification

05C82, 94.30, 91D30

Web Links

iwcsn.eie.polyu.edu.hk/2015/Home.html

Other Sponsors

ANZIAM, Centre for Chaos and Complex Networks, City University of Hong Kong, Faculty of Engineering, Computing and Mathematics, The University of Western Australia, IEEE Circuits and Systems Society

Key Contact

Prof. Michael Small, The University of Western Australia, **michael.a.small@gmail.com**

UNRAVELLING THE MATHEMATICAL WEB BEHIND COMPLEX SYSTEMS AND NETWORKS

By Professor Michael Small

From the complex webs of social media and human interaction to power-grid substation interconnections, networks surround every facet of our lives. Linking all these systems are complex structures characterised by interconnected components or nodes connected by edges. Understanding the way in which these nodes connect is instrumental to understanding and eventually controlling system behaviour. In societies, studying connections between individuals allows us to better map the spread of disease and engineer control strategies. Modelling the structure of electrical power distribution networks is essential to building systems robust to cascading outages.

An emerging field and evolution of mathematical graph theory and of particular interest to statistical physicists, networks are widely studied as a paradigmatic model of interaction. As computational resources and data become more plentiful, many of the theoretical results related to large interconnected systems can now be applied to real physics systems—from the human genome to the internet or global social and communication networks. Advances in data intensive science have placed complex systems theory at the forefront of basic mathematics where it is being adapted and applied to large, complex, real-world systems.

While interaction at an individual level may be simple and well understood, one of the most interesting aspects of these systems is how little is understood about their collective behaviour. In an increasingly interconnected world, examples of such systems are now everywhere. In the natural world, individual and presumably simple interactions between neighbouring birds in a flock lead to spectacular and complex murmurations—a phenomenon which has application to crowd control, traffic management and the design of autonomous vehicles and drones.

The Internet itself has emerged as the medium underpinning global trade and communication. Yet the network is a vast web of interconnected components each following very simple rules to transmit data. Understanding how this system functions allows us to develop the network into a more efficient and robust system.

Levels of networks exist on top of the Internet, each suggesting new applications for complex systems theory—from the World Wide Web, to social networks and even communication among distributed organisations attempting to evade detection on the so-called "dark web".

Run annually, the *International Workshop on Complex Systems and Networks* fosters engagement across the pipeline from global field experts and emerging academic and student researchers to industry stakeholders. As Australia's resources industry hub, Perth was an ideal setting to explore engineering challenges facing remote operations and the role of complex systems in engineering best practice through reliability engineering, virtual networks and complex engineering systems.

With speakers leading discussion on physics, engineering, mathematics, social networks, granular systems, electronic systems, robotics and guidance systems, and business and innovation, this year's program provided an ideal platform for exploration of complex systems and networks.

Australian scientists are increasingly contributing to the development of complex systems science, with a strong focus on problems related to complex networks and their applications. At RMIT, Professor Xinghuo Yu leads a large and very successful group investigating control of dynamical systems embedded on networks. Sydney has several key researchers looking at →

Global Leaders at the Meeting

Professor Celso Grebogi

A Brazilian physicist, Professor Grebogi is renowned for his work in the area of Chaos Theory—in particular chaos control. The Sixth Century Chair in Nonlinear and Complex Systems at the University of Aberdeen, he is a Fellow of The Royal Society of Edinburgh, as well as a Fellow of the Brazilian Academy of Sciences, the World Academy of Sciences (TWAS/UNESCO), the American Physical Society, and the Institute of Physics (UK). His work has attracted over 30,000 citations. Notably his collaboration with Edward Ott and James Yorke, has resulted in a numerical example illustrating the conversion of a chaotic attractor to a range of possible time-periodic attracting motions using only small time-dependent perturbations of an available system parameter. This is known as the OGY Method, after each of the three authors.

Professor Jürgen Kurths

A mathematician and physicist with the Potsdam Institute for Climate Change Research, Professor Kurths also holds chair positions at Humboldt University, Potsdam University, and the University of Aberdeen. He is a Fellow of the American Physical Society, a Member of the Macedonian Academy of Sciences and Arts, and recipient of multiple honorary doctorates, professorships and awards. He has had more than 60 PhD students from about 20 countries with 30 now in tenured positions. Highly cited, he has published over 500 articles and eight books and is currently on the editorial board of more than 10 scientific journals. Professor Kurths' research on the basics of complex systems theory has had application to the Earth system, the human brain, the cardio-respiratory system and other systems characterised by a high degree of complexity and nonlinearity.

Professor Guanrong Chen

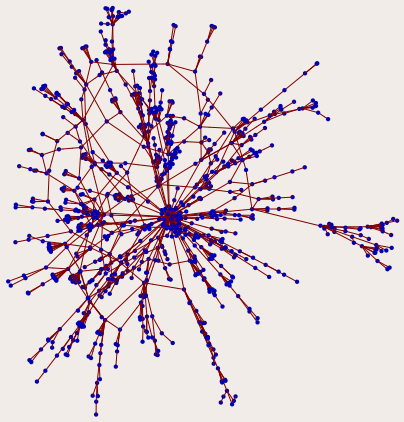
Professor Chen has held a chair professorship in electrical engineering, at the City University of Hong Kong since 2000. He is widely lauded for his work in chaos theory and complex systems. Notably he proposed a double scroll chaotic, Chen's attractor, in 1999. Professor Chen is a Member of Academia Europe and a Fellow of IEEE, Highly published, his work has attracted over 70,000 citations, and he is currently Editor-in-Chief of International Journal of Bifurcation and Chaos.

engineering applications of complex systems—for example in power grids.

Over in Western Australia, Curtin University's Professor Ba-Ngu Vo is currently driving development of tracking systems and robotics to improve multi-agent systems management. At the University of Western Australia, Professor Melinda Hodkiewicz is leading investigation into application of current understanding of system failure and lifetime prediction to problems of system reliability in engineering operations—particularly in the resource sector in WA. Integration of system-level information will enable development of better models to demonstrate impacts of component interdependence on overall system performance. And her colleague Professor Michael Small, who was chair of this conference, leads a joint initiative between CSIRO Mineral Resources and UWA Faculty of Engineering, applying the mathematics of Complex Systems theory to problems in Engineering for Remote Operations.

Australia is also fostering international collaborations within the field, with University of Adelaide's Dr Lewis Mitchell working with Dr Dion O'Neale, from the University of Auckland, to apply theoretical modelling to the understanding of social systems.

PREFERENTIAL ATTACHMENT



Construct a network as follows. At each step add a new node with m edges, each of those m edges connects to existing nodes with probability proportional to the number of edges that that node already has. Over time, the network will evolve a scale-free structure—the probability of a node having k edges is given by $P(k) \propto k^{-\gamma}$ for $k \geq m$ and a positive constant γ. This means that there is a finite non-zero probability of nodes having an arbitrary large number of connections.

Figure 1: A scale free network with exponent $\gamma<2$. Such things exist and can be generated (with techniques proposed by Professor Small), but are not a consequence of preferential attachment.

CONTROLLABILITY

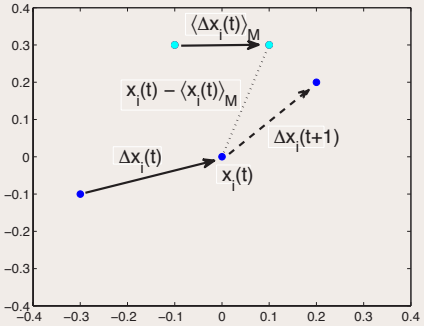


Figure 2: State estimation and update according to a discrete filtering scheme of Professor Small.

Consider a network of N nodes coupled through an adjacency matrix A ($a_{ij}=1 \leftrightarrow$ node-i and node-j are connected, 0 otherwise) and construct the following coupled dynamical system:

$$\frac{dx_i}{dt} = f(x_i) + c\sum_{i=1}^{N} a_{ij} H x_j$$

where H is an input matrix. Under what conditions (on A and c) do the states of the nodes synchronise? Or do clusters synchronise? How does one control this system to achieve a particular state?

COLLECTIVE MOTION

Consider a swarm of interacting but independent agents. Each is driven by a desire to remain close to the rest of the flock, but also to maintain a safe distance. Velocity is then controlled by a trade-off between *attraction* $\mathcal{A}$, *repulsion* $\mathcal{R}$ and *alignment* $\mathcal{G}$. Update the position of particle i at time t via

$$x_i(t) = x_i(t-1) + \mathcal{A} + \mathcal{R} + \mathcal{G} = x_i(t-1) + \delta\left(\lambda\phi\left(\frac{1}{N}\left\|\sum_{\|x_n - x_i\|<\epsilon} x_n(t-1) - x_i(t-1)\right\|\right) + \frac{1-\lambda}{N}\sum_{\|x_n - x_i\|<\epsilon} v_i(t-1)\right)$$

where the potential ϕ accounts for both attractor and repulsion, and v is the velocity alignment term. Collective behaviour such as swarming and murmuration emerge from this simple model.

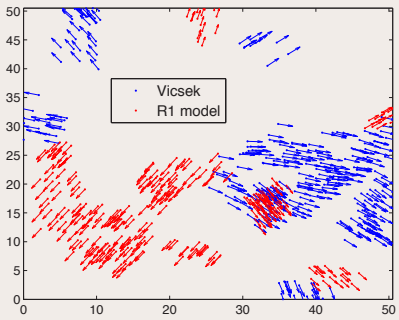


Figure 3a: Flocking motion from a model of collective motion and from a numerical modelled fitted to data generated from the first model.

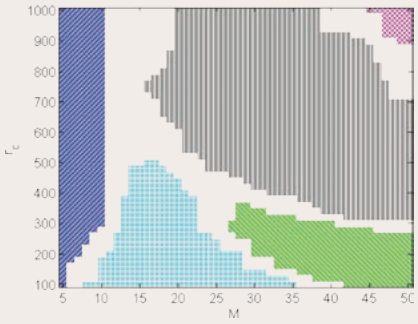


Figure 3b: A bifurcation diagram of collective motion for a model built from (real) flocking pigeons. The different colours denote parameter regions exhibiting distinct dynamical behaviours.

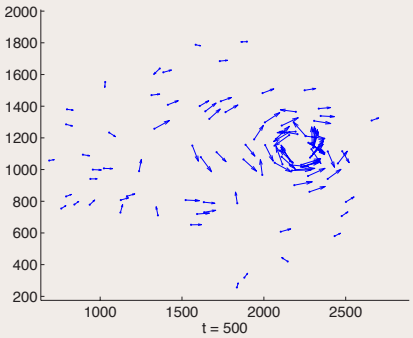


Figure 3c: Collective motion model exhibiting counter-rotating vortices. This is something that is not possible with the most common models of collective motion, but which can arise from the model above proposed by Professor Small.

1.07 AUSTRALIA-JAPAN GEOMETRY, ANALYSIS AND THEIR APPLICATIONS

The University of Adelaide, 19–23 October 2015

The *Australia-Japan Geometry, Analysis and Their Applications* workshop drew a diverse group of primarily Australian and Japanese mathematicians to Adelaide in a quest to build research links and open pathways for future collaboration. Participants explored a robust program of topics ranging from geometry and topology and analysis and differential equations, to operator algebras and mathematical physics.

Geometry and analysis are highly complementary fields of inquiry, with geometrical information vital to manifolds analysis, such as studying the long-time solutions to evolution equations. These evolution equations can then be applied to analysis of the behaviour of related linear and non-linear partial differential equations (PDE) solutions. On the other hand, techniques from analysis often prove useful in geometry, for example, geometric considerations in gauge theory can be characterised by non-linear PDE.

Central to the workshop, the open problem session provided an informal forum for participants to explore areas of interest under discussion. Having broken the ice during lunch, participants presented several open problems for discussion and to share solution ideas. The session was very successful, leading to progress in an open problem presented by Dr Guo Chuang Thiang, which has since been published on arXiv (**http://arxiv.org/abs/1510.04785**).

Given the wide range of backgrounds among the participants, one of the primary challenges for this workshop was to promote interdisciplinary communication. That this was successfully achieved was in no small part due to the hard work put in by the speakers to make their talks accessible to wider audiences than a usual disciplinary conference. Their efforts were greatly appreciated. A number of participants commented on talk quality in their evaluation forms.

"Very warm atmosphere, which will create a new bridge of international collaboration between Australia and Japan,"

Professor Tsuyoshi Kato

Organisers

Dr David Baraglia, The University of Adelaide
Prof. Alan Carey, The Australian National University
Prof. Tsuyoshi Kato, Kyoto University, Japan
Dr Melissa Tacy, The University of Adelaide
Dr Guo Chuan Thiang, The University of Adelaide
Prof. Mathai Varghese, The University of Adelaide

Special Presenters

Prof. Peter Bouwknegt, The Australian National University
Research interests: string theory, conformal field theory, T-duality and integrable models of statistical mechanics
Prof. Alan Carey, The Australian National University
Research interests: analysis and geometry, mathematical physics
Dr Florica Cirstea, The University of Sydney
Research interests: nonlinear equations and their applications
Prof. Miko Furuta, University of Tokyo, Japan
Research interests: Atiyah-Singer index theory and gauge theory
Dr Kiyonori Gomi, Shinshu University
Research interests: geometry and topology
Prof. Martin Guest, Waseda University
Research interests: geometry
Emer. Prof. Keith Hannabuss, University of Oxford
Research interests: quantum field theory, quantum measurement, operator algebras, noncommutative geometry
Prof. Andrew Hassell, The Australian National University
Research interests: spectral and scattering theory, partial differential equations and microlocal analysis
Prof. Tsuyoshi Kato, Kyoto University
Research interests: differential geometry
Asst. Prof. Yoshikata Kida, University of Tokyo
Research interests: group theory and ergodic theory
Assoc. Prof. Adam Rennie, University of Wollongong
Research interests: noncommutative geometry, index theory, operator algebras, applications to topology and geometry
Prof. Steven Rosenberg, Boston University
Research interests: differential geometry in finite and infinite dimensions, mathematical physics
Dr Adam Sikora, Macquarie University
Research interests: linear Partial Differential Equations and Harmonic Analysis, Analysis, Lie groups: singular integrals, spectral and Fourier multiplier theorems, Bochner-Riesz summability, functional calculi and spectral analysis of elliptic and sub-elliptic differential operators, spectral analysis of operators with periodic or almost periodic coefficients, Riesz transforms, semi-groups of operators and heat kernels, wave equation
Dr Anne Thomas, The University of Sydney
Research interests: geometric group theory and rigidity
Dr Leo Tzou, The University of Sydney
Research interests: linear and nonlinear analysis, mathematical physics
Prof. Joseph Wolf, University of California, Berkeley
Research interests: Lie groups and homogeneous spaces, harmonic analysis, complex manifolds, Riemannian geometry

MathSciNet Classification

58G15, 81T13, 58Z05

Web Links

www.iga.adelaide.edu.au/workshops/WorkshopOct2015/

Other Sponsors

Institute for Geometry and its Applications, The University of Adelaide, AustMS

Key Contact

Dr David Baraglia, The University of Adelaide, **david.baraglia@adelaide.edu.au**

1.08 RECENT TRENDS IN NONLINEAR EVOLUTION EQUATIONS

The University of Sydney, 4–5 November 2015

National and international field experts highlighted both the spectacular progress and key challenges in the study of nonlinear evolution equations. With a strong mix of established, emerging and student research talent, the event proved effective in stimulating collaboration and setting future research priorities.

This workshop showcased recent developments in the study of both nonlinear diffusion equations and equations of geometric flows. It highlighted key challenges for future investigation in this area, including quantitative analysis of the dynamics of solutions arising from the flows generated by deterministic and nondeterministic and geometric evolution equations.

The two-day program featured 17 talks delivered by research leaders in nonlinear diffusion equation and geometric flows. Stimulating discussion, these highlighted salient ideas, proofs and questions in the field. A conference highlight, invited speaker Professor Fernando Quirós, from the Universidad Autónoma de Madrid, Spain, presented his recent results on the regularity theory of nonlocal diffusion equations. The University of Adelaide's Dr Melissa Tacy also won praise for her presentation.

The conference attracted participants from all over Australia including postgraduate students and early career researchers. Plenty of breaks were built into the program to allow for networking and discussions between participants.

"Very nice talks and good organisation."

Professor Yihong Du

Organisers

Dr Daniel Hauer, The University of Sydney
Dr Valentina Wheeler, The University of Wollongong

Special Presenters

Prof. Ben Andrews, The Australian National University
Research interests: differential geometry, partial differential equations, and their applications
Dr Yann Bernard, Monash University
Research interests: geometry of elastic surfaces, functional analysis, harmonic analysis, geometric analysis, elliptic and parabolic PDEs, variational calculus
Prof. Norman Dancer, The University of Sydney
Research interests: nonlinear analysis, especially degree theory, Morse theory and Conley index; applications to nonlinear ordinary and partial differential equations, including singular perturbations; bifurcation theory.
Assoc. Prof. Daniel Daners, The University of Sydney
Research interests: partial differential equations (particularly elliptic and parabolic boundary value problems), dynamical systems, analytic semigroup theory, operator theory
Dr Jérôme Droniou, Monash University
Research interests: theoretical and numerical analysis of partial differential equations, analysis, applied mathematics
Dr Weiwei Ding, The University of New England
Research interests: Nonlinear partial differential equations, propagation phenomena
Prof. Yihong Du, The University of New England
Research interests: nonlinear elliptic and parabolic equations and nonlinear functional analysis
Dr David Galloway, The University of Sydney
Research interests: solar and geodynamo modelling
Assoc. Prof. Zihua Guo, Monash University
Research interests: harmonic analysis and nonlinear PDEs
Dr Andree Lischewski, University of Adelaide
Research interests: Differential geometry, Pseudo-Riemannian geometry and twistor theory
Assoc. Prof. James McCoy, University of Wollongong
Research interests: geometric analysis, differential geometry, partial differential equations and topology
Dr Pierre Portal, The Australian National University
Research interests: Fourier analysis
Prof. Fernando Quirós Gracián, Universidad Autónoma de Madrid, Spain
Research interests: nonlinear diffusion equations
Prof. Derek Robinson, The Australian National University
Research interests: Lie groups, harmonic and Fourier analysis, operator algebras and functional analysis, partial differential equations
Dr Melissa Tacy, The University of Adelaide
Research interests: semi classical analysis, harmonic analysis, analysis of PDEs
Prof. Xu-Jia Wang, The Australian National University
Research interests: elliptic and parabolic partial differential equations and applications in geometry and physics
Dr Glen Wheeler, University of Wollongong
Research interests: geometric analysis,

MathSciNet Classification

35K92, 35K93, 35B40

Web Links

www.maths.usyd.edu.au/u/dhauer/nonlinear-evolution/

Other Sponsors

Kopystop

Key Contact

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1.09 SM² STATISTICAL MECHANICS OF SOFT MATTER

Swinburne University of Technology, 30 November–1 December 2015

With a focus on mathematical modelling of soft matter, this workshop brought together researchers at the interface of mathematics and physics to build links and strengthen the community.

The SM² workshop covered some of the current and most important issues within the field of mathematical modelling of soft matter. The variety and depth of the scientific programme allowed discussions of a vast range of paradigms, techniques and concepts in the field, including continuum, discrete and stochastic modelling of liquid, gaseous, granular and colloidal systems out of equilibrium. Polymer rheology and surface science, active matter dynamics and fundamentals of thermodynamics and statistical mechanics of non-equilibrium were also amply addressed.

Findings presented at SM² are likely to have a strong impact on Australia's research landscape. These included:

- new results in non-equilibrium fluctuation relations, as applied to homogeneous and inhomogeneous systems such as nanopores
- advancements in modelling energy exchange and storage at chemically different surfaces, with possible technological value for energy capture techniques in saline waters
- improved continuum modelling of membranes using Calculus of Variations methods, with regards to wrinkling and folding
- advancement of algorithms for the simulation of self-avoiding walks
- better modelling of colloidal interactions, in agreement with newly-developed experimental techniques
- innovative directions in the simulation of active and biological matter, in relation to pattern formation, using continuum and stochastic equations
- fresh paradigms in analytical methods for integral equations
- novel results in rare gas dynamics and nanoscale liquid-solid interactions via Boltzmann equation and MD
- progression in quantifying thermo-dynamical properties of liquids using geometry and lattices

A robust exchange of ideas, the event fostered collaboration among the scattered research groups leading Australian discovery in this field through regular discussion opportunities. There was a palpable sense of community with strengthening relationships and students and early career researchers supported in presenting their work.

Providing a strong foundation for growth, women accounted for 15 per cent of participants. Organisers are exploring a number of strategies to strengthen female attendance including a scholarship program to assist with travel expenses and increased presence of women within the keynote speaker panel.

SM² proved to be a sought-after, enjoyable and productive workshop, which significantly contributed to the strengthening and enrichment of the mathematically oriented soft matter community in Australia.

"SM² Statistical Mechanics of Soft Matter 2015 brought together many of the leaders in the statistical mechanics of soft matter in Australia. New developments were shared in a program of oral presentations. A highlight of the workshop was the provision of opportunities for discussion of research questions by the delegates, including research leaders, emerging leaders and research students. This allowed a number of fundamental problems and approaches to be debated that will enhance development in this important area, and especially the understanding of nonequilibrium systems.

Professor Debra Bernhardt

Organisers

Dr Nathan Clisby, The University of Melbourne
Dr Federico Frascoli, Swinburne University of Technology
Dr Andrey Potosky, Swinburne University of Technology
Dr Richard Sadus, Swinburne University of Technology
Prof. Billy Todd, Swinburne University of Technology

Special Presenters

Prof. Debra Bernhardt, The University of Queensland
Research interests: theoretical and computational approaches to developing and applying a fundamental understanding of the behaviour of matter within a wide range of problems including transport in nanopores, fluctuation phenomena, design of materials, gas separation, energy storage and conversion

Prof. Denis Evans, The Australian National University
Research interests: non-equilibrium statistical mechanics and thermodynamics

Prof. David Huang, The University of Adelaide
Research interests: statistical mechanics, soft condensed matter theory, computer simulation of liquids and complex fluids, organic photovoltaics, microfluidics and nanofluidics, water at hydrophobic surfaces, nucleic acid structure, dynamics and thermodynamics.

MathSciNet Classification

82C05, 82B35, 82B05

Web Links

http://smsq.github.io/2015

Other Sponsors

ACEMS, Department of Mathematics, Swinburne University of Technology

Key Contact

Dr Federico Frascoli, Swinburne University of Technology, **ffrascoli@swin.edu.au**

1.10 KOZWAVES 2015: THE SECOND INTERNATIONAL AUSTRALASIAN CONFERENCE ON WAVE SCIENCE

University of Adelaide, 6–9 December 2015

With a focus on the development of mathematical and numerical tools, *KOZWaves 2015* brought together wave scientists from academia, industry and government to discuss contemporary wave research.

KOZWaves 2015 provided a multi-disciplinary forum for dissemination of contemporary wave research between the different branches of wave theory and its applications. Discussion focused on the development of mathematical and numerical tools that underpin the range of wave phenomena.

The second in the series, this event brought together 56 wave scientists from academia, industry and government agencies, a 40 per cent increase in participation over the first *KOZWaves* conference in 2014. Over 90 per cent of attendees presented their work at the conference.

Key themes at *KOZWaves 2015* included:

- Optimisation of ocean wave energy devices, for example, by maximising the capture width of individual devices, and arranging multiple devices to interact constructively.
- Development of active and passive cloaking devices, and of metamaterials, used, for example, for super resolution optical imaging.
- Modelling ocean waves in extreme environments, in particular, during hurricanes, rogue wave events, and waves in the sea ice-covered oceans, including wave impacts on ice shelves.

Four highly regarded international research leaders attended the conference as invited speakers. Professor Mathias Fink, the founder of the Langevin Institut in Paris, France and one of the pioneers of time reversal imagery presented his research on wave control with space or time manipulations. Professor William Perrie, a Chief Scientist at Canada's largest centre for oceanography discussed updates to the *WAVEWATCHIII* forecast model for wave scattering in the marginal ice zone and its use in marine forecasting. Associate Professor William Parnell, a mid-career researcher who leads the Waves in Complex Continua group at the University of Manchester, UK talked about elastodynamic metamaterials. Finally Associate Professor Ying Wu, another mid-career researcher who leads the Waves in Complex Media Research Group at the King Abdullah University of Science and Technology, Saudi Arabia, gave a presentation on homogenisation schemes for periodic structures and their applications to metamaterials.

There were several other invited speakers from Australia and New Zealand and many other researchers from Australasia, the UK, USA, China, Germany and Singapore contributed presentations to the conference.

Collaboration was also a key component of *KOZWaves 2015*, with many constructive comments and questions after each presentation, and a high level of interactions between the participants. Lively discussions continued into the evenings over dinner, and a number of research collaborations were established as a result of the conference.

Feedback from the participants indicated how much they gained from the conference and how much they enjoyed it. In particular, they commented on the usefulness of the broad range of applications covered and the clear mathematical connection between the different research areas. They unanimously endorsed the size, format and atmosphere of the conference. The organising committee was particularly pleased at the high attendance of the General Meeting with approximately 30 of the conference delegates participating. The attendees voted that the next meeting in the series would be held in Auckland in two years' time.

One aspect that will be addressed as a priority going forward to the next conference, which will be held in New Zealand in 2018, is increasing the participation of women in the conference. While two out of the eight invited speakers were female, only eight out of 56 conference participants were women and attempts to encourage more female participation were unsuccessful.

Organisers

Dr Luke Bennetts, The University of Adelaide
Dr Hyuck Chung, Auckland University of Technology, NZ
Prof. Ross McPhedran, The University of Sydney
Assoc. Prof. Mike Meylan, The University of Newcastle
Dr Fabien Montiel, University of Otago, NZ

Special Presenters

Prof. Richard Blaikie, University of Otago, NZ
Research interests: nanophotonics, micro and nano fabrication, electronic device engineering
Prof. Mathias Fink, Institut Langevin, France
Research interests: time reversal mirrors, transient elastography
Assoc. Prof. Nicole Kessissoglou, The University of New South Wales
Research interests: acoustics, structural vibration and transmission, fluid-structure interaction, active vibration control
Prof. Yuri Kivshar, The Australian National University
Research interests: nonlinear wave science
Assoc. Prof. Richard Manasseh, Swinburne University of Technology
Research interests: fluid dynamics, bubble acoustics
Prof. William Parnell, University of Manchester, UK
Research interests: continuum mechanics, solid mechanics, acoustics, elasticity, elastodynamics, homogenisation, micromechanics
Prof. William Perrie, Bedford Institute of Oceanography, Canada
Research interests: ocean wave modelling, role of waves in global climate system
Assoc. Prof. Ying Wu, King Abdullah University of Science and Technology, Saudi Arabia
Research interests: metamaterials, time-reversal imaging, super-resolution

MathSciNet Classification

35L05, 74J99, 76D33

Web Links

www.maths.adelaide.edu.au/kozwaves2015/

Other Sponsors

The University of Adelaide, Auckland University of Technology, ANZIAM, National Computational Infrastructure, Office of Naval Research Global

Key Contact

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KOZWAVES 2015

By Dr Luke Bennetts

Waves are fundamental to our understanding of science and nature. They surround us on water and land, in sound and light and in modern technology, such as fibre optic cables and medical imaging. We surf water waves, protect our towns and cities from earthquakes and tsunamis, and use electromagnetic waves in technologies that save lives and keep us globally connected.

Bringing these phenomena together is a unifying framework known as wave theory, an area of strength within the local scientific community. Australasian scientists are currently leading projects in many areas of wave science, including design of ocean wave energy devices, development of cloaking devices and metamaterials, and modelling ocean waves in extreme environments, such as during hurricanes and in the sea-ice-covered oceans.

With an Australasian wave science community essential to encourage collaboration and advance discovery, local researchers launched the KOZWaves conference series in 2014. Now running biennially, this event provides both a platform for discussion and a launching pad to strengthen the region's global impact. Quickly growing as it catches international attention, the event attracts leading mathematicians, physicists, material scientists, engineers and geophysicists.

There is no doubt KOZWaves is already having a positive impact both locally and internationally. On the back of the second conference, held at the University of Adelaide in December 2015, organiser Dr Luke Bennetts will undertake a project with members of the DST Group to design ultrathin soundproof coatings. He has also been invited for a research trip to the Waves in Complex Media Group at KAUST, Saudi Arabia.

Closer to home, Australian researchers are rapidly discovering new applications of wave theory. Research teams at Swinburne University (led by Associate Professor Richard Manasseh) and the University of Adelaide (led by Professor Ben Cazzolato) are helping develop efficient devices to extract vast sources of renewable energy available in ocean waves. This will significantly impact current projects to deploy wave energy devices off the Australian coastline. An Australian-New Zealand collaboration, involving researchers at the University of New South Wales, is also underway to investigate sonic crystals. These structures are designed to act as shields from noise pollution such as near highways and railways.

The Aussie-Kiwi collaborations are set to continue with teams working to shed light on the destructive effects of ocean waves on sea ice in the Arctic and Antarctic. These findings have the potential to significantly improve climate studies and safety forecasts for shipping and other human activity in and around ice-covered oceans.

As the community thrives, KOZWaves is predicted to become one of the premier events in an increasingly important area of scientific discovery. In February 2018, KOZWaves will move to New Zealand with the third event to take place in Auckland.

Global Leaders to Watch

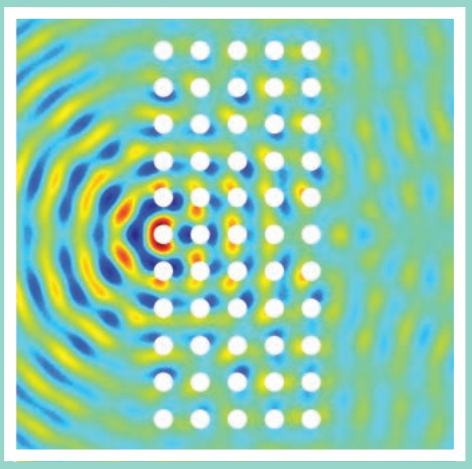
Professor Mathias Fink

Based at France's Ecole Superieure de Physique et de Chimie Inustrielles (ESPCI) in Paris, Professor Fink is unquestionably one of the world's leading wave scientists with 55 patents and over 350 papers to his name. He founded and directed the world-leading centre for wave science and a French 'laboratory of excellence', the Lagevin Institute at ESPCI. A member of the French Academies of Science and Engineering and Chair of Technological Innovation at the College de France, he is best known for pioneering time reversal mirrors. Used to focus waves, this work has been applied in medical imaging and electromagnetic communications.

Professor William Perrie

A Chief Marine Scientist at Bedford Institute of Technology, Canada's largest centre for ocean research, Professor Perrie is a leading authority on ocean wave modelling. Furthering understanding of these models, he has used numerical models, field experimental data and remote sensing methods to explore their role in the global climate system. He has led research investigations into extreme "hurricane" waves: wave interactions with currents and waves in the Arctic Ocean. Highly published he has written over 180 journal articles and two books, and is currently Editor-In-Chief of leading international journal Ocean Modelling.

The presentations at KOZWaves covered a range of governing equations, including Helmholtz equation (e.g. acoustic waves), potential-flow equations (e.g. surface water waves) and thin-plate equations. These are illustrated by the figures below.

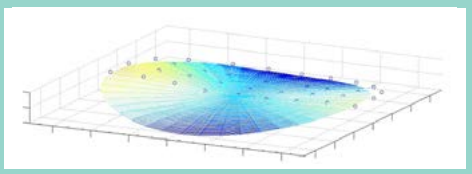


Acoustic waves travelling through a lattice of circular sound-hard inclusions (Fabien Montiel, Uni Otago, NZ).

Figure A shows acoustic waves travelling through a lattice of sound-hard inclusions, which is governed by the Helmholtz equation

$$\Delta\phi + k^2\phi = 0$$

in the region surrounding the inclusions, where $\Delta = (d/dx, d/dy)^2$ and ϕ is the acoustic potential, and $\phi_n = 0$ on the boundaries of the inclusions.



A thin floating elastic disk bending under water wave forcing (Fabien Montiel, Uni Otago, NZ).

Figure B shows a thin floating elastic disk bending under water wave forcing. The motion of the plate is governed by the Kirchhoff-Love thin-plate equation

$$(1-\sigma M)\,w + F\Delta^2 w = \phi$$

where w is the vertical displacement of the plate, σ is a frequency parameter, M and F are scaled versions of the mass and flexural rigidity of the plate, and ϕ in this case is the velocity potential of the water at the lower surface of the plate.

1.11 GUTTMANN 2015–70 AND COUNTING

Noah's on the Beach, Newcastle, Australia, 7–8 December 2015

This conference highlighted Professor Tony Guttmann's contributions to the field of critical phenomena and the study of complex systems in both mathematics and physics.

This two-day international conference honoured the work of Professor Tony Guttmann as he celebrated his 70th birthday. Professor Guttmann has made many outstanding contributions to the field of critical phenomena and to the mathematics community of Australia, and the conference was very well attended in recognition of this.

The overall theme of this workshop was critical phenomena. These are universal features of complex systems, which display emergent behaviour, and describe phenomena whereby macroscopic behaviour emerges from interactions between simpler, microscopic components.

One of the outstanding features of this area is the cross-flow of research outcomes. Methods developed to study exact solutions have opened new avenues for understanding pure combinatorics while conversely results from pure combinatorics have been applied to successfully solve a wide class of models exhibiting complex behaviour.

Professor Mireille Bousquet-Mélou (University of Bordeaux) gave a talk about lattice paths in the quarter plane. These paths are used to model polymer phase transitions. She discussed many interesting combinatorial aspects of these paths, particularly how to solve certain enumeration problems—an essential first step towards an exact understanding of the phase behaviour of polymer models. Professor Christian Krattenthaler (University of Vienna) discussed how many random walkers with excluded volume constraints (a model of polymer phase transitions) are related to group characters—a very interesting connection one would not naturally expect. Professor Jon Borwein (University of Newcastle) provided another interesting connection with random walks, illustrating deep connections with number theory.

Another connection between critical phenomena and pure mathematics occurs with conformal field theory, which has many connections with topology and algebra. Professor Jesper Jacobsen from the Ecole Normale Supérieure in Paris spoke about the connection between graph colourings (related to the famous four colour problem) and its unexpected connection with conformal field theory.

A different approach to understanding complex phenomena is to use computer simulations. One of the major hurdles of Monte Carlo simulations is to overcome the phenomena of critical slowing down. To obtain useful results near the phase transition it is necessary to develop algorithms to overcome this slowing down. Dr Tim Garoni (Monash University), who reviewed the famous Swendson-Wang algorithm showing how it could be extended to other models, discussed this topic in his talk.

The above selection of presentations is a small subset of the twenty-one talks. They all connected to either (or both) the physics or mathematics associated with critical phenomena. The satisfying feature of these talks was how well attended they all were demonstrating the broad interest of the talks.

The conference ended with a well-attended public lecture, *Journeys through Mathematics and Life*, by the University of Newcastle's Professor Nalini Joshi and high school mathematics teacher Cassandra Portelli (Hunter School of Performing Arts). The lecture was an illuminating presentation of how mathematics has been woven into their lives and careers. It was jointly presented by this conference and the adjacent ANZAMP conference at Newcastle City Hall.

The conference was unexpectedly well attended, pointing to the value of Professor Guttmann's contributions to mathematics in Australia and internationally over the course of his career. Holding it in the lead up to the ANZAMP conference meant that many participants were able to attend both conferences.

"Tony's many research interests were all represented, resulting in a nice mix of participants and talks across statistical mechanics and enumerative and algebraic combinatorics."

Professor Ole Warnaar

Organisers

Dr Andrea Bedini, The University of Melbourne
Dr Richard Brak, The University of Melbourne
Dr Nathan Clisby, The University of Melbourne
Kerry Hill, The University of Melbourne
Dr Judy-Anne Osborn, The University of Newcastle
Prof. Aleks Owczarek, The University of Melbourne

Special Presenters

Prof. Mireille Bousquet-Mélou, University of Bordeaux, France
Research interests: enumerative combinatorics, properties of large random objects (permutations, graphs, maps, lattice walks)
Prof. Jesper Jacobsen, Ecole Normal Supérieure, Paris, France
Research interests: statistical physics, disordered systems, conformal field theory, exactly solvable models
Prof. Christian Krattenthaler, University of Vienna, Austria
Research interests: enumerative and algebraic combinatorics, hypergeometric series and number theory
Prof. Jean-Marie Maillard, CNRS, Pierre and Marie Curie University, Paris, France
Research interests: mathematical physics, integrable systems
Prof. Christoph Richard, Friedrich-Alexander-Universität Erlangen-Nürnberg
Research interests: mathematical theory of aperiodic order, exactly solvable models, enumerative combinatorics, asymptotic analysis, dynamical systems, ergodic theory, probability theory

MathSciNet Classification

82B27, 05.10

Web Links

www.andreabedini.com/guttmann2015/

Other Sponsors

ACEMS

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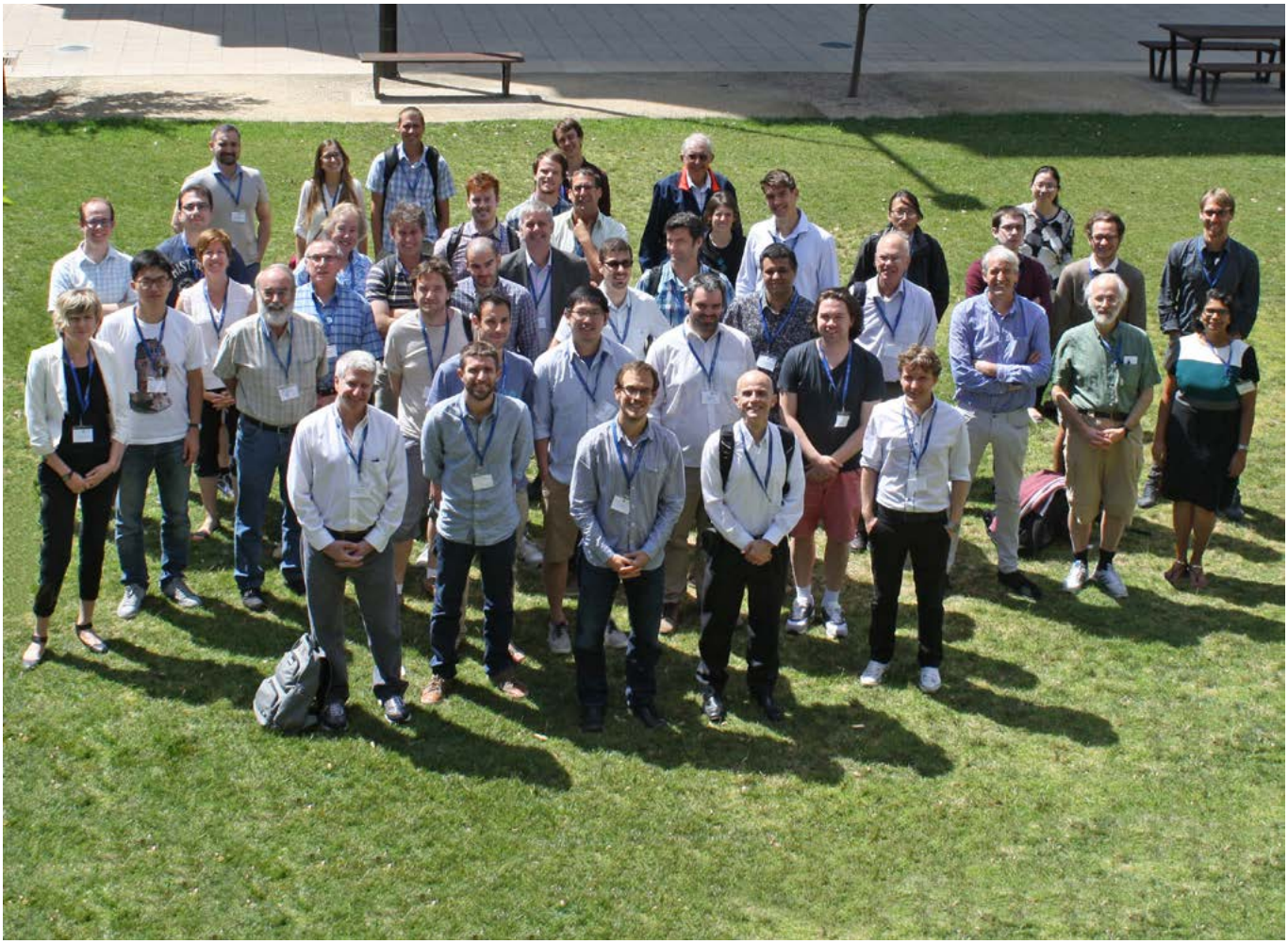
Centre of Excellence for Mathematics
and Statistics of Complex Systems



GUTTMANN 2015: MODELLING PHASE TRANSITIONS

By Dr Nathan Clisby

Phase transitions, where materials change from one state to another, are ubiquitous in nature, and give us a fundamental organising principle for understanding our world. One of the most powerful techniques for understanding phase transitions is to study mathematical models that reproduce this behaviour. In Guttmann 2015 we celebrated the career of Professor Tony Guttmann, one of the key researchers in this field, and presented and discussed the latest research arising in the study of these mathematical models.

Professor Guttmann has been a pioneer in the study of simple mathematical models which are able to give us deep insight into real world phenomena, in particular into the nature of phase transitions such as the boiling of water as it changes state from a liquid to a gas. Examples of such simple models include the Ising model, which models the behaviour of a magnet, the percolation model, which describes how water moves through sediments and floating sea ice, and self-avoiding walks, which models polymers (long molecules, such as proteins or DNA). These simple models are generally studied on a grid (or lattice), and although they are only very rough approximations of real world systems, it turns out that due to "universality" they give exact information about the nature of phase transitions. The field of physics devoted to the understanding of phase transitions is called critical phenomena.

Professor Guttmann has been a pioneer in the study of simple mathematical models, which are able to give us deep insight into real world phenomena

As a consequence of these models being on a lattice, many of their basic properties can be understood by exactly counting the number of allowed configurations for small systems, and then trying to extrapolate these counts to larger systems in order to extract information about the phase transition. For example, self-avoiding walks are walks on a grid, for which the only rule is that the walk cannot visit a grid site twice, and by counting the number of walks with 1, 2, 3, 4$\cdots$ steps we are able to estimate the properties of extremely long polymers (sophisticated computer algorithms have allowed us to discover that there are 101947102 935574661937879000071923676 self-avoiding walks of 79 steps on the square lattice, and 2941370856334701726560670 self-avoiding walks of 36 steps on the simple cubic lattice).

This area of research is known is physical combinatorics, and it is an extremely rich area because not only does the principle of universality allow us to get exact information from simple models, the physics of the systems studied can often inspire interesting and beautiful combinatorial problems, which are of mathematical interest in their own right.

Professor Guttmann has been instrumental in obtaining longer series for self-avoiding walks and many other models, and then developing sophisticated methods to analyse these series and extract as much information from them as possible.

The *Guttmann 2015 – 70 and Counting* conference was held in honour of his broad and deep contributions to this field in Newcastle, Australia from December 7–8, 2015.

At the conference, Professor Mireille Bousquet-Mélou (University of Bordeaux) gave a talk about lattice paths avoiding the quarter plane. These paths are used to model polymer phase transitions. She discussed many interesting combinatorial aspects of these paths, particularly how to solve certain enumeration problems — an essential first step towards an exact understanding of the phase behaviour of polymer models. Professor Christian Krattenthaler (University of Vienna) discussed how many random walkers with excluded volume constraints (a model of polymer phase transitions) are related to the mathematical study of group characters — a very interesting connection one would not naturally expect. The late Professor Jon Borwein (University of Newcastle) provided another interesting connection with random walks, illustrating deep connections with number theory.

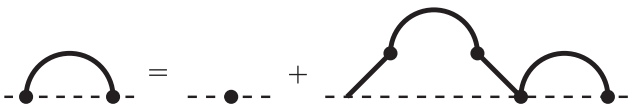
The study of critical phenomena via combinatorial models continues to be an extremely active area, despite its long history. There is the prospect of mathematically proving some key statements about self-avoiding walks, which have long been "known" to be true (in the sense that there is overwhelming numerical evidence in support of them). The study of more and more complicated models of walks that can be solved exactly also continues, giving us deeper physical insight into polymer systems.

Exactly solvable models

One of the most powerful methods to exactly solve models of walks is to first derive a recursion relation, which gives an equation for "generating functions" which count the number of walks. Often these recursion relations can be represented with appropriate pictures; indeed, finding an appropriate picture can make the derivation dramatically easier to discover.

Dyck paths are directed walks which are attached to a surface at each end, and which lie above the surface (possibly touching it) between these two ends. We show an example of a Dyck path with 10 steps. Note that Dyck paths must always have an even number of steps, as there must be an equal number of up and down steps to end on the surface.

The recursion relation in the following figure is a statement of the following fact: a Dyck path either has 0 steps, or it has at least 2 steps, and it consists of an up step, then a Dyck path (with respect to the surface $y = 1$), then a down step, and another Dyck path.



This can be written as an equation for the generating function for Dyck paths, which we call D(x), which satisfies

$$D(x) = 1 + xD(x)xD(x)$$

We can solve this equation to obtain

$$D(x) = \frac{1}{2x^2}\left(1 - (1 - 4x^2)^{1/2}\right)$$
$$= 1 + 1 \cdot x^2 + 2 \cdot x^4 + 5 \cdot x^6 + 14 \cdot x^8 + 42 \cdot x^{10} + 132 \cdot x^{12} + \cdots,$$

and reading off the coefficients we find that the number of Dyck paths with 0 steps is 1 (constant term), the number with 2 steps is 1 (coefficient of x^2), the number with 6 steps is 5 (x^6), etc. In fact, this sequence of numbers is one of the most famous in combinatorics, known as the Catalan numbers.

1.12 CONFERENCE ON GEOMETRIC REPRESENTATION THEORY

Mooloolaba, Queensland, 14–18 December 2015

With a mix of early career researchers and established international and Australian experts, this conference built on existing links between Australia's expanding representation theory community and its international counterpart.

A growing area of mathematics, representation theory is currently enjoying considerable local and international attention. Australia's standing in this field has been bolstered in recent years with a number of university appointments and a growing cohort of early career researchers and students in the field. This conference served to further strengthen ties between the Australian and international representation theory communities.

The conference featured a strong panel of prominent international and Australian categorical representation theory experts. Topics included interactions between representation theory, algebraic geometry, symplectic geometry, and number theory.

Emerging and established researchers also attended as plenary speakers, while Australian and international students embraced the rare opportunity to engage with national and global field leaders.

Women were also well represented at the conference—six of the 23 speakers and more than 15 per cent of the attendees were female.

Organisers

Assoc. Prof. Pramod Achar, Louisiana State University
Dr Masoud Kamgarpour, The University of Queensland
Dr Tony Licata, The Australian National University
Prof. Amnon Neeman, The Australian National University

Special Presenters

Assoc. Prof. Pramod Achar, Louisiana State University, USA
Research interests: geometry and combinatorics of objects arising in the representation theory of algebraic groups
Dr Emily Cliff, University of Oxford, UK
Research interests: geometric representation theory, especial chiral and factorisation algebras
Asst. Prof. John Duncan, Emory University, USA
Research interests: number theory, algebra, geometry and mathematical physics
Dr Ben Elias, University of Oregon, USA
Research interests: categorical representation theory
Prof. Doctor Peter Fiebig, Friedrich-Alexander Universität Erlangen-Nürnberg, Germany
Research interests: dualities in representation theory and geometry
Iordan Ganev, University of Texas, USA
Research interests: representation theory, algebraic geometry and quantum algebra
Dr Nora Ganter, The University of Melbourne
Research interests: elliptic cohomology and its role in representation theory
Dr Sam Gunningham, University of Texas, USA
Research interests: geometric representation theory, homotopy theory, and microlocal geometry
Prof. Anthony Henderson, The University of Sydney
Research interests: geometric and combinatorial aspects of representation theory
Prof. Michael Hopkins, Harvard University, USA
Research interests: algebraic topology, stable homotopy theory
Dr Martina Lanini, Friedrich-Alexander Universität Erlangen-Nürnberg, Germany
Research interests: representation theory, algebraic combinatorics, algebraic geometry
Dr Chul-hee Lee, The University of Queensland
Research interests: connections between number theory and mathematical physics, modular forms and q-hypergeometric series, representations of Lie algebras and quantum groups, functional relations in integrable systems (Q-systems, T-systems and Y-systems)
Asst. Prof. Elizabeth Milicevic, Haverford College, USA
Research interests: interactions between modern methods in algebraic geometry, algebraic combinatorics, and representation theory
Prof. Ivan Mirkovic, University of Massachusetts, Amherst, USA
Research interests: geometric representation theory
Dr Justin Noel, University of Regensburg, Germany
Research interests: homotopy theory, algebraic geometry
Asst. Prof. You Qi, Yale University, USA
Research interests: higher representation theory, algebraic geometry, and applications to low dimensional topology
Prof. Arun Ram, The University of Melbourne
Research interests: combinatorial representation theory
Prof. Daniel Sage, Louisiana State University, USA
Research interests: the geometric Langlands program, geometric and combinatorial methods in representation theory, Hopf algebras and quantum groups, composite materials and the G-closure problem
Dr Peng Shan, Université Paris-Sud, Orsay, France
Research interests: representation theory
Dr Pablo Solis, California Institute of Technology, USA
Research interests: loop groups, moduli spaces, and representation theory
Prof. Monica Vazirani, University of California, Davis, USA
Research interests: representation theory, combinatorics, discrete math, Hecke algebras, crystal graphs, DAHA, KLR algebras, parking functions
Dr Geordie Williamson, Max-Planck-Institut für Mathematik
Research interests: representation theory

MathSciNet Classification

17B67, 17B69, 22E50, 20G25

Web Links

sites.google.com/site/masoudkomi/mooloolaba

Other Sponsors

The University of Queensland, The Australian National University, AustMS

Key Contact

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1.13 GROMOV-WITTEN THEORY, GAUGE THEORY AND DUALITIES

Mathematical Sciences Institute and Kioloa Campus, The Australian National University, 6–16 January 2016

Closing out the Mathematical Sciences Institute's *Special Year on Geometry and Physics*, this workshop and accompanying mini-courses highlighted key areas of current research at the intersection of geometry and physics. Prominent international and Australian researchers attracted participants from Australia and overseas to foster communication and build links.

This January's workshop on *Gromov-Witten theory, Gauge Theory and Dualities* was the final event in the Mathematical Sciences Institute 2015 *Special Year on Geometry and Physics*.

The workshop began at ANU with three mini-courses on the key research priority areas of Gromov-Witten theory, gauge theory and dualities led by Professors Kenji Fukaya, Kauro Ono and Bohui Chen.

Mini Course Details:

- Prof. Kenji Fukaya, one of the world's most distinguished geometers, gave an exciting mini-course on his current work constructing a (4-3-2)-dimensional Yang-Mills field theory mixing Gauge Theory and the Fukaya category (involving holomorphic curves with boundaries on Lagrangian submanifolds). Constructing such a field theory relating Gauge Theory and the Fukaya category is an important open problem, and the subject of the famous Atiyah-Floer conjecture.
- Prof. Kauro Ono introduced attendees to symplectic topology and applications of holomorphic curves, much based on his own research with Fukaya and others.
- Prof. Bohui Chen lectured on foundations of the analysis of holomorphic curves, the subject of his work with Bai-Ling Wang.

With a solid background on each of topics these mini-course speakers brought attendees right to the frontier of current research. In particular, students were filled with excitement for further explorations.

Following the mini courses, the conference moved to ANU's coastal campus at Kioloa, where the line-up of international speakers included five ICM-invited speakers. The talks were excellent, and ranged from gauge theory and homological mirror symmetry, to Gromov-Witten invariants and contact topology.

The conference concluded with a problem session where Prof. Kenji Fukaya and Prof. Hiroshi Iritani listed some of most important open problems in the areas of the conference. Plans are in place to publish lecture notes from the mini-courses and conference contributions in the *Proceedings of the CMA* series

Both the conference and preceding mini-courses attracted a strong attendance with all participants gaining mathematically. In particular, there was a strong showing of international participants at the mini-courses who outnumbered domestic attendees.

While female attendance was strong, only one female speaker was able to present during the conference in part a reflection of the field's gender imbalance.

"The conference provided a perfect setting for some wonderful talks on some very interesting and deep mathematics. I learned a great deal about recent advances in fields related to my own."

Dr Daniel Mathews

Organisers

Prof. Peter Bouwknegt, The Australian National University
Assoc. Prof. Paul Norbury, The University of Melbourne
Dr Brett Parker, The Australian National University
Assoc. Prof. Bryan Wang, The Australian National University

Special Presenters

Prof. Bohui Chen, Sichuan University, China
Research interests: Yang-Mills theory and symplectic topology
Prof. Cheol-Hyun Cho, Seoul National University, South Korea
Research interests: homological mirror symmetry and Fukaya category
Prof. Huijun Fan, Beijing University, China
Research interests: Fan-Javis-Ruan-Witten theory
Assoc. Prof. Bohan Fang, Beijing University, China
Research interests: mirror symmetry for toric Calabi-Yau 3-folds
Prof. Kenji Fukaya, Simons Centre for Geometry and Physics, Stony Brook, USA
Research interests: Fukaya Category in homological mirror symmetry
Prof. Andriy Haydys, University of Bielefeld,
Research interests: higher dimensional gauge theory
Asst. Prof. Pedram Hekmati, IMPA, Rio de Janeiro, Brazil
Research interests: moduli spaces, generalised geometry and mathematical physics
Prof. Jianxun Hu, Zhongshan University, China
Research interests: Gromov-Witten theory
Assoc. Prof. Hiroshi Iritani, Nagoya University, Japan
Research interests: quantum cohomology and mirror symmetry
Prof. Bumsig Kim, KIAS, Seoul
Research interests: algebraic geometry
Prof. of Mathematics Xiaobo Liu, Peking University
Research interests: symplectic topology
Asst. Prof. Ziming Ma, National Taiwan University
Research interests: Calabi-Yau geometry and SYZ conjecture
Prof. Alina Marian, Northeastern University, USA
Research interests: algebraic geometry
Dr Daniel Mathews, Monash University
Research interests: contact Floer homology
Prof. Yong-Geun Oh, IBS, South Korea
Research interests: Lagrangian Floer theory and mirror symmetry
Prof. Hiroshi Ohta, Nagoya University, Japan
Research interests: Lagrangian Floer theory and mirror symmetry
Prof. Kauro Ono, Kyoto University, Japan
Research interests: Lagrangian Floer theory and mirror symmetry
Dr Brett Parker, The Australian National University
Research interests: tropical geometry and Gromov-Witten theory
Prof. Siye Wu, National Tsing-Hua University, Taiwan
Research interests: gauge theory, symplectic geometry and dualities

MathSciNet Classification

14D20, 14N35, 53D37, 53D45, 57R57

Web Links

http://maths.anu.edu.au/events/gromov-witten-theory-gauge-theory-and-dualities

Other Sponsors

AustMS

Key Contact

Assoc. Prof. Bryan Wang, The Australian National University, **bai-ling.wang@anu.edu.au**

1.14 CAPITAL NUMBER THEORY

The Australian National University, 8–9 April 2016

This workshop brought together academic researchers, students and industry to focus on the intersection of number theory with computation. It took advantage of the concentration of expertise to strengthen linkages and open the way toward collaborative investigations of new problems in this research field.

Many results are known 'for all sufficiently large integers'. With a focus on the intersection of number theory with computation, this workshop challenged attendees with the mission of addressing issues concerning the remaining cases—relatively small integers. This often requires pushing theoretical arguments, and computations, to their limits.

Professor Roger Heath-Brown's stimulating talk on Vinogradov's mean-value theorem was a program highlight. His close interaction with most of the students and academics at the conference also facilitated an exciting exchange of ideas and research topics.

The event took advantage of the concentration of expertise with inbuilt networking sessions between lectures and talks to strengthen linkages and open avenues for collaborative investigations of new problems within this area. Highly popular and effective, the program was structured using randomised talk order among speakers, with names drawn out of a hat to determine speaking order and even the chair of each session. There are plans to replicate this for future meetings.

The conference actively encouraged student talks and topics included new methods in number theory (algebraic, analytic, computational), and the use of computation.

That so many students, early career researchers and female researchers attended an event for what is a very nascent field in Australia, was in itself a significant achievement.

Industry presence was also high, with a large contingent—almost a quarter of attendees—from the Defence Department. This argues the case for a regular meeting in Canberra to foster collaboration between university-based academics and defence personnel.

This is especially important given the flagged changes to research funding, and the Government's proposals on cyber-security. Number theorists in and out of Defence can meet and foster collaboration at the repeated instalments of Capital Number Theory.

Most importantly, the success of the conference demonstrated that a short, informal, autumn meeting of the Australian number theory community is not only possible, but also exceptionally beneficial.

Organisers

Dr Mumtaz Hussain, The University of Newcastle
Dr Tim Trudgian, The Australian National University

Special Presenters

Prof. Roger Heath-Brown, University of Oxford
Research interests: analytic number theory, the Riemann zeta-function, distribution of primes, sieve theory, Diophantine approximation, and the study of rational points on surfaces

MathSciNet Classification

11M06, 11N05, 11P05

Web Links

maths.anu.edu.au/events/capital-number-theory

Key Contact

Dr Tim Trudgian, The Australian National University,
timothy.trudgian@anu.edu.au

1.15 PROBABILISTIC AND EXTREMAL COMBINATORICS DOWNUNDER

Monash University, 13–17 June 2016

With influence on computer science and other areas involving the properties of large networks, there is growing interest in probabilistic and extremal combinatorics. An Australian first, this event gathered international and Australian researchers and students for a robust exploration of the latest field advances and opportunities for collaboration.

The first Australian-led workshop dedicated to the study of probabilistic and extremal combinatorics, this event reinforced Australia's global positioning within what is a multi-impact area of research. Drawing a strong attendance of global field experts, the workshop created a vibrant platform to explore new research priorities and collaborative opportunities.

The event featured two keynote presentations on key areas within the field. Professor Noga Alon spoke on the universality of graphs, giving a survey of the area and presenting a striking new result on the old problem of determining the minimum number of vertices of a graph that contains every k-vertex graph as a subgraph, →

"The workshop was fabulous in all respects. I learned a lot, enjoyed talking to the younger mathematicians, and hope I will have the opportunity to participate in a similar event in the future."

Associate Professor Dhruv Mubayi

achieving the asymptotic leading term for the first time. Professor János Pach wound up the talks with an in-depth overview of the Vapnik-Chervonenkis dimension of graphs, and its uses in combinatorial geometry, giving new extremal results for graphs of bounded VC-dimension.

The workshop participation was strong with 65 attendees including 32 international visitors. The invited speaker program was a major feature, with many participants remarking it was the strongest group of invited speakers they had ever seen at a conference. The contributed talks were also of a very high standard. Featuring many of the world's top research leaders working in the field, the event proved an ideal platform to strengthen engagement between local mathematicians and students and international field leaders. In particular it was a powerful opportunity for postgraduate students and early career researchers to participate in discussion with potential research mentors and role models.

The workshop format included long coffee breaks and onsite lunch breaks allowing for ample discussion between participants. This engagement has resulted in several new partnerships, including a collaboration between a Monash postdoctoral researcher and Professor Noga Alon, which has already produced a paper ``Optimal induced universal graphs for bounded-degree graphs"(**http://arxiv.org/abs/1607.03234**).

As well as strong student and early career researcher attendance, women accounted for almost 25 per cent of participants, including five of the invited speakers.

"Meetings of this size and nature are critical for building community and connecting Australian mathematics to the rest of the world. The workshop was extremely well organised for the promotion of scientific discussion, with the inclusion of a problem session much appreciated."

Dr Judy-anne Osborn

Organisers

Dr Jane Gao, School of Mathematical Science, Monash University
Prof. Brendan McKay, Research School of Computer Science, The Australian National University
Prof. David Wood, School of Mathematical Science, Monash University
Prof. Nick Wormald, School of Mathematical Science, Monash University

Special Presenters

Prof. Noga Alon, Tel Aviv University
Research interests: combinatorics, graph theory and their applications to theoretical computer science; combinatorial algorithms and circuit complexity; combinatorial geometry and combinatorial number theory; algebraic and probabilistic methods in combinatorics
Prof. János Pach, École Polytechnique Fédérale de Lausanne
Research interests: combinatorics and discrete and computational geometry
Prof. Amin Coja-Oghlan, Goethe University
Research interests: combinatorics, probability theory, algorithms and complexity
Prof. David Conlon, University of Oxford
Research interests: combinatorics and number theory, Ramsey theory, extremal graph theory, additive combinatorics, pseudorandomness and random graphs
Prof. Michael Drmota, Technische Universität Wien
Research interests: number theory, combinatorial enumeration and analysis of algorithms, stochastic processes in combinatorial structures
Assoc. Prof. Catherine Greenhill, University of New South Wales
Research interests: combinatorics, asymptotic enumeration of combinatorial structures
Prof. Jim Fill, Johns Hopkins University
Research interests: probability, stochastic processes (esp. Markov chains), random structures and algorithms
Prof. Penny Haxell, University of Waterloo
Research interests: extremal combinatorics and graph theory
Prof. Mihyun Kang, Graz University of Technology
Research interests: combinatorics, discrete probability, algorithms
Prof. Alexandr Kostochka, University of Illinois at Urbana-Champaign
Research interests: combinatorics, graph theory
Prof. Michael Krivelevich, Tel Aviv University
Research interests: probabilistic methods in combinatorics, random structures, hypergraphs, extremal graph theory, Ramsey theory, positional games, theoretical computer science
Prof. Malwina Luczak, Queen Mary, University of London
Research interests: probability theory
Prof. Tomasz Łuczak, Adam Mickiewicz University
Research interests: combinatorics, discrete structures
Prof. Colin McDiarmid, University of Oxford
Research interests: discrete mathematics, random structures, algorithms and complexity, combinatorial optimisation, mathematics of operational research
Prof. Dhruv Mubayi, University of Illinois at Chicago
Research interests: combinatorics, especially extremal and probabilistic questions on graphs and hypergraphs with applications to theoretical computer science
Prof. Sang-il Oum, Korean Advanced Institute of Science and Technology (KAIST)
Research interests: graph theory, combinatorics, combinatorial optimization, graph algorithms, structural graph theory, width parameters
Prof. Angelika Steger, ETH Zurich
Research interests: graph theory, combinatorics, randomized algorithms,, probabilistic methods, combinatorial optimization, approximation algorithms
Prof. Prasad Tetali, Georgia Institute of Technology
Research interests: discrete math, probability and theory of computing: Markov chains, isoperimetry and functional analysis, combinatorics, computational number theory, and randomized algorithms
Prof. Andrew Thomason, University of Cambridge
Research interests: combinatorics, graph theory, algorithms
Dr Lutz Warnke, University of Cambridge
Research interests: probabilistic combinatorics, random discrete structures

MathSciNet Classification

05C80, 05C35, 05D40

Web Links

users.monash.edu.au/~davidwo/Downunder/

Other Sponsors

School of Mathematical Sciences at Monash University, AustMS

Key Contact

Prof. Nicholas Wormald, Monash University, **nicholas.wormald@monash.edu**

NETWORKS AND COLLABORATIONS:

THE PROBABILISTIC AND EXTREMAL COMBINATORICS DOWNUNDER WORKSHOP

By Professor Nicholas Wormald

Probabilistic and extremal combinatorics account for a significant part of the mathematics of combinatorial structures, such as networks or graphs. While extremal combinatorics examines the optimal value of functions defined on such structures, probabilistic combinatorics focuses on randomly selected structures, with varying kinds of probability distributions, and this often leads to strong results in extremal combinatorics.

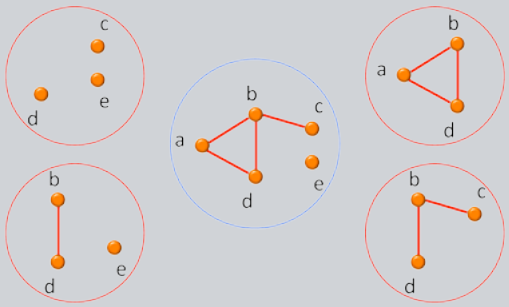
While these areas of research are largely in the realm of pure mathematics, real-world applications and motivations are not far away, including strong links to computer science algorithms, statistical physics, and complex networks such as the study of the world wide web, sociological networks, disease spread and communication barriers in engineering and health management. Randomised algorithms, which form a cornerstone of modern methods in theoretical computer science, are intimately related with probabilistic combinatorics, sharing many underlying methods.

Specific applications of probabilistic combinatorics include error-correcting codes and erasure codes, which are used in mobile communications to replace missing pieces of transmission. Random networks can also produce good examples of hash functions for computer science, and help to study the phase transitions of the truth of random logical formulae, which figure in the famous—and unsolved—problem of P versus NP. Extremal combinatorics assists with optimal design of networks and layouts.

The study of large networks has recently flourished resulting from various applications in disciplines such as computer science, biology and sociology. New trends and methods of analysis are regularly being discovered, and the next period may be one of maturity, consolidation and greater understanding of the basic principles involved.

An Australian first for this topic, the *Probabilistic and Extremal Combinatorics Downunder* workshop provided a conduit for engagement and collaboration between participating Australian and international researchers. Many significant new discoveries were presented at the workshop inspiring several notable new collaborations.

Professor Noga Alon from Tel Aviv University shared his exciting insights into universal graphs in his keynote presentation. For example, an induced universal graph for a given set H of graphs is a graph G, such that a copy of any graph in H can be made by restricting G to a subset of its vertices. A very simple example is shown in the figure below, where the central graph is induced universal for the set of 3-vertex graphs, as shown in the outer circles of the figure.



This concept can be useful in VLSI design, where one chip can have many different uses by being restricted to parts of its circuit. Professor Alon spoke on his new result that approximately determines the size $f(k)$ of the smallest graph that is induced universal for the set of k-vertex graphs. He showed that $f(k)$ is asymptotic to $2^{(k-1)/2}$ as k tends to infinity. This improved weaker results obtained in the past by many other mathematicians. The proof combines probabilistic and combinatorial arguments with some group theoretical facts.

Following on from this presentation, Professor Alon has since collaborated with Monash University research fellow Dr Rajko Nenadov to improve the best known results for universal graphs in which the degrees of the nodes are bounded.

Another international collaboration arose from Professor Sang-il Oum's talk on defective graph colourings. In graph

colourings, nodes joined by edges must have different colours, which is a concept useful for modelling timetabling problems for example. Professor Oum focused on defective graph colourings, in which it is permissible for small groups of like-coloured nodes to be joined. This led to collaboration between Professor Oum, from the Korean Advanced Institute of Science and Technology, Professor Patrice Ossona de Mendez from the CNRS in France, and Monash University's Professor David Wood. They have succeeded in proving a general result that extends known results on defective colourings of graphs embedded in surfaces.

Associate Professor Catherine Greenhill, from the University of New South Wales, spoke on a new result estimating the number of spanning trees in graphs with given degrees. When the degrees are all equal, the graph is called regular. She is now collaborating with Monash University's Dr Jane Gao on a project of randomly sampling regular subgraphs of a large regular graph. Random sampling is useful for studying properties of graphs statistically.

Professor Andrew Thomason from the University of Cambridge provided another highlight as he revealed a new method of using so-called "containers" to prove extremal results about graphs. This entails finding a small number of large pieces of a structure that contain all the sub-parts of the structure that are of interest for some purpose. Making this idea precise has yielded significant new results.

The introduction of complex martingales by Professor Brendan McKay and Dr Mikhail Isaev of The Australian National University was a new variation of a standard object in probability. They used them for new asymptotic formulae that count graphs of certain types. Johns Hopkins University's Professor Jim Fill presented an examination of randomised *Quicksort*, the most widely used sorting algorithm in computing, and established for the first time a local limit theorem for the number of key comparisons used. This gives very precise information on the running time of the algorithm.

In graph theory, a phase transition is the point at which the largest connected piece of a growing network suddenly grows from microscopic size to envelop a large proportion of the nodes. Dr Lutz Warnke gave an outstanding analysis of a random graph process originally introduced by the famous mathematician Paul Erdős, thereby demonstrating that this process exhibits a phase transition of the same type as other key processes within random graphs and statistical mechanics.

Keynote Speakers

Professor Noga Alon

A world leader in the area of probabilistic methods, he received his PhD from the Hebrew University of Jerusalem and is Baumritter Professor of Mathematics and Computer Science in Tel Aviv University, Israel. He is the author (with Joel Spencer) of the leading research textbook in the probabilistic method and the recipient of many mathematical prizes. He was a plenary speaker at 2002 International Congress of Mathematicians and has written over 550 papers, mainly in a wide variety of probabilistic and extremal combinatorics and related theoretical computer science. He became a Fellow of the American Mathematical Society in 2016.

Professor János Pach

A mathematician of the highest calibre, Professor János Pach received his Candidate degree from the Hungarian Academy of Sciences and is currently Chair of Combinatorial Geometry at École Polytechnique Fédérale de Lausanne, Switzerland. His mathematical contributions are in combinatorics and discrete geometry, and include initiating the systematic study of extremal problems on topological and geometric graphs, seminal contributions in Ramsey theory, developing the notion of semi-algebraic graphs and hypergraphs, and results on the Erdős-Hajnal conjecture (one of the most famous conjectures in extremal graph theory), amongst many others. In 2016 he became a Fellow of the American Mathematical Society.

1.16 COMPUTATIONAL SCIENCE WORKSHOP

Geoscience Australia, 7–9 June 2016

Computational scientists from a variety of disciplines and government agencies used this workshop as a platform to share ideas and explore new avenues for collaborations.

The overarching theme of the *Computational Science Workshop* was the use of computational science within the government agencies with a view to building new inter-agency collaborations, strengthening existing ones and connecting agency researchers with university computational scientists.

The workshop brought together more than 50 researchers from government agencies including Geoscience Australia, Defence Science and Technology Group, CSIRO, the National Computational Infrastructure (NCI), the Bureau of Meteorology, as well as academic researchers for three days of talks and presentations.

The overview presentations from Geoscience Australia, NCI and CSIRO IMT (Information Management and Technology) and Data61 on their strategic planning for the next generation of computational science developments were a highlight along with the talks from mathematicians at ANU, UQ and QUT on their cross-disciplinary work and computation in the presence of uncertainty.

The workshop also included three "challenge" sessions, dedicated to current technical and strategic issues including the use of modelling in the geosciences, and the creation of a platform for cooperation between agencies.

The workshop was a first for computational scientists across mathematics, statistics and computer science and in domains from meteorology, seismology and social science to engineering and supercomputing. The eagerness for collaborations between agencies and with universities was strong and pervasive, and the organisers will continue to pursue cooperative opportunities.

"A really worthwhile opportunity for computational scientists to share ideas across a wide range of agencies and universities. We'll definitely do it again!"

Professor Geoff Prince

Organisers

Prof. Geoff Prince, Australian Mathematical Sciences Institute
Dr Ole Nielson, Geoscience Australia

Special Presenters

Alan Agon, Defence Science and Technology Group
Assoc. Prof. Nick Barnes, CSIRO Data61
Research interests: computer vision, connections between computer vision and neuroscience
Prof. Lindsay Botten, National Computational Infrastructure
Research interests: computational science, optics, photonics
Dr Ross Brodie, Geoscience Australia
Research interests: geophysics
Prof. Phil Cummins, Geoscience Australia
Research interests: seismology and mathematical geophysics
Dr Gareth Davies, Geoscience Australia
Research interests: tsunami, coastal geomorphology, numerical modelling, hudrodynamics, statistical modelling
Assoc. Prof. Diane Donovan, The University of Queensland
Research interests: combinatorial structures
Dr Ben Evans, National Computational Infrastructure
Dr Andrew Feitz, Geoscience Australia
Research interests: environmental chemistry, green chemistry, materials chemistry
Dr Charmaine Franklin, Bureau of Meteorology
Dr Alexei Gorbatov, Geoscience Australia
Research interests: geodesy and surveying, geology, volcanology
Dr Craig Harrison, Geoscience Australia
Prof. Markus Hegland, The Australian National University/ANZIAM
Research interests: computational mathematics, data mining
Tom Jovanovic, The Australian National University
Pablo Rozas Larraondo, National Computational Infrastructure
Dr Brodie Lawson, Queensland University of Technology
Research interests: mathematical representation of real-world phenomena, populations of models, stochastic modelling, cellular automata/agent-based modelling
Sam Moskwa, CSIRO Information Management and Technology
Mai-Chi Nguyen, Defence Science and Technology Group
Dr Dale Roberts, National Computational Infrastructure
Assoc. Prof. Stephen Roberts, The Australian National University
Research interests: numerical solution of partial differential equations
Dr Linda Stals, MSI, The Australian National University
Research interests: efficient solution of large scale problems, parallel numerical methods, multigrid methods, cache optimisations of iterative methods, finite element methods, discrete thin plate splines, adaptive optics
Dr John Taylor, CSIRO Data61
Research interests: computational science, climate, global biogeochemical cycles, air pollution
Dr Anand Tularam, Griffith University
Research interests: partial differential equations, applications to real life problems
Prof. Stephen Tyson, The University of Queensland
Research interests: 3D visualisation, geological modelling
Dr Alf Uhlherr, CSIRO Information Management and Technology
Dr Mirko Velic, Bureau of Meteorology
Research interests: remote sensing, geomorphology, geochemistry
Dr Marshall Ward, National Computational Infrastructure
Dr John Wilford. Geoscience Australia
Dr Andy Wilkins, CSIRO
Dr Lesley Wyborn, National Computational Infrastructure

MathSciNet Classification

62Pxx, 65-XX, 68-XX, 86Axx

Other Sponsors

Geoscience Australia

Key Contact

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1.17 OTHER AMSI-SUPPORTED EVENTS

AMSI also supported a number of other events during 2015–2016.
These events included:

Analysis and Partial Differential Equations Workshop

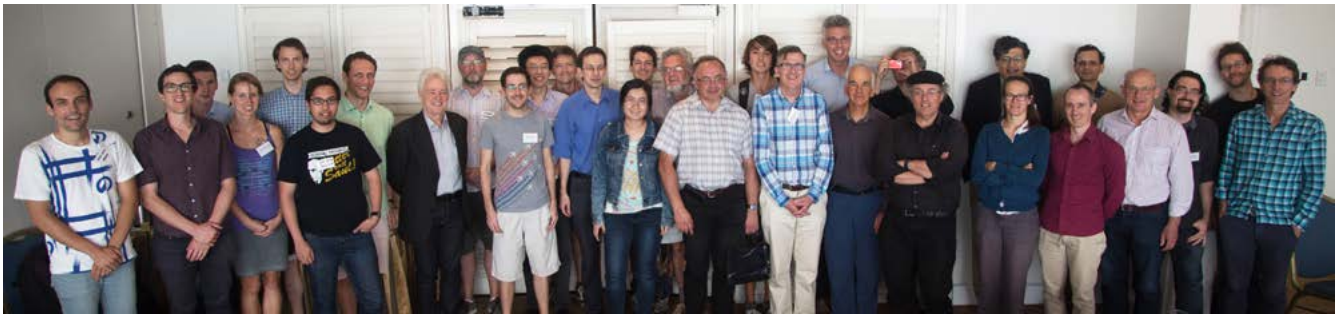
University of Wollongong
20 July 2015

Workshop in Honour of Brailey Sims

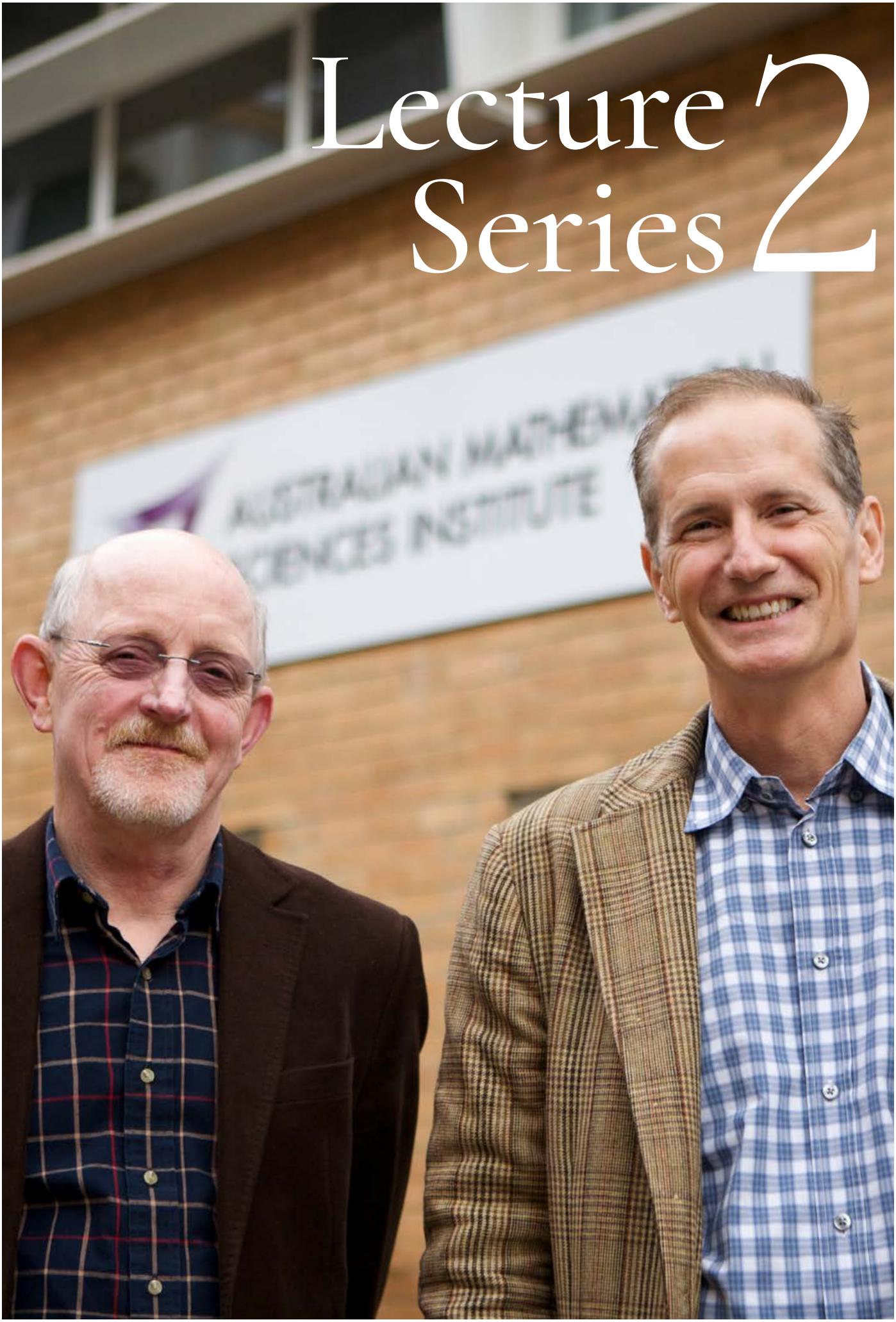
CARMA, The University of Wollongong
21–22 August 2015

STEMS2016

University of Technology Sydney
2–3 June 2016



Lecture Series 2



2 LECTURE SERIES OVERVIEW

Our world-class national tours, specialist lectures and outreach events stimulate discussion and collaboration at the cutting edge of the mathematical sciences. Both challenging and inspiring, the opportunity to engage with international field experts delivers an enhanced research experience for students, early career and established mathematical scientists.

AMSI sponsored 10 lectures across 5 states and 10 member universities.

> *"People are at the core of knowledge transfer, and now, more than ever, innovation across multiple disciplines is essential for Australia to remain competitive in the global economy."*
>
> Professor Geoff Prince, AMSI Director

2.1 AMSI-ANZIAM LECTURER PROFESSOR MICHAEL SHELLEY

Professor Michael Shelley, 27 July–12 August 2015

Sponsored in conjunction with ANZIAM and SSA, the annual AMSI Lecture Tour brings eminent international researchers to Australia, giving the research community and general public an opportunity to hear from top mathematics and statistics.

The 2015 AMSI-ANZIAM lecturer was Professor Michael Shelley, from New York University's Courant Institute of Mathematical Sciences. In late 2016, Professor Jeffrey Rosenthal, from the University of Toronto, will tour Australia as the AMSI-SSA lecturer.

Collaborative Brainpower

Taking a different view of the world from most people, Professor Michael Shelley uses mathematics to understand natural phenomena. He visited Australia as the 2015 AMSI-ANZIAM Lecturer, sharing his ideas, advanced theoretical work and tools with Australia's brightest minds.

Founder of the Applied Mathematics Laboratory at New York University's Courant Institute of Mathematical Sciences, he is interested in understanding how structures move and interact with fluids. His tools in this quest, he says, "are mathematical modelling, simulation and analysis."

For inspiration he turns to the natural world—flags flapping in the wind, snakes slithering underfoot and bacteria swimming through baths. Often making connections not obvious to others, such as flapping flags and renewable hydroelectricity.

"My theories on flags influenced engineers who design flapping devices to extract energy from flowing water. And my modelling of "turbulent" bacterial baths has helped biophysicists understand that how bacteria swim—by turning their flagellae—can have a huge effect on collective behaviour and gave new theoretical tools for studying other more complicated problems in biology."

By working on understanding natural phenomena, Michael explains, groundwork is being laid for others to work on problems of higher complexity. Innovation of this kind requires collaboration across many fields of research such as mathematics, biology, physics, engineering and chemistry.

"People are at the core of knowledge transfer," says Professor Geoff Prince, AMSI Director. "And now, more than ever, innovation across multiple disciplines is essential for Australia to remain competitive in the global economy."

Lecture Tour dates 2015

Specialist lectures

The mathematics of swimming collectives
27 July - The University of New South Wales

Microtubule and motor-protein assemblies in biology and physics
28 July - University of Wollongong

Microtubule and motor-protein assemblies in biology and physics
6 August - The University of Melbourne

Mathematical modelling and analysis of active suspensions
10 August - Queensland University of Technology

Boundary integral methods for flows interacting with moving and flexible structures
12 August - The University of Newcastle

Public lectures

Active and flexible bodies moving with(in) fluids
30 July - The University of Western Australia

Active and flexible bodies moving with(in) fluids
4 August - University of Adelaide

Active and flexible bodies moving with(in) fluids
5 August - La Trobe University

Active and flexible bodies moving with(in) fluids
6 August - Swinburne University

Active and flexible bodies moving with(in) fluids
11 August - The University of Queensland

Biography

Professor Michael Shelley is an American applied mathematician at New York University's Courant Institute of Mathematical Sciences, where he is the Lilian and George Lyttle Professor of Applied Mathematics and Professor of Mathematics, Neural Science, and Mechanical Engineering.

Professor Shelley's research interests are in understanding complex phenomena arising in active matter, biophysics, and complex fluids, as well as in intricate fluid-structure problems that arise in understanding swimming and flying.

More specifically, he works on the modelling and simulation of complex systems arising in physics and biology. This has included free-boundary problems in fluids and materials science, singularity formation in partial differential equations, modelling visual perception in the primary visual cortex, dynamics of complex and active fluids, cellular biophysics, and fluid-structure interaction problems such as the flapping of flags, stream-lining in nature, and flapping flight.

While his own research tools are mathematical modelling, analysis, and simulation, Professor Shelley collaborates very closely with experimentalists working in biology and physics. A large part of this collaboration happens in the Applied Mathematics Laboratory at Courant Institute of Mathematical Sciences, of which he is a Co-Director and Co-Founder.

Public Lecture Abstract

Active and flexible bodies moving with(in) fluids

We are surrounded by structures that move and interact with a fluid—a flag flaps in a stiff breeze, a bird flies overhead, or a microscopic bacterium swims across a droplet of water. The study of how such immersed bodies interact with fluids has a long and interesting history, and defines a class of "moving boundary problems" that are central to science. What makes such problems especially difficult, and so fascinating for an applied mathematician is that the dynamics of body and fluid are intimately intertwined and must be treated in an integrated way. I will discuss fluid-structure interactions ranging those we can directly see, like flapping flags and flying birds—to those we cannot, such as collective behaviours of swimming microbes and the transport of structures in biological cells. These examples will make clear the absolutely fundamental role that size plays in organizing our understanding.

Technical Lectures Abstracts

Mathematical modelling and analysis of active suspensions

Complex fluids that have a "bio-active" microstructure—like suspensions of swimming bacteria or assemblies of immersed biopolymers and motor-proteins—are important examples of so-called active matter. These internally driven fluids can have strange mechanical properties, and show persistent activity-driven flows and self-organisation. I will show how first-principles PDE models are derived through reciprocal coupling of the "active stresses" generated by collective microscopic activity to the fluid's macroscopic flows. These PDEs have an interesting analytic structures and dynamics that agree qualitatively with experimental observations: they predict the transitions to flow instability and persistent mixing observed in bacterial suspensions, and for microtubule assemblies show the generation, propagation, and annihilation of disclination defects. I'll discuss how these models might be used to study yet more complex biophysical systems.

Microtubule and motor-protein assemblies in biology and physics

Many important processes in the cell are mediated by stiff microtubule biopolymers and active motor proteins moving upon them. This includes the transport of subcellular structures—nuclei, chromosomes, organelles—and the self-assembly, positioning, and maintenance of the mitotic spindle. I will discuss recent work in modelling and simulating some of these phenomena as multi-scale, geometrically complex problems in fluid/structure interactions. My focus will be on a large-scale computational model of how the pronuclear complex, with its hundreds of attendant microtubules, moves into "proper position" within an embryonic cell prior to cell division. Different assumptions on how the microtubules interact with the cell's cytoplasm (the fluidic interior) and its periphery give very different predictions for this dynamics.

The mathematics of swimming collectives

Swimming, also described as self-propulsion through a fluid, is associated with a range of life forms from algae, bacteria and birds to whales. It even occurs inside of cells. Swimming becomes especially fascinating when it involves collectives—like flocks and schools—that interact through the fluid. I'll give several interesting examples, but focus on recent experiments that explore the interactions of many flapping flyers (think of geese in formation flight). They show that surprising collective effects—bistable fast and slow "gears" and increased locomotive efficiency—can occur due to the ability of a high-Reynolds number flow to store information on its past history of wing interactions. While simulations readily reproduce these observations, much reduced models involving peculiar delay differential equations and iterated maps of wing-vortex interactions give understanding and a surprisingly good accounting. They also show an unexpected connection to hydrodynamic analogues of pilotwave theory.

Boundary integral methods for flows interacting with moving and flexible structures

In either the inviscid limit of the Euler equations, or the viscously dominated limit of the Stokes equations, the determination of fluid flows can be reduced to solving singular integral equations on immersed structures and bounding surfaces. Further dimensional reduction is achieved using asymptotics when these structures are sheets or slender fibres. These reductions in dimension, and the convolutional second-kind structure of the integral equations, allows for very efficient and accurate simulations of complex fluid-structure interaction problems using solvers based on the Fast Multipole or related methods. These representations also give a natural setting for developing implicit time-stepping methods for the stiff dynamics of elastic structures moving in fluids. I'll discuss these integral formulations, their numerical treatment, and application to simulating structures moving in high-speed flows (flapping flags and flyers), and for resolving the complex interactions of many, possibly flexible, bodies moving in microscopic biological flows.

THE TAO OF MATHS

Fields Medallist and AMSI Scientific Advisory Committee member, Professor Terry Tao took time out of his busy schedule at UCLA to chat with AMSI. He reveals what's exciting him in mathematics, his recent collaborations and how he approaches complex problems.

What's exciting you in mathematics at the moment?

It changes a lot from year to year—there are so many things going on in different parts of mathematics, it seems! I can name two recent breakthroughs in the last year or two, which have generated a bit of excitement. The first is the recent proof of the Kadison-Singer conjecture by Marcus, Spielman, and Srivastava, which used radically new methods (in particular, interlacing polynomials) to solve a notoriously difficult problem in operator algebras and matrix analysis. It looks like there are other applications of this method (for instance, to theoretical computer science). The other is the breakthrough result of Matomaki and Radziwill earlier this year in understanding short sums of multiplicative functions in number theory. This has made several open problems in number theory (e.g. the Chowla conjecture, a cousin of the twin prime conjecture) look much more within reach. Recently I was able to use the Matomaki-Radziwill theorems to prove some partial results towards the Chowla conjecture, which could in turn be used to settle a long-standing conjecture of Erdos on the discrepancy of sequences. I'm confident that we'll be seeing other striking applications of Matomaki and Radziwill's results in the near future.

Why do you think women are underrepresented in mathematics?

That's a good question. Up to about the high school level, we seem to have fairly good parity these days; if anything, female maths students may even be slightly more numerous and a bit stronger. But then there is a lot of attrition at the undergraduate level and beyond. It seems there are a lot of reasons for this. One is that nearby disciplines (e.g. the life sciences) have much better gender balance and this can be more attractive than a discipline where one is in the minority. Another is the relative lack of high-profile female role models in mathematics, though there are excellent top female mathematicians who do their heroic best to counteract this. Then there is the fact that the graduate and postdoctoral portions of one's career in mathematics can be rough on people who are also trying to start or raise a family. There are some little positive steps in these directions (for instance, child care availability is now taken as a serious issue in mathematics departments, institutes, and conferences, and more efforts are being

made to overcome conscious or unconscious biases against minority candidates in hiring and in giving presentations), but there is still a long way to go here.

From a personal perspective what are your top three open problems in mathematics? What are their prospects for resolution?

Well, this is very subjective, and depends a lot on what you mean by "top". There are statements, which would have enormous implications if they could be definitively proved (e.g. the six remaining Millennium prize problems), but the likelihood of actually doing so is so remote, I don't think these are the problems that we should be devoting the bulk of our mathematical manpower to attacking. (Though I do like to keep tinkering with an approach I have to disproving global regularity for the Navier-Stokes equations…) My philosophy is to focus on those open problems that are only a little bit out of reach of current techniques and methods—problems that require "only" one new breakthrough to solve, rather than a half-dozen. In number theory, I think the twin prime conjecture is getting close to this level of feasibility; in analysis, the Kakeya conjecture has already had much headway made against it from the previous four or five breakthroughs in the area, and one can hope that just one more is needed to finish it off. More ambitiously, I think the soliton resolution conjecture in PDE would be a fantastic result to settle, though this is currently well out of reach except in very special cases (e.g. completely integrable equations, perturbative data, or other very symmetric and special equations).

"My philosophy is to focus on those open problems that are only a little bit out of reach of current techniques and methods—problems that require 'only' one new breakthrough to solve, rather than a half-dozen."

I read somewhere recently that as a child, you thought research was driven by a problem posing committee. Do you think the free ranging, creative side of mathematics comes off second best to problem solving for kids and adolescents interested in maths?

Well, I think even problem solving comes off as second best to the computation-intensive mathematics one sees in schoolwork. Certainly when I was a child, the only glimpses I saw of true mathematical research were in some more advanced level books I got from the library, or the informal discussions I had with some active and retired mathematicians in Adelaide. One big plus in today's world though is that, with the internet, one can now listen to public lectures or other talks by some very good mathematical speakers, or see good examples of accessible mathematical writing online. Even just the mathematics section on Wikipedia is a wonderful resource which I would have very much enjoyed as a child. So it seems the hard part is to locate the kids with a potential interest in mathematics and inspire them to go explore for themselves.

When it comes to collaboration are you a workshop person? Or do you have a different MO?

I love collaboration; most of my papers are joint, and most of the mathematics I have learnt, I have learnt from my various co-authors. But the style is different for each co-author. One of them, for instance, likes to stick to the famous Hardy-Littlewood rules of collaboration (which include such counterintuitive rules that there is no obligation to respond to any research communication from the other author). I work with some authors almost exclusively by email, others by trying to secure a week at a location conducive to brainstorming at a blackboard. More recently, I've been involved with massively collaborative "polymath" projects where dozens of mathematics communicate through wikis and blogs to attack a single problem. Not every collaboration style is suited for every problem, but they are all fun!

You have a very different approach from others in your field such as Andrew Wiles, did you make a conscious decision to have broad mathematical interests?

Actually I think it was my co-authors that helped me broaden the most. When I was a postgraduate student I was initially rather narrowly focused on harmonic analysis. But my co-author Allen Knutson got me interested in algebraic combinatorics and representation theory. My co-author Mark Keel got me into PDE, my co-author Ben Green got me into analytic number theory and additive combinatorics, my co-author Emmanuel Candes got me into signal processing, and so forth. I have a great respect for those mathematicians who drill deeply into a single field and extract some very profound results as a consequence, but I have always been more comfortable with entering a new field (usually with the assistance of a collaborator in that area) and seeing if any ideas or results from a previous one can be profitably applied to this new one.

What advice would you give to a philanthropist with deep pockets who wanted to invest in mathematics?

Well, that is certainly very admirable! I think as far as greatest need is concerned, prizes, scholarships and grants for junior mathematicians, e.g. to be able to attend conferences and have the opportunity to work with leaders in the field, are the most important. But unfortunately these don't get nearly as much publicity and notice as the larger prizes that go to more established people for more visible accomplishments. It seems that a good compromise is to combine the two—to couple a larger prize with some smaller prizes aimed at junior mathematicians.

Which parts of maths do you think pay the greatest social dividend? Should we divert talent from the finance sector, into these areas? How?

Well, progress in mathematics isn't just a matter of throwing money and resources into a given area; sometimes a field is just not yet ripe for dramatic progress, needing a little bit of serendipity to have someone find the key insight. Even very pure areas of mathematics can unexpectedly have tangible real world impact; I and several others had done some purely theoretical work on random matrices, for instance, that ended up being useful for compressed sensing, which is now used for instance to speed up MRI scans. The other thing is that while we certainly do need good people in mathematical research, not every person who is talented in, say, mathematical finance, would also be suitable for this; there are some qualities (e.g. the need to "play", almost to the point of obsession, with mathematical concepts and problems) that are useful in research but perhaps not in other areas. So I don't think we should actively try to divert people from a career that they already enjoy and are successful at, but we can certainly raise awareness that there are many areas of both pure and applied mathematics which need good people and which can be rewarding in many ways.

Terry is a long-term member of AMSI's Scientific Advisory Committee and AMSI's first director, Garth Gaudry, was Terry's mentor as a student at Flinders University. Terry continues to be a strong advocate for the Australian mathematical sciences community.

3 Research Training

3 RESEARCH TRAINING OVERVIEW

AMSI's national research training infrastructure sets the gold standard for discipline-wide higher degrees by research (HDR) graduate training in Australia. Established in 2003, our training schools, graduate courses and scholarships prepare STEM graduates to engage in cross-disciplinary research and drive innovation within the public and private sectors.

In 2015–2016, almost 450 students and researchers participated in the Institute's flagship research training programs, including the AMSI Winter and Summer Schools, BioInfoSummer and the Vacation Research Scholarships program.

In 2016–2017, the number of participants is expected to rise, with the addition of new flagship program AMSI Optimise, which will provide an essential platform to strengthen engagement between the mathematical sciences and industry.

"Inspiring students, researchers and professionals to pursue study and careers in fields such as bioinformatics, is crucial to the future of research and innovation in Australia. That is why the Australian Government supports events such as this and is continuing to encourage the uptake of science, technology, engineering and mathematic subjects in schools, universities, and in vocational education and training."

Senator the Honourable Simon Birmingham, Minister for Education and Training

Research Training Events

The Institute co-funds a program of vacation schools and scholarship programs with the Australian Government Department of Education and Training.

3.01 AMSI WINTER SCHOOL ON ALGEBRA, GEOMETRY AND PHYSICS 2015

29 June–10 July 2015, The University of Queensland

AMSI Winter School is one of four flagship higher education vacation schools and outreach programs delivered by the institute and its member institutions. In partnership with The University of Queensland, it features a cutting-edge research program led by well-established Australian and international senior researchers, many of whom received their PhD's from some of the world's premier institutions (for example Yale University, Massachusetts Institute of Technology and Stanford University) and who have now settled relatively recently at various Australian universities.

Aimed at postgraduate students and postdoctoral fellows in the mathematical sciences and related disciplines, the courses expand on traditional academic program content to expose participants to new skillsets and areas of research.

The 10th annual AMSI Winter School explored contemporary aspects of Algebra, Geometry and Physics. The University of Queensland hosted 39 students for a two-week series of mini-courses, introductory lectures, and specialist lectures. Highlights of this year's social program were the public lecture given by Professor Arun Ram (The University of Melbourne) and the popular Women in Maths networking event, which attracted more than 80 people.

Participants in the Winter School also presented a 15-minute talk on the area of their research (or related field), linking it to this year's theme.

"The lectures were at the same time fast paced and packed with knowledge, but at the same time comprehensible and pulled you along."

Ross Ogilvie, The University of Sydney

Courses details

Moduli Spaces and Symplectic Geometry

Week 1 - Dr Joan Licata, The Australian National University

This course developed some beautiful constructions that illustrated one role of moduli spaces in contemporary symplectic geometry. The program started with an overview of classical Morse theory on finite-dimensional manifolds, describing some of the key results and examining the technical considerations that make the theory work, and introducing some basic objects in symplectic geometry in order to define Lagrangian intersection Floer homology.

Further discussion focused on explaining the sense in which this construction is a natural infinite-dimensional analogue of Morse theory, as well as Heegaard Floer homology, a package of topological invariants of low-dimensional manifolds, which can be defined using Lagrangian intersection Floer homology.

Week 2 - Dr Brett Parker, The Australian National University

A beautiful formulation of classical mechanics goes by the name of Hamiltonian mechanics. In Hamiltonian mechanics, the phase space has the structure of a symplectic manifold. It was demonstrated that any volume preserving transformation of phase space may be approximated (in some weak sense) by a Hamiltonian mechanical system, and that symplectic manifolds are very flexible.

Geometric Representation Theory

Representation theory, the study of (for example) matrix representations of groups, Lie algebras or quantum groups, plays a major role in areas such as algebra, algebraic topology, differential geometry and mathematical physics. One of the major trends in modern representation theory has been the discovery of geometric constructions of representations, which arise by applying technology such as cohomology, K-theory or sheaf theory to spaces such as flag varieties, quiver varieties and nilpotent cones. The benefits of such constructions range from canonical bases for ease of computation to theoretical understanding of higher-level categorical structure. Ideas were introduced in some of their simplest forms, concentrating on the prototypical case of the general linear group and its associated Lie algebras and quantum groups.

Week 1 - Dr Masoud Kamgarpour, University of Queensland and **Tony Licata**, The Australian National University

Topics covered included:

- Classical representation theory of the general linear group and its Lie algebra
- Borel-Weil construction of representations using line bundles on the flag variety
- Nakajima's construction of representations using cohomology of quiver varieties

Week 2 - Prof. Anthony Henderson, University of Sydney

Topics covered included:

- Quantisation and affinisation of Lie algebras
- Lusztig's geometric Hall algebra construction of quantum groups
- Nakajima's construction of representations of quantum loop algebras

K-Theory and its applications

Week 1 - An Introduction to K-Theory

Dr Vigleik Angeltveit, The Australian National University

Using ideas introduced by Grothendieck, Atiyah and Hirzebruch defined topological K-theory from the set of vector bundles on a space X by applying group completion (also known as the Groth-endieck construction). K-theory forms a multiplicative cohomology theory with an obvious geometric interpretation, and for many purposes it is a more useful invariant than ordinary cohomology.

The course defined vector bundles, and generalised standard constructions such as direct sum, tensor product and exterior powers, from vector spaces to vector bundles. An explanation was

Time, Space and Mathematics

FROM TIME TRAVEL, WORMHOLES and warping space to the mathematics of bubbles. Two-time AMSI Winter School attendee, Ross Ogilvie followed a childhood passion for science fiction into the mind-bending world of differential geometry.

At seven, with no idea what a mathematician was, Ross wanted to be a scientist. Now the avid hiker, rock climber and computer enthusiast is studying the mathematics behind general relativity to help describe spaces and their geometries. He uses bubbles to explain his work, not the familiar glossy spheres from childhood, but harmonic tubes (tubes with as little surface area as possible).

"If you look at the same equations that describe harmonic surfaces in other geometric spaces (not the type of 3D space we live in) then the bubble can assume all sorts of interesting shapes. I'm trying to classify certain types of bubbles and determine which ones can be deformed (continuously bent and stretched) into one another," Ross explains.

This work forms part of a broader family of equations with a number of scientific applications including particle physics, the study of matter, the nature and make up of particles and the laws that control the physical universe.

> *For Ross one of the greatest challenges facing mathematicians is the need to communicate and incorporate what they do it into society in a way that is seen as useful and appealing.*

"When I tell people what I am studying, it is alarming how often they say 'oh I hated mathematics at school'. I can't think of another profession that elicits such a reaction.

given on how to define K-theory by considering formal differences of vector bundles. After establishing some formal properties of K-theory, the focus moved to the theory of characteristic classes.

The course concluded with an application to pure mathematics, using certain operations on K-theory, an easy proof was presented, due to Adams and Atiyah, of the Hopf Invariant One theorem. One easy consequence of this theorem is that there are no real division algebras in dimensions other than 1, 2, 4 and 8.

Week 2 - Applications to Index Theory and Physics

Dr Pedram Hekmati, The University of Adelaide

The Atiyah-Singer index theorem is arguably one of the most significant achievements of 20th century mathematics. It draws on and bridges several branches of mathematics and its impact is felt strongly today. K-theory is the natural framework for proving the index theorem and historically these theories were developed in tandem. The aim of these lectures was to formulate the index theorem, sketch the K-theory proof and consider an application to physics.

The course began with an introduction to elliptic differential operators on compact manifolds and explored how their symbol determines a class in K-theory. Next, the notion of analytic index and topological index for elliptic operators was defined. The Atiyah-Singer index theorem is the statement that these two index maps are equal.

After explaining the basic idea behind the proof and deriving a cohomological formula, an application to symmetry breaking and particle physics was considered. The background in gauge theory, the mathematical theory underpinning particle physics was reviewed, and an explanation how the breaking of local gauge symmetry can be described by the index theorem.

Moonshine Conjectures and Vertex Operator Algebras

Week 1 - A General Introduction to Moonshine

Dr Nora Ganter, University of Melbourne

An introduction was given on the topic of moonshine, and generalised moonshine, with special attention on different interpretations of the role of phase factors (line bundle over moduli space and the categorical picture). Replicability, Hecke operators, Hecke monicity and Carnahan's approach to the genus zero property was discussed.

Week 2 - Newer Moonshines

Assoc. Prof. Terry Gannon, University of Alberta, Canada

The course reviewed the background on modular forms and finite group representation theory, and explored newer moonshines, including the Mathieu Moonshine.

Introduction to Vertex Operator Algebras

Prof. Geoffrey Mason, University of California, Santa Cruz, USA

Vertex operator algebras facilitate the construction of the Moonshine Module, and are valuable tools in 2-d conformal field theory, string theory and a variety of mathematical applications. Vertex operator algebras were introduced, demonstrating some of the fascinating results and applications associated with their structure.

Topics covered included:

- Axioms for vertex algebras: Definition of a vertex k-algebra, category of vertex k-algebras, modal endomorphisms, translation covariance, locality.
- Existence theorems: Field-theoretic characterisations, Heisenberg algebra (free-field theory), Virasoro algebra, vertex operator algebras (VOA), Heisenberg VOA, Virasoro VOA, VOAs associated to affine Lie algebras
- Characters and representations: Partition functions, modules over a VOA, finiteness theorems, modular functions, modular-invariance theorems, connections with Monstrous Moonshine

Other Sponsors

Department of Education and Training, The University of Queensland, The Australian National University, Biarri, PIMS, QCIF

3.02 AMSI BIOINFOSUMMER 2015

7–11 December 2015, The University of Sydney

Australia's leading bioinformatics and mathematical and computational biology training event, AMSI BioInfoSummer has been running since 2003. A flagship AMSI higher education and outreach program, the event is aimed at undergraduate and postgraduate students, researchers and professionals to foster Australia's bioinformatics and computational biology research capability.

Bioinformatics is an exciting, fast moving area, analysing and simulating the structures and processes of biological systems. It is a truly interdisciplinary field that uses mathematics, statistics and information technology to analyse large and complex biological datasets.

Featuring bioinformatics experts from Europe and the US, as well as Australia, the one-week event explored current research and developments in bioinformatics as well as hands-on introductory and advanced computer workshops.

More than 225 researchers and students from a variety of scientific backgrounds were inspired and upskilled by an outstanding array of Australian and international speakers and a series of parallel lab sessions tailoring to various backgrounds and interests. A wet lab experience was introduced for computational students, placing BioInfoSummer towards a path of a genuinely interdisciplinary experience.

"BioInfoSummer was a wonderful chance to hear about home-grown and international research, at a level that is accessible to someone who may not be that field. It offered a snapshot into what the state of the art of various areas of bioinformatics and computational biology was. The workshops in particular were a great way to showcase various analysis tools and methods and the time dedicated towards the workshops was optimal"

Shila Ghazanfar, The University of Sydney

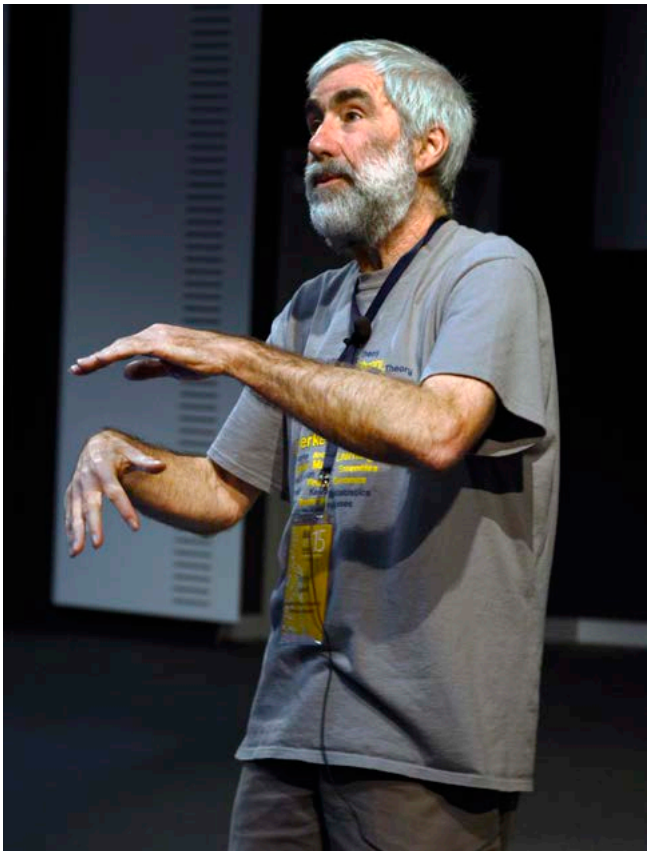
The conference was officially opened with a message from Senator the Honourable Simon Birmingham, highlighting the importance of bioinformatics to the future of research and innovation in Australia. Other highlights of the program included the Maths Saves Lives panel discussion, which examined the new field of forensic bioinformatics, as well as the COMBINE Careers Panel, the Women in Science Networking event and a student poster session.

Conference speakers

SPEAKER	ORGANISATION	TALK TITLE
Dr Mark Ibberson	Swiss Institute of Bioinformatics	A systems biology approach to the study of type 2 diabetes (T2D)
Prof. Sue Wilson	The Australian National University	An introduction to statistics in the omics era
Prof. Susan Holmes	Stanford University	Analysing multidimensional time course data for the analysis of the human microbiome
Prof. Claire Wade	The University of Sydney	Beginning a selection program for working behaviour in the Australian Working kelpie
Prof. Sue Clark	Garvan Institute of Medical Research	Beyond the genome
Prof. Shoba Ranganathan	Macquarie University	Biomarker discovery in ovarian cancer – A systems approach
Dr Alicia Oshlack	Murdoch Childrens Research Institute	ChIP and chips: bioinformatics for epigenomics
Dr Natalie Thorne	Walter and Eliza Hall Institute of Medical Research	Clinical bioinformatics – an introduction to an exciting new field
Prof. Vanessa Hayes	Garvan Institute of Medical Research	Complex genomic view of prostate cancer
Dr Uri Keich	The University of Sydney	Controlling the rate of false discoveries in tandem mass spectra identifications
Prof. Sean O'Donoghue	Garvan Institute of Medical Research	Data visualisation: a strategy for complex biological data
Dr Peter Kim	The University of Sydney	Dynamics of anti-cancer viruses and dendritic cell vaccines
Dr Rachel Wang	Stanford University	Gene coexpression measures in large heterogeneous samples using count statistics
Prof. Keith Baggerly	University of Texas, MD Anderson Cancer Centre	Genomics and ovarian cancer
Dr Judith Zaugg	European Molecular Biology Laboratory	Integrative epigenomics: the genetic basis of variation in gene regulation and its link to complex diseases
Prof. David James	The University of Sydney	Metabolic cybernetics
Assoc. Prof. Katerina Kechris	University of Colorado, Denver	Metabolomics and translational research in pulmonary disease
Assoc. Prof. Neville Firth	The University of Sydney	Molecular biology crash course
Prof. Marc Wilkins	The University of New South Wales	Proteome-scale discovery of protein isoforms, including those predicted from RNA-seq analysis
Assoc. Prof. Aaron Darling	University of Technology Sydney	Statistical, computational, and laboratory techniques for deconvolving metagenomes into genomes
Prof. Terry Speed	Walter and Eliza Hall Institute of Medical Research	The relentless march of technology: how to survive in a rapidly changing world
Dr Jerry Gao	Walter and Eliza Hall Institute of Medical Research	Visualisation and analysis techniques for single cell haematopoietic lineage tracing

Other Sponsors

The University of Sydney, Australian Government Department of Education and Training, ABACBS, BHP Billiton Foundation (as part of the Choose Maths Project), EMBL Australia, DNANexus, Illumina



Musician Makes Key Change to Fight Cancer

AS FAR AS PHD STUDENT AND AMSI BioInfoSummer (BIS) 2015 participant, Charles Gray is concerned there is nothing far fetched about a musician becoming a mathematician.

"It was it was music's mathematical axioms I was drawn to the most."

Now after a decade in music and the arts, she has realised her lifelong maths dream. After completing honours in Pure Mathematics, she has transitioned to a PhD in the more practical and career friendly area of statistical genomics.

> *"I always wanted to do maths, but didn't have courage until my thirties. I was drawn to biostatistics as it plays to my creative strengths and has wider career options."*

Her recent AMSI BioInfoSummer experience confirmed she has made the right decision. "I can't think of anywhere else you can access a week of bioinformatics perfectly pitched to someone with my level of mathematics and biology."

Charles is thriving on the sense of belonging as part of Australia's medical discovery fraternity and support from AMSI, as she progresses her PhD research to minimise effects in the measurement of DNA methylation, a mechanism that activates cells that is of particular interest in epigenetics and cancer research.

> *"AMSI has been an ever present entity in my world, opening up opportunities such as a Victorian Research Scholarship at Walter and Eliza Hall Institute and its world-class training events."*

3.03 AMSI SUMMER SCHOOL 2016

4–29 January 2016, RMIT University

Australia's biggest student mathematics event, the AMSI Summer School is a four-week residential research training program designed to take students to the cutting-edge of mathematical sciences to enhance discipline knowledge and employability. With a commitment to outstanding education and training, sessions count as course credits, with career development and networking opportunities giving students the competitive edge as they pursue their research career.

The 14th Annual AMSI Summer School brought 127 honours and postgraduate students from around the country for an intensive four-week residential program. Students had the opportunity to tackle one or two of the eight intensive honours level pure and applied mathematics and statistics subjects on offer. During their time at the residential school, students complemented their academic work with enrichment lectures, social events, a careers afternoon and other special events.

A highlight was the public lecture given by Margaret Werthiem on *Corals, Carbon and the Cosmos: The story of hyperbolic Space*, which was attended by more than 200 members of the public.

Courses details

Design and Analysis of Experiments

Dr Stelios Georgiou, RMIT University

Design and Analysis of Experiments is an important tool that helps researchers to design and perform experiments related to any field of applied science. The methods described in this subject provided an introduction to basic statistical techniques and illustrated the power of statistical experimentation for inference. Emphasis was given to principles and guidelines of fundamental statistical techniques and experiments. Applications and examples were conducted using the Minitab statistical package.

Calculus of Variations

Dr Julie Clutterbuck, Monash University

Dr Anja Slim, Monash University

In many physical problems, the solutions we seek to minimise an energy, and as a consequence, these solutions will also satisfy a partial differential equation. This subject showed students how to find the partial differential equation associated with an energy; how to ensure that minimisers exist; how to deal with constraints; how to model these problems numerically; and the techniques of stability analysis. Throughout the subject, the introduction and examination of applications were applied to capillary surfaces, geodesics, hair curling, elastica, optimal control, and the brachistochrone, as well as Hamilton's principle.

Complex Networks

Dr Stephen Davis, RMIT University

This subject presented the mathematical and statistical techniques used to classify and characterise complex networks, which allowed students to work with real data sets to visualise and study the kinds of networks that arise in ecology and epidemiology.

Conic Programming

Dr Vera Roshchina, RMIT University

Conic programming is one of the core areas in modern optimisation. Conic models such as semidefinite programming have broad applications in real life, but at the same time present nontrivial computational challenges that result in rich underlying theory and interesting research problems. This subject was designed to review the fundamentals of conic optimisation and provide an overview of the research field.

Linear Control Theory

Dr Yoni Nazarathy, The University of Queensland

This subject covered the core elements of linear dynamical systems, control theory and Markov chains simultaneously, where relationships between these objects also exist. The students explored these related fields together with applications, computation and theory.

Modern Numerical Methods

Dr Jérôme Droniou, Monash University

The content of this subject reviewed numerical methods — mostly finite volume schemes — developed in the past 15 years to tackle the numerical approximation of diffusion models under these engineering constraints. The construction of these schemes hinges on the analytical properties of the equations. These properties were detailed first, before considering the numerical schemes.

Projective Geometry

Assoc. Prof. John Bamberg, The University of Western Australia

There are essentially four schools of practice in geometry: axiomatic, synthetic, analytic and transformational. In most modern day secondary and tertiary education, the analytic perspective holds sway. This course redressed this situation by emphasising the synthetic and transformational approach to projective geometry. The synthetic approach recaptures what geometry is all about, whilst bringing in the modern transformational perspective initiated by Hjelmslev, Hessenberg, Thomsen and Bachmann

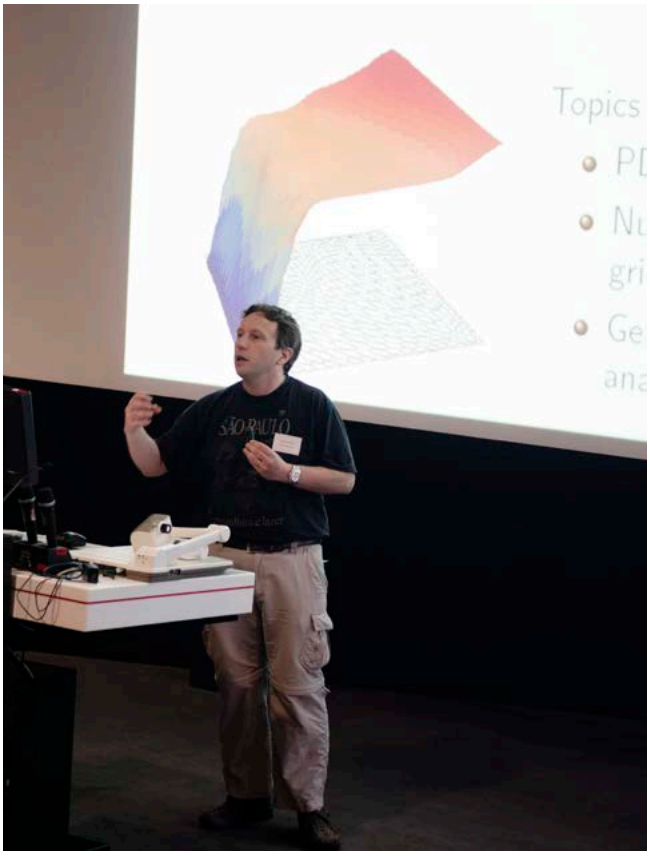
Stochastic Modelling

Dr Giang Nguyen, The University of Adelaide

Randomness is an important factor in modelling and analysing various-real life situations. This subject covered key aspects in stochastic modelling, including the theory underlying Brownian motions and diffusion processes, as well as techniques for numerical simulations.

Other sponsors

Australian Government Department of Education and Training, AustMS, ANZIAM, RMIT University, Australian Government Department of Defence, BHP Billiton Foundation (as part of the Choose Maths Project), CSIRO, Optiver, City West Water



The Elegant Satisfaction of Geometry

FOR UNIVERSITY OF WESTERN Australia PhD student, Jesse Lansdown, geometry is both elegant and satisfying. His PhD research looks at when ovoids—a set of points where every line is incident with exactly one point in polar spaces—occur and why or why not.

"This has a range of applications including cryptography and coding theory," he explains.

Despite a passion for the subject, Jesse didn't see mathematics as a career pathway until he began engineering at university. After enrolling in mathematics as a second major, he realised his passion was matched with natural aptitude and switched degrees. This is not surprising, given his experience of the subject in high school.

> *"My teachers helped me to see the challenge and satisfaction maths could bring. However, it was only in university that I took it seriously."*

Recently he chose to spend his summer expanding his mathematical knowledge of Projective Geometry and Conic Programming at AMSI Summer School.

He is impressed at AMSI's efforts to enhance the profile of Australian mathematical sciences and encouraging efforts at all levels.

"Many people tend to view maths as elusive or obscure when in actual fact it is useful, learnable and interesting.

3.04 AMSI VACATION RESEARCH SCHOLARSHIPS 2015/16

December 2015–January 2016

Fifty of our brightest undergraduate students gave up lazy summer days at the beach last summer to work on AMSI Vacation Research Scholarship (VRS) projects.

Through this program, AMSI provides monetary scholarships to give students a taste of research life and encourage them to pursue mathematics as a career. Over six weeks, participants experience life as a researcher, working closely with a supervisor to complete a research project. The program aims to inspire students to continue with further research in the future, and for some the Vacation Research Scholarship project leads to their first academic publication.

At the end of the summer, students presented their findings at the AMSI Big Day in student conference (to be renamed AMSI Connect in 2017) at the University of Melbourne. In addition to presenting their work, students write blog posts outlining their research and results, giving them experience in scientific writing for broader audiences.

Web Links

http://vrs.amsi.org.au,
http://vrs.amsi.org.au/projects/
http://vrs.amsi.org.au/vrs-blog/

Big Day In

9–11 February, 2016, the University of Melbourne

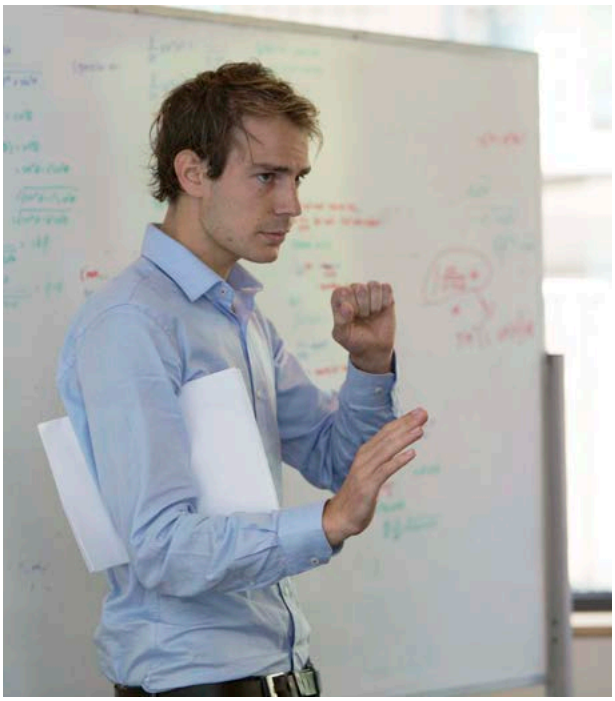
The 2016 Big Day In was held at International House, the University of Melbourne. Following an ice-breaking game of dodge ball between students and academics, AMSI's Research and Higher Education Program Manager, Simi Henderson, opened the event.

The program began with a presentation from University of Melbourne postgrad Elena Tartagila who took the students on a journey of valour and discovery as she discussed life as a PhD student.

Dr Federico Frascoli then brought the opening to a close with an inspirational talk, covering the ideas and values that made him "choose" a career in research and academia.

All students got the opportunity to present their own research findings as part of the event's two-day program

The presentations were all enthusiastically received with prizes awarded by their peers to Xiangyuanchai Guo (The Australian National University) and Padraic Gidney (The University of Sydney) for best student presentations.



"Working on a real project was an invaluable experience. Exploring topics that may or may not have ever been addressed before, and being required to find my own way to tackle the problem, brought a strong sense of connection to mathematics and ownership of my own work. As a result I learnt a lot more in the time I had, than I ever have from typical undergraduate coursework."

Morris Vsyma, the University of Newcastle

2016 Students and projects

Student	Supervisor/s	Project Title
FEDERATION UNIVERSITY AUSTRALIA		
Debra Briggs	Assoc. Prof. David Yost	Comprehensive Catalogue of Polyhedra
LA TROBE UNIVERSITY		
Alex Ligthart-Smith	Dr David Farchione and Assoc. Prof. Luke Prendergast	A Comparison of Longitudinal Data Models that Include Time-Varying Covariates
Elisa Tancredi	Assoc. Prof. Katherine Seaton	Factors Affecting Success in Mathematics at La Trobe University
Maxwell Cairns	Assoc. Prof. Luke Prendergast	New Interval Estimators for the Ratio of Quantiles from Two Independent Populations

Student	Supervisor/s	Project Title
MONASH UNIVERSITY		
Haris Sahovic	Dr Joel Miller and Assoc. Prof. Manoj Ghambir	What do we Need to Know to Respond to the Next Emerging Disease?
Jamieson Kaiser	Dr Joel Miller and Prof. Hans De Sterck	The Spread of Dynamic Processes on Random Graphs with Spatial Structure
Joshua Cameron	Dr Joel Miller and Dr Jennifer Flegg	The Role of Concurrent Relationships in Disease Spread
Kevin Duxbury	Dr Jennifer Flegg	Reaction-Diffusion Model for Human Oocyte Symmetry Breaking
Rhiannon Kirby	Dr Simon Clarke	Spatial Interactions of Infected Mosquito Populations
QUEENSLAND UNIVERSITY OF TECHNOLOGY		
Amy Stringfellow	Prof. Scott McCue	Droplet Pearling
Emma Johnston	Dr Tim Moroney	Fractional Reaction-Diffusion Models for Anisotropic, Heterogeneous Media
James Bubear	Dr Joanne Hall	Skolem Sequences and Graphs
Lachlan Tyrrell	Prof. Scott McCue and Dr Chris Green	Evolving Bubbles in a Hele-Shaw Cell
Luke Ginn	Prof. Troy Farrell	Mathematical Modelling of Battery Electrodes:
Nicholas Johnson	Prof. Matthew Simpson	The G'/G-Expansion Method for Nonlinear Differential Equations
RMIT UNIVERSITY		
Peter Wreford	Dr Stephen Davis	Analysis of Vector Dissimilarity Measures To Build Gene Networks From Chickpea Expression Data
Sarah Gazelle	Assoc. Prof. John Shepherd	The Von Bertalanffy Population Model Applied in Tumour Growth Modelling
THE AUSTRALIAN NATIONAL UNIVERSITY		
An Ran Chen	Dr Anthony Licata	Random Planar Graphs
Anna Vaughan	Prof. Peter Bouwknegt	Introduction To String Theory
Maxim Jeffs	Dr Bryan Wang	The Donaldson-Floer-Fukaya Category in Yang-Mills Theory
Xiangyuanchai Guo	Prof. Alan Welsh	Models for Selection Effects
Yinli Wang	Assoc. Prof. Barry Croke and Prof. Tony Roberts	Modelling Surface Water Flow in the Lower Campaspe Catchment
THE UNIVERSITY OF ADELAIDE		
Angus Lewis	Dr Giang Nguyen	Approximating Heavy-Tailed Distributions Using Infinite Phase-Type
Daniel Kon	Prof. Patty Solomon	A Statistical Model for Missing Data in Proteomics Studies of Gastric Cancer
John McCarthy	Dr Thomas Leistner	Lorentzian Surfaces
Matthew Ryan	Prof. Michael Murray and Nick Reed	Knots and Sticks
Michael Hallam	Prof. Finnur Larusson	Internal Hom-Objects in the Category of Topological Spaces
Russell Edson	Dr Sarthok Sircar	Cartilage Biomechanics: Multi-Scale Modelling, Analysis and Scientific Computing
THE UNIVERSITY OF MELBOURNE		
Albert Zhang	Prof. Derek Chan and Dr Qiang Sun	Benchmarking a Novel Electromagnetic Scattering Method
Joseph Johnson	Prof. John Sader	Numerical Solution of the Boltzmann Equation for Rarefied Gas Flows
Shane Henry	Prof. Peter Taylor and Nicholas Read	Forecasting Fire Bugs
Timothy O'Sullivan	Prof. John Sader	Molecular Dynamics
Todd Neve	Dr Iwan Jensen and Dr Naida Lacevic	Partition Function Zeros and the Ising Model in a Field
William Stewart	Prof. Derek Chan and Dr Qiang Sun	Benchmarking a Novel Electromagnetic Scattering Method
THE UNIVERSITY OF NEWCASTLE		
Morris Vysma	Dr Bjorn Ruffer and Ben Babao	Chaos Encrypted Communication Channels
Timothy Tillman	Prof. George Willis	Unicellularity of Shift Operators
THE UNIVERSITY OF QUEENSLAND		
Aiden Suter	Assoc. Prof. Jorgen Rasmussen	Calculus of Formal Distributions and Vertex Operator Algebras
Ainsley Pullen	Dr Clement Maria	Indecomposables of Quiver Representations in the Category of Finitely Generated Abelian Groups
Alexander Baker	Dr Artem Pulemotov	The Geometry of Homogeneous Spaces
Anna Kervison	Dr Artem Pulemotov	The Ricci Curvature of Rotationally Symmetric Metrics
THE UNIVERSITY OF SYDNEY		
Abdul Zreika	Dr Stephan Tillmann	The Space of Closed Essential Normal Surfaces in Knot Complements
Alexander Stokes	Prof. Nalini Joshi	Symmetry Analysis of Pole Distribution of Special Solutions of the Continuous/Discrete Painleve Equations
Eric Hester	Dr Geoff Vasil	Studies of Dead Water in Stratified Fluids
Padraic Gidney	Dr Robert Marangell	Spectral Dynamics of Periodic Wavetrains in Reaction Diffusion Equations
Steve Xu	Dr Ray Kawai	Acceleration of Stochastic Approximation Parameter Search in Adaptive Monte Carlo Simulation
THE UNIVERSITY OF WESTERN AUSTRALIA		
Dimitrio Sidi	Dr Neville Fowkes	Rhino Conservation Problem
UNIVERSITY OF SOUTH AUSTRALIA		
Xuemei Liu	Assoc. Prof. Regina Burachik	Study of Duality Schemes with Sequential Lagrangian Updates
UNIVERSITY OF TECHNOLOGY SYDNEY		
Andy Chu	Assoc. Prof. Christopher Poulton	Modelling of Absorbing Thin Film Optical Materials in the Presence of Highly Conductive Gratings
Logan Haami	Assoc. Prof. Christopher Poulton	Modelling of Absorbing Thin Film Optical Materials in the Presence of Highly Conductive Gratings
UNIVERSITY OF WOLLONGONG		
Penelope Drastik	Dr Dave Robertson and Dr Nathan Brownlowe	Zappa-Szep Products of Compact Quantum Groups

VRS – FEATURED RESEARCH

These four summaries illustrate the breadth of research projects undertaken by this year's VRS students.

Pole distributions of rational special solutions of the Painlevé equations

Scholar: **Alexander Stokes**, The University of Sydney
Supervisors: **Professor Nalini Joshi, Dr Nobutaka Nakazono & Dr Yang Shi**, The University of Sydney

The Painlevé equations are six second-order nonlinear ordinary differential equations whose general solutions are transcendental functions. All but one of these equations contains one or more parameters, at special values of which rational special solutions exist. Recent numerical studies including [1], [2] and [3] have revealed the distributions of poles of these special solutions in the complex plane to be highly structured and symmetrical. The form of these solutions is such that the poles occur at the zeroes of special polynomials. Among the observations made about these distributions are properties analogous to those of the classical special polynomials. In this paper, we introduce several notions of symmetry of the Painlevé equations and use them to explore the properties of these distributions, arriving at the following main result.

Theorem: *Let Y_n denote the nth of the Yablonskii-Vorob'ev polynomials that arise from rational special solutions of the second Painlevé equation. The real roots of Y_n and Y_{n+1} are interlaced for each integer $n \geq 1$.*

[1] P. A. Clarkson. Painlevé transcendents. In NIST handbook of mathematical functions, pages 723–740. U.S. Dept. Commerce, Washington, DC, 2010.

[2] Peter A. Clarkson. Painlevé equations—nonlinear special functions. In Orthogonal polynomials and special functions, volume 1883 of Lecture Notes in Math, pages 331–411. Springer, Berlin, 2006.

[3] V. Y. Novokshenov. Distributions of poles to Painlevé transcendents via Padé approximations. Constr. Approx., 39(1):85–99, 2014.

Bringing Real Life to the Art of Mathematics

Alexander Stokes is currently completing dual Bachelors in mathematics and the arts, including courses in electroacoustic and computer music at the Sydney Conservatorium of Music. The University of Sydney student is no stranger to combining arts with mathematics having begun his formal mathematics education in Japanese.

"The language's mathematical and modular structure opened different ways of organising and sequencing ideas," he recalls.

This came in handy during his recent Vacation Research Scholarship project on Integrable Systems and the algebraic and geometric properties that explain their strangely ordered behaviour under University of Sydney's Professor Nalini Joshi AO.

"Understanding the hidden structure behind such systems will make it the easier for scientists to identify when they are dealing with one, such as in models of electrodiffusion or rogue open ocean waves," he explains.

Unpredictable and dangerous, rogue, freak, episodic or killer waves create perilous conditions for ocean traffic including large vessels such as cruise liners, making the ability to use modelling to predict these events critical to forecasting conditions and improving safety.

It is this use of the language, logic and rigour of mathematics to reformulate the scientific that attracts Alexander.

For Alexander, VRS was a chance to taste the realities of this type of observation and research in a real-world context.

> *"Applied mathematicians develop and analyse the problem and our observations to form conclusions about the system's initial state and evolution. There's a beautiful mathematical structure behind what we do and how."*

"Far from the stereotype of solitary scribbling and light bulb moments, this experience highlighted the critical need to be able to communicate your ideas and see what you do in wider perspectives both within and beyond your discipline," he reveals.

Droplet Pearling

Scholar: **Amy Stringfellow,** Queensland University of Technology
Supervisors: **Professor Scott McCue & Dr Timothy Moroney**, Queensland University of Technology

Droplets flowing are a natural phenomenon we frequently interact with in every day life, and the mathematical models of droplets involve an interesting set of fluid mechanical processes. The flow of a droplet is a specific case of a thin film flow. The specific case developed involves a droplet rolling down a dry inclined surface when being acted upon by gravity. There is also additional physics required to model this system beyond the general thin film problem, due to the molecular forces which occur at the meeting of the surface of the fluid to the solid substrate. The major assumption in the model is that of a thin precursor film across the domain. The governing equation to this system is a fourth-order, two-dimensional nonlinear partial differential equation that describes the height evolution of the system over time. The feature of highest academic interest in this problem is the boundary of the fluid droplet's contact with the surface. This boundary is known as the contact line. This report considers the different behaviours of the droplet tail or the rear contact line of the droplet. The use of numerical techniques rendered simulations of the droplets that described droplets similar to those formed by Mayo, McCue & Moroney [1].

[1] Mayo, L., Moroney, T., & McCue, S., 2011, Flow of a Thin Liquid Film Down an Inclined Surface, Queensland University of Technology, Brisbane.

Forecasting Fire Bugs

Scholar: **Shane Henry**, The University of Melbourne
Supervisors: **Nicholas Read & Professor Peter Taylor**, The University of Melbourne

Arson is a serious problem in Australia and certainly in Victoria, where there have been roughly 5,000 maliciously lit fires per year since 2000. Patterns of arsonists can be examined statistically to determine if there are any links between variables and locations of ignition points. This study consisted of two parts. The first part examined the distributions of distance between ignitions and the nearest road, and also the type of road, whether it be primary, secondary or non-road. It was found that the popular theory that more fires are lit off secondary roads had some validity, however it was found that per kilometre of road by class, there was a higher amount of ignitions nearest to tertiary and primary roads compared with secondary roads. The second part of the study examined logistic regression models using a large number of covariates to determine which have a statistically significant effect on the probability of an ignition occurring in a certain location on a certain day. In the case where nearest distance to any road was used as a covariate, without density of roads, it was found that of the 11 covariates used, only daily maximum temperature, daily precipitation, population density and proportion of urban area definitely had a significant effect, however other covariates could be significant, which would need to be determined with further research.

The Space of Closed Essential Surfaces in Knot Complements

Scholar: **Abdul Zreika**, The University of Sydney
Supervisor: **Dr Stephan Tillmann**, The University of Sydney

The existence of a closed essential surface in a knot complement has been an important area of recent research with regards to classifying and distinguishing between hyperbolic knots. Instead of looking at individual normal surfaces within the ideally triangulated knot complement, we analyse the entire space of closed essential normal surfaces and investigate its different properties by constructing a corresponding polytope out of the surfaces. Since these polytopes tend to have dimensions much larger than four, we use a collection of visualisation techniques, particularly Hasse diagrams, to more effectively examine them.

Through this process, we are able to extract information about these knot complements such as the number of admissible essential n-faces in the polytope and the magnitude of correlation between the knot crossing number and the amount of admissible closed surfaces its complement contains.

3.05 CHOOSE MATHS GRANTS

Funded by BHP Billiton Foundation as part of its five-year Choose Maths partnership project with AMSI to empower students, particularly young women and girls to pursue mathematics. Working across four key components including national careers awareness and women in maths campaigns, the project aims to improve the health of the mathematical pipeline from classroom through university and the workplace.

Support for students and early career researchers

The Choose Maths Grants provide full or partial support for Australian female mathematical sciences students and early career researchers seeking to build and extend their skills and professional networks at AMSI training events.

- Awarded on a competitive basis by the Choose Maths Grant Committee, the grants support:
- Attendance at AMSI Flagship events (including support for second time attendees)
- Partner and child travel and/or accommodation support
- Caring responsibility support (for example childcare or temporary respite)

2015–2016 recipients:

BioInfoSummer

Rosemarie Herbert, Monash University
Atma Ivancevic, The University of Adelaide
Himel Nahreen Khaleque, Curtin University of Technology
Farhana Sadia, Monash University
Lu Zeng, The University of Adelaide

Summer School

Azam Asanjarani, The University of Queensland
Xuemei Liu, University of South Australia
Meghann Spinner, University of Wollongong

Interview with Rosemarie Herbert

Rosemarie Herbert, PhD student, McGraw Lab, Biological Sciences, Monash University

Your PhD research focuses on genetics, specifically the genetic basis of poor adaption between *Wolbachia* and novel host species and dengue virus transmission in mosquitoes. Can you give me an example of this research and its potential impacts for the broader community?

Well, Dengue virus is one of those diseases you catch once, and you might have mild flu symptoms. It's the second time that you catch it that it kills you, sometimes literally. It's spreading into Australia from Queensland and tourism, and its only going to get worse as the tropical areas of the world expand. Researchers have discovered that putting *Wolbachia* into mosquitoes stops Dengue virus from being transmitted, but we have no idea why. What I am trying to do is work out what changes are associated with the bacteria interacting with the mozzie before Dengue virus is even present. Hopefully this will help us prevent the virus circumventing the new biocontrol procedures.

You received a Choose Maths Grant to assist your attendance at AMSI BioInfoSummer. This allowed you to travel with your partner and child. How important was this in terms of your ability to attend and fully participate in the sessions throughout the week?

Without the grant, there was no way I was going to be able to afford to come. Although my child is in Primary School, it's often underestimated how much work still goes into this. As I am the parent with the more flexible schedule, it is my role to meet those childcare needs.

When I received this grant, I was very excited, as it was the first conference I had attended outside my home university. The workshops were amazingly helpful, and being able to attend without worrying what time I needed to get home was priceless.

One of the areas you were hoping to build on at BIS was your understanding of complex statistics. Did you end up addressing this, what else did you take away that has impacted your research?

I felt quite overwhelmed for learning some of the complex statistics, but I got a better grasp on the medium concepts that I never could have mastered on my own. The biggest thing for me was being able to get a taste of a range of offerings, and so think about other projects that might be of interest next. Attending things like this mean that pieces of science that seem otherwise unattainable suddenly become reasonable to learn.

You plan to pursue research consultancy opportunities within Bioinformatics rather than a fulltime academic career. What factors has influenced this decision? Is this indicative of a broader issue for women in research?

I'm passionate about teaching in a university setting. I've always had fantastic teachers that were involved in my love of science, and I want to give something back.

I'm not particularly interested in academic career because of the job instability. With a young child and a partner in a specific work role, we are unable to move to meet my work needs. Going overseas to chase 'tenure-track' positions is out of the question.

Choose Maths is also about strengthening mathematics education at the school level both through teacher training and student engagement with a focus on girls and women. Did you always want to pursue science and maths? Were you encouraged to study these subjects at school? Do any particular mentors come to mind?

I always knew I wanted to pursue science and math. I was always good at math, but science ended up being my true calling. I had very encouraging male and female teachers of science through high school. This culminated in having a fantastic female biology teacher who took students into her home to tutor them. She knew that I was passionate about science, and supported my interest into tertiary study.

3.06 ACE HONOURS COURSES

The standard undergraduate degree program is a three-year bachelor course followed by an honours year, including a research thesis. AMSI member institutions run annual mathematical Honours year subjects in the Advanced Collaborative Environment (ACE Network) enabling students from several universities at once to participate in Honours subjects remotely.

Course details

Theory of Statistics

July–October 2015, La Trobe University

Associate Professor Paul Kabaila

Synopsis: Aimed at fourth year students, this subject covered key topics within classical statistical inference.

Number of participants: 3

Complex Networks

July–October 2015, RMIT University

Dr Stephen Davis

Synopsis: Focusing on recent advances over the last two decades this course examined current understanding of the structure of complex networks. With an emphasis on the analytical techniques used to classify and characterise networks, students were asked to analyse real networks themselves.

Number of participants: 5

Survey Design and Analysis

July–October, 2015, The University of Wollongong

Associate Professor Robert Clark, Professor Ray Chambers, Professor David Steel

Synopsis: This subject provided a foundational understanding of model-based prediction approaches to sample surveys. The subject closely followed the textbook *Introduction to Model-Based Survey Sampling with Applications*

Number of participants: unrecorded

Experimental Design

July–October, 2015, The University of Wollongong

Professor Brian Cullis

Synopsis: The design of comparative experiments is the cornerstone of much medical, biological and agricultural sciences research. This course equipped students to provide experiment proposals, pose pertinent questions examining the experiment aims, the treatments and their structure, the experimental units and the inter-relationship between the experimental units and the treatments.

Number of participants: unrecorded

Topological Groups

July–October, 2015, The University of Newcastle

Dr Colin Reid

Synopsis: An introduction to the theory of topological, and in particular locally compact groups, this course explained and, in special cases, proved fundamental theorems.

Number of participants: unrecorded

Analysis

March–May 2016, Macquarie University

Professor Xuan Duong

Synopsis: An advanced analysis course, students closely followed the first five chapters of the textbook *Real and Complex Analysis* by Walter Rudin

Number of participants: Unrecorded

Advanced Collaborative Environment (ACE) Network

The Advanced Collaborative Environment (ACE) at AMSI member universities enables maths departments to collaborate through advanced video conferencing and desktop sharing facilities. It has been established to facilitate greater collaboration between the mathematical sciences community both within Australia and internationally.

Advanced Data Analysis

March–May 2016, University of Wollongong

Dr Pavel Krivitsky

Synopsis: This course introduced students to a variety of advanced data analysis techniques covering regression, handling categorical, dependent and nonlinear data, and situations where parts of the model are unknown or misspecified. Students considered generalised linear models in detail, as well as exploring other approaches to model nonlinearity, such as nonlinear models and nonparametric analysis.

Number of participants: Unrecorded

Partial Differential Equations in Mathematical Biology

March–May 2016, The University of Sydney

Dr Peter Kim

Synopsis: The course focused on partial differential equation (PDE) models in mathematical biology. PDE models capture a wide range of biological phenomena, including spatial and age-structured interactions.

Number of participants: 10

Model Theory

March–May 2016, La Trobe University

Associate professor Tomasz Kowalski

Synopsis: This subject introduced model theory: a branch of mathematics that deals with classification of structures by means of logical formulas.

Number of participants: 3

Integrable Systems

March–May 2016, The University of Sydney

Professor Nalini Joshi and Dr Milena Radnovic

Synopsis: An introduction to mathematical properties of integrable systems, participants studied solutions, as well as symmetry reductions called the Painlevé equations and their discrete versions. The course also covered mathematical methods created to describe the solutions of such equations and their interrelationships.

Number of participants: 14

Fractional Calculus with Applications

March–May 2016, University of Wollongong

Dr Marianito Rodrigo

Synopsis: This course covered the basics of fractional calculus, or more aptly called the calculus of derivatives and integrals to an arbitrary order. Starting with a historical survey, students were encouraged to consider some special functions that are frequently used in this field.

Number of participants: 6

3.07 EARLY CAREER WORKSHOP AT THE ANZIAM 2016 CONFERENCE

QT Hotel Canberra, 6–7 February 2016

The ANZIAM Early Career Workshop provides an opportunity for early career researchers—from PhD students to those who are about five years post-PhD—to network while learning from the experience of a panel of world field leaders.

Held immediately preceding the ANZIAM conference, this year's workshop focused on advice sessions rather than research talks, with a focus on academic and industry career opportunities and skill development to improve opportunities for current students and recent graduates. Topics included research program development, establishing research collaborations, academic career paths within and beyond Australia and New Zealand and balancing research with other commitments.

The majority of the 24 participants were PhD students, with a small number of postdoctoral researchers and other early career mathematicians. The panel members included mathematicians from both academia and industry, and from a variety of career stages from early career to established professors.

"I particularly enjoyed having a range of experience levels on the panel - from PhD candidates through to professors. And the career path of each speaker was varied and different, allowing me to envisage my own career path in many different ways!"

"People with different lifestyle choices or priorities can take different career paths and be successful—there is no 'one way' to be a good researcher."

Organisers

Dr Roslyn Hickson, IBM Research - Australia
Dr Melanie Roberts, IBM Research - Australia
Dr Leesa Sidhu, The University of New South Wales

Invited Speakers

Dr Steven Barry, Air Services Australia
Dr Adelle Coster, The University of New South Wales
Alexandra Hogan, The Australian National University
Dr Mike Planck, The University of Canterbury
Dr Jane Sexton, Geosciences Australia
Prof. Peter Taylor, The University of Melbourne

Program structure

This workshop consisted of panel discussions, hands-on active workshops and presentations.

Weblinks

austms.org.au/tiki-calendar.php?calitemId=703

Other Sponsors

ANZIAM, AustMS

Contact

Anziam2016@adfa.edu.au

3.08 AUSTRALIAN MATHEMATICAL SCIENCES STUDENT CONFERENCE

The University of Tasmania, 30 November–2 December 2015

Today's postgraduate students ultimately become tomorrow's research leaders. Early opportunities to network are therefore critical to the progression of students' careers. However, the tyranny of distance and Australia's expansive geography remains a barrier for engagement between Australian universities.

The Australian Mathematical Sciences Student Conference (AMSSC) provides postgraduate students from across the country with opportunity to showcase their work, facilitate dialogue, and explore future collaborations. In addition it provides students with the opportunity to gain conference experience.

Complementing the AMSI summer and winter schools, AMSSC is primarily directed towards Australian postgraduate and honours students from all areas of the mathematical sciences, inclusive of but not limited to applied/pure mathematics, statistics, mathematical physics, oceanography and mathematical biology. It provides an opportunity for honours and postgraduate students to present their own research—for many attendees this will be their first chance to do so—facilitates networking and encourages collaboration within a friendly and informal atmosphere.

In 2015, 15 students presented on key areas of applied and →

"I really enjoyed it! I found it much less daunting that other academic conferences to present at, which was good for my confidence when presenting at another conference soon after."

pure mathematics, while three plenary speakers presented on their own research as well as providing early career advice.

The conference gave attendees the opportunity: to obtain experience applying for travel funding to attend academic conferences; to share their own research within a friendly and encouraging atmosphere; to obtain experience presenting at an academic conference; to meet other Australian honours and postgraduate level students from the mathematical sciences; and to learn about the research that other Australian honours and postgraduate level students are undertaking. The conference also gave the organisers the opportunity to obtain experience with and knowledge for how to successfully organise and run a conference.

Organisers

Michael Cromer, The Australian National University
Nick Ham, University of Tasmania
John Harrison, The University of Newcastle
Arwin Kahlon, University of Tasmania
Jesse Swan, University of Tasmania
Matthew Tam, The University of Newcastle

Special presenters

Assoc. Prof. Benjamin Burton, The University of Queensland
Research interests: computational geometry and topology, combinatorics, and information security
Dr Jaclyn Brown, CSIRO, Tasmania
Research interests: climate variability and change in the Tropical Pacific Ocean
Dr David Ridout, The University of Melbourne
Research interests: integrable models, representation theory, vertex operator algebras, conformal/quantum field theory

Web Links

www.amssc.org/2015/

Other Sponsors

AustMS, University of Tasmania

Contact

Michael Cromer, The Australian National University,
michael.cromer@anu.edu.au

3.09 HEIDELBERG LAUREATE FORUM

23–28 August 2015

A highlight of the international mathematics and computer science calendars, the Heidelberg Laureate Forum provides highly talented young researchers with the opportunity to engage with the winners of the most prestigious scientific awards in Mathematics (Abel Prize, Fields Medal and Nevanlinna Prize) and Computer Science (ACM Turing Award). This provides an outstanding platform for scientific dialogue across generations. Each year AMSI and AustMS provide funding to support young Australian researchers' attendance at the event.

2015 recipients

Philipp Bader, La Trobe University
Melissa Lee, The University of Western Australia
Matthew Tam, The University of Newcastle
Anna Tomskova, The University of New South Wales
John Tsartsaflis, La Trobe University

3.10 WOMEN IN MATHEMATICS

Improving gender ratios in the mathematical sciences—AMSI's approaches

Women and girls continue to be underrepresented in mathematics. Challenging traditional mathematical career narratives and championing the participation of women and girls at all stages of the discipline pipeline remains essential.

Less than 30 per cent of all undergraduate and postgraduate students in Australia are female; similarly, women account for fewer than 30 per cent of staff employed by mathematical sciences departments. This figure drops significantly with the level of seniority, with fewer than 10 per cent of staff employed at the highest levels female.

As facilitator of the Australian Mathematical Society's Women in Mathematics Special Interest Group (WiMSIG), AMSI is actively challenging the mathematical and general communities to address this issue. The embedding of a series of public "women in Mathematics" events into each flagship training program has increased awareness of issues faced by women in the mathematical sciences and helped to create a national support network.

At the ground level, AMSI is strongly encouraging organisers of AMSI-sponsored workshops to improve the participation of female researchers through a range of measures including, the inclusion of at least one women on the organising committee, engagement of female speakers and provision of information such as childcare availability. The current goal for female attendees at AMSI-sponsored programs is 30 per cent. In 2015–2016, female mathematicians attending AMSI-sponsored workshops made up 14 per cent of the participants across the 16 funded workshops.

AMSI's Choose Maths travel grants provide support to remove barriers and empower Australian female mathematical sciences students and early career researchers to participate in AMSI's flagship programs (Winter and Summer Schools, BioInfoSummer and the Vacation Research Scholarship program). The competitive grants cover attendance at the event, as well as financial support for partner and child travel/accommodation, and/or caring responsibility (childcare or temporary respite).

The grants are funded by BHP Billiton Foundation as part of Choose Maths, its partnership project with AMSI. This initiative aims to strengthen Australia's mathematics capability over the next five years. The team is working with schools in metropolitan and regional areas across Australia to implement strategies at key stages of the pipeline to strengthen mathematics education outcomes and to entice more girls and young women into mathematics.

Program components include teacher professional development, national campaigns to drive careers awareness and challenge gender narratives within the discipline through the Inspiring Women in Mathematics initiative and the BHP Billiton Awards for Excellence in the Teaching and Learning of Mathematics (Choose Maths Awards).

Events in 2015–16:

- In December 2015 AMSI hosted the Women in Mathematics Lunch with WiMSIG, featuring a talk by Professor Marilys Guillemin (Associate Dean Learning and Teaching in the Faculty of Medicine Dentistry and Health Sciences), at the University of Melbourne on *Addressing gender inequity in STEMM: What can we learn from local and international initiatives?*
- Professor Nalini Joshi and Cassandra Portelli gave a public lecture *Journeys through Mathematics and Life* as part of the Guttmann 2015 workshop held in Newcastle in December 2015
- Summer School Women in Maths Afternoon
- Margaret Werthiem gave a public lecture *Corals, Carbon and the Cosmos: The Story of Hyperbolic Space* during the 2016 Summer School held in Melbourne
- Winter School Women in Maths Networking event
- BioInfoSummer Women in Science event

WOMEN IN MATHEMATICS - **BY THE NUMBERS**

Workshops stats

Invited speakers receiving funding: 9% female

Workshop participants: 14% female

Participants receiving travel funding from AMSI: 16% female

Flagship program stats

While female participation in 2015/16 was stronger than in previous years, Winter School proved an exception. Overall, women account for about 35% of attendees across the four flagship training programs

Winter School

Women accounted for 10% of students and 20% of speakers

(The poor female representation in this area of mathematics has affected both the number of students and the number of speakers that are female)

BioInfoSummer

Women accounted for 47% of participants and 45% of speakers

Summer School

Women accounted for 34% of students 44% of lecturers

Vacation Research Scholarships:

Women accounted for 29% of students and 13% of supervisors

AMSI Intern:

To date, 35% of the participants in the AMSI Intern program have been female

OVERCOMING BARRIERS TO SUCCEED IN MATHEMATICS

An interview with Professor Cheryl Praeger, Vice-President of the International Commission for Mathematical Instruction, Professor of Mathematics, University of Western Australia and Foreign Secretary, Australian Academy of Science.

Can you tell me a little about your background and how this influenced your pursuit of a career in mathematics? Were you encouraged in your studies at home and school growing up?

As well as attending various country schools, I spent three years at a Brisbane private girls' school where I thrived with the freedom to enjoy learning. In particular I loved science and mathematics. I don't come from an academic family but my parents always encouraged me and I was thrilled to have the good fortune to attend such a school. My mother in particular, was determined that at least one of her children would attend university, so my parents were supportive of me continuing my studies provided I had scholarship support. After winning a mathematics competition (run by the Queensland Association of Mathematics Teachers) in my last year of school, I gained the confidence to go to university to study mathematics. I was the only girl at my school to pursue maths, with most following the well-trodden paths of nursing, physiotherapy or teaching as I was told "girls don't do maths, they don't pass". Thankfully my teachers joined my parents in supporting my ambitions.

At University I was immediately in the minority, of the 80 students in my first year honours mathematics class: only ten of us were girls. A mid-year exam saw numbers fall to 30 with only four girls and by my second year I was the only one. Despite this I still felt there was a place for women with mathematics, a position only strengthened by two women maths lecturers, excellent mentorship and a Vacation Scholarship with the ANU.

You are considered one of Australia's leading pure mathematicians. What drew you to pure mathematics, in particular the theory of permutation groups (finite and infinite, as well as in algorithmic group theory, graph theory, and other combinatorial theories)?

I loved my maths undergraduate courses, but most of all I loved the courses in algebra taught by Anne Street and Sheila Macdonald (now Sheila Williams). Perhaps my attraction to pure mathematics was cemented by my first research experience as a vacation scholar at the ANU where I worked on a project solving an integer difference equation with Professor B. H. Neumann. That led to my first journal article, written while I was an honours student. Then in Oxford I did a project on permutation groups for my masters, and really loved it. I ended up writing my DPhil thesis in this area. I love symmetry and studying its effect on combinatorial structures such as graphs and designs. My major research area is still permutation groups and their applications in algebraic graph theory.

In 1983 you became the second Australian female Mathematics Professor after Hanna Neumann. Who were your role models and mentors as a woman entering the mathematical sciences? How important was this support entering such a male dominated area?

Anne and Sheila were my role modes as an undergraduate. I met Hanna Neumann in Canberra when I was a vacation scholar. I admired her immensely, and had the ambition to be a professor like her: a top researcher, a great teacher, a mentor to her staff and students, forging her career while bringing up her family.

Unfortunately Hanna died while I was studying in Oxford. But I had two life-long mentors and friends who have been very important to me: Hanna's husband Bernhard who had been supervisor for my vacation scholarship (and on through the next year writing up that journal paper); and their first son Peter, who became my D Phil supervisor.

Mentors, strong voices of encouragement and wisdom are essential. Every generation needs those role models who inspire and show them what is possible, that someone else has been there. I have been fortunate to have the opportunity to in turn take on this role and help nurture new generations of female mathematicians.

In what ways have you encountered gender bias within the mathematical sciences? Is this improving? How have things changed since you entered academic mathematics?

There is pervasive community perception of maths being a male subject. This immediately puts girls at a disadvantage regardless of curriculum or course structure. It has also driven the narrative fed to many girls by well-meaning parents and educators who advise them against serious pursuit of mathematics. I saw this as I was coming through school with most girls directed to caring professions and physical sciences such as nursing, physiotherapy or teaching.

I have always believed that intelligence is not the sole prerogative of one gender. We need women as well as men in the mathematical sciences. Fortunately, I was lucky enough to be surrounded by a network supportive of this.

As I have said, at university I began as one of ten women and ended up the only one in my course. Things have improved and we are seeing greater numbers of girls and women participating in mathematics but gender inequality is still a big problem.

The problem is, however, now very much out in the open. There's greater public debate about gender issues, and we now have programs such as Choose Maths.

Employment of women across Australian University mathematics departments remains low (22 per cent). Why do you think is driving this gender divide? How can we address this?

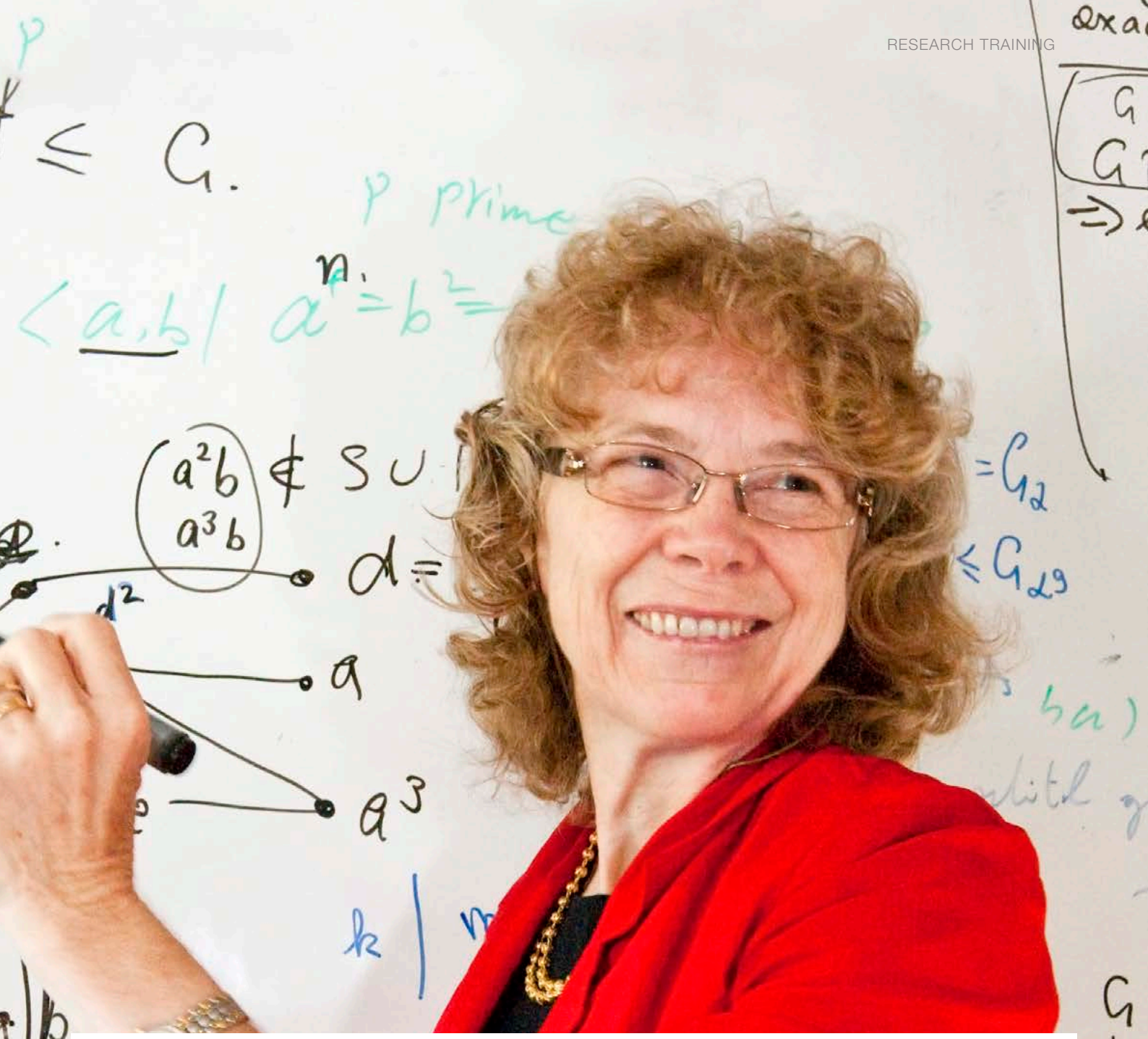
There are a number of barriers for women in mathematics. As I have said, maths has traditionally been seen as male. A second factor is the family background of the students; girls are often brought up to cooperate rather than compete, which disadvantages them in the competitive academic environment. A move toward teaching strategies that encourage cooperative and collaborative approaches would not only benefit female students but all students in mathematics courses.

Having role models and mentors to encourage and support young female mathematicians is another important factor.

The AustMS WiMSIG Cheryl E. Praeger Travel Award is named in honour of your contribution as a role model and mentor for women and girls in maths. What involvement have you had with WiMSIG and how important are such support networks and grant programs for women?

I was delighted when WIMSIG was established as a "Women in Maths" Special Interest group of the Australian Mathematical Society. And especially delighted when WIMSIG decided to establish a small grant scheme to assist women — especially women with small children — to attend conferences and undertake research projects away from home (the Praeger Travel awards). I had nurtured and encouraged women to meet together at the annual Maths Society meetings for almost a decade before WIMSIG was established. We had to wait to establish this until the next generation of young women knew they wanted such an organization and were ready to lead it.

Organisations such as WIMSIG play a critical role in strengthen-



ing the networks of mathematical women. These help women gain invitations to research meetings, which in turn lead to collaborations. Some female mathematicians have felt uncomfortable about being part of 'all female' groups but this collective voice helps nurture new generations. Senior women mathematicians have an important mentoring role to play. I would love the day to come that such gatherings and organisations were no longer needed, but it seems unlikely that the seamless inclusion equally of women and men in mathematical networks and decision making will happen for some time yet.

Through the Family Maths Program Australian (FAMPA) you have helped foster engagement of girls in mathematics, what drew you to this program. Why are programs such as this and Choose Maths so important?

FAMPA (Family Maths Program) was a WA Education Department initiative. My links with this program were essentially at the local level. At the time I was Chair of the Nedlands Primary School Council — where my two sons attended school. I encouraged the school to take an active part in the program. I had known a lot about the FAMPA program through my role as Ministerial appointee on the Federal government's Curriculum Development Council — we heard a lot about various State education initiatives. The program involved teachers, parents and students. It was a good experience to promote whole-of-community involvement in the mathematics program of the school — the best thing to support our kids.

What do you think the Australian research community should be doing now grow its capacity?

UNESCO sees education as "an act of faith in the future" and Nelson Mandela called it "the most powerful weapon which you can use to change the world". As an example, focus on education and research in post-war South Korea, especially in maths and science, has led to a staggeringly successful economic recovery for that country. When I was asked in 2014 what was needed to find a new "Korean story" — and how wonderful it would be to find it in Australia — I replied that it requires a country to have both a strengthening economy and decision-makers who see education as the right long-term strategy for positive change.

What else can we do? Implement the maths decadal plan; be in tune with the government's "Innovation Agenda" funding, strengthen our international links, and nurture the next generation of young mathematicians.

Industry Research Programs 4

4 INDUSTRY RESEARCH PROGRAMS OVERVIEW

AMSI's industry work programs aim to boost Australian business engagement with mathematical sciences research. It is essential to ensure Australia has the mathematical and statistical skills to remain internationally competitive and protect national security, population health and climate stability into the future. Future mathematical literacy requires decisive policy action and reform today.

Up to 75% per cent of Australia's fastest growing employment areas require STEM.

> *"We owe it to our STEM PhD graduates to prepare them for industry careers, not just because the opportunities in academia are limited but because the paths in industry can be extremely rewarding."*
>
> Dr Alan Finkel, Australia's Chief Scientist

4.1 AMSI INTERN

AMSI Intern works at the interface between academia and industry, creating and strengthening linkages and awareness of the business value and impact of engaging high-level research capability to drive innovation.

Operating across all disciplines and sectors, the program delivers Australia's young and brilliant minds to industry to enhance the postgraduate experience by providing opportunity for practical application of research skills within a commercial context. This in turn provides a platform for industry to engage with and attract talent into their organisation through short-term tightly focused research projects.

AMSI Intern is Australia's leading PhD internship program having placed over 150 postgraduate students from 30 universities into industry. More than 90 businesses and government agencies have hosted interns since the program's inception in 2007, and significantly, more than 60 per cent are repeat customers.

In 2015, the program placed 18 interns from 7 disciplines with 14 industry partners across 9 industry sectors. In the first half of 2016, 30 interns have been placed across all industry sectors and disciplines.

Initially focused on placement of mathematical sciences interns the program has expanded to work across all disciplines and sectors as it increases its network of industry partners.

In 2015, AMSI Intern established a strategic partnership between eight AMSI member universities to expand the program in Victoria and New South Wales, a model, the first of its kind with dedicated business development managers driving placements from these universities into industry.

AMSI Intern provides a crucial boost to business and university partnerships. Australia currently ranks 29 out of 30 countries in the OECD for business-university collaboration—a stark contrast to its ranking as ninth in research output per capita amongst OECD nations.

"Australia must increase the penetration of Australian graduates with advanced research expertise into the private sector. They will boost innovation and business-university collaboration but we must give them those skills. And give business the confidence to employ them"

Professor Geoff Prince, AMSI Director.

Looking Ahead

Planning is underway for potential expansion in 2017, with the aim of re-positioning the program to lead postgraduate internship placements nationally.

This would provide internship access to industry at a reduced cost to enable placement of around 1400 postgraduate students over four years. Additionally this next phase would align to current STEM equity priorities to support increased female participation in traditionally male-dominated sectors.

Proposed as part of the federal government's election package, a national program would drive delivery of the public research commercialisation agenda. Critically internships would contribute to strengthening collaboration between academia and industry—ensuring a work-ready PhD student and a significant outcome for the industry partner.

"AMSI Intern would appear to be the closest Australia has to a national coordination of industry placement opportunities for HDR graduates, For small and medium sized enterprises this can prove a significant barrier as opportunities to collaborate with universities to develop mutually beneficial training opportunities can be difficult to find"

Review of Australia's Research Training System final report, ACOLA.

Opening the Door to a Statistical Future
Intern and Mentor Build a Lifetime Bond

AMSI Intern from both sides: The Intern

It has been said, "In theory, theory and practice are the same. In practice, they are not." This truth is not lost on Dr David Price, who recently discovered the challenges of industry thanks to an AMSI Intern placement with SA Pathology. The then PhD student provided applied statistics expertise to improve outcomes for Chronic Myeloid Leukaemia patients through tailored treatment plans.

"The internship was the first time I had properly worked with non-statistical research scientists on a project. Adding to the challenge it was also an unfamiliar research area, which required close collaboration with experts outside my field," Dr Price explains.

With industry engagement a big part of the job for applied statisticians, David welcomed the chance to gain experience under the guidance of his University of Adelaide supervisor and mentor, Dr Jonathan Tuke. A former veterinarian, Jonathan's biology background and understanding of industry proved invaluable.

"I was excited to take on this challenge with him, as I know he is a fantastic supervisor and mentor. As well as valuable insights from his background and personal experience, he was always there to provide support as needed," he said.

Jonathan also worked closely with David to develop his soft-skills such as time management, planning, data storage and cross-discipline communication.

"This experience has given me the skills and confidence to seek cross-discipline consulting opportunities in the future. Jonathan's insights regarding industry, best consulting practices and communication with non-statistical research scientists were invaluable."

After years of focusing on tools and methodology, the internship helped David understand the value of his statistics expertise as he put theory into practice.

"This project showed me how the skills and knowledge I have gained through my studies could be applied to deliver practical outcomes."

"It was a chance to visit the other side of industry engagement and work on a real-world problem but with a safety net."

As he steps into a postdoctoral role at the University of Cambridge he will have ample opportunity to make use of the skills he developed through AMSI Intern.

"At Cambridge, I will be working closely with biologists, the experience through AMSI Intern will mean I am able to communicate effectively and establish their needs and preferences as I progress my project."

As for future endeavours with Jonathan, he makes it clear the door is well and truly open.

"Jonathan has made it clear he is available if I need anything. He is someone I thoroughly enjoy working with and would love to do so again in the future if possible."

AMSI Intern from both sides: The Academic Mentor

Summing up the challenge of applying academic theory in the real world, the University of Adelaide statistics lecturer and former veterinarian, Dr Jonathan Tuke draws on personal experience, "books don't bite but dogs do."

As a veterinarian science graduate, it was only after months on the job and more than a few bites and scratches that he felt he was a vet. The same can be said for his current field of statistics, says Jonathan, with the divide between theory and practical application just as wide.

"So often in practical application, statistical theory and modelling collapse under the wings of reality. Suddenly you are in the real world with all the variables and challenges that brings."

When he was given the opportunity to act as an Academic Mentor on a project with AMSI Intern industry partner, SA Pathology, Jonathan immediately thought of student and collaborator, David Price. Now nearing the end of his PhD, the internship was the perfect opportunity for David to gain exposure to statistics in the real world.

"We provide PhD students with strong theoretical and academic backgrounding, but not the understanding of the real-life application of their work. AMSI Intern was the ideal platform to address this for David through industry exposure and soft skill development."

Leaving David to drive the project, Jonathan used his mentor role to provide support and guide him on industry best practice, as well as tools of the trade. Thanks to his biology background, he was also able to help facilitate cross-discipline communication.

"Working in statistics, you invariably end up working in someone else's backyard. My role was to equip David with the skills and confidence to work with non-statistical researchers as well as solve problems within industry environments."

Jonathan also hopes the experience will shape David's approach when he trains the next generation of statisticians.

"When he comes to teaching his own students, I hope he will in turn harness opportunities such as AMSI Intern to direct them towards consulting."

There were also benefits for Jonathan. A closer relationship with SA Pathology has opened doors for future consultation and opportunities for other students.

"This project has been a great stepping stone for further conversation with SA Pathology and involvement in their research. They now have a better idea of what I can do and how statistics can benefit their work."

As for whether he has played any role in David's success—he has recently taken up a postdoctoral position with the University of Cambridge—Jonathan gives his student all the credit.

"David is not only a skilled statistician but a great communicator. I have just been lucky enough to steer him in the right direction."

Telstra Gets Ahead With AMSI Intern

MORE THAN SIMPLY THE BUZZ PHRASE OF THE MOMENT, Big Data represents one of the most exciting optimisation opportunities within Australian and global industry. With every click consumers create a complex digital footprint of their online preferences and behaviours. Information businesses are using Big Data to transform customer communication and service delivery.

Steve Morris, General Manager of Technology and Analysis—Big Data, and his team are at the frontline of Telstra's Big Data response. Using new approaches and technology, they are helping to manage and harness the growing volumes of insights and information being produced across the organisation.

To maintain Telstra's competitive edge, Steve turned to leading Australian postgraduate internship program AMSI Intern, hosting two interns to assist on network and customer advocacy projects. With a tailored approach and access to Australia's brightest minds, the program was a perfect fit to help optimise Big Data application and innovation at Telstra for the future.

"As the technology pace quickens, industry needs to be innovating for the future and thinking about the challenges of the next horizon. Working with researchers connected to enterprise realities is essential to stimulate this process with management and internal staff."

Steve Morris, General Manager of Technology and Analysis — Big Data at Telstra

University of Melbourne PhD student Bahar Salehi was one of two interns who completed placements with Steve and his team in 2015. Her natural language processing expertise and fascination for artificial intelligence — the provision of human language understanding to computers — made her a perfect fit to enhance customer engagement.

"One of the goals of the project was to use intelligence systems to optimise Telstra's customer engagement. The project strongly aligned with the work I was doing as part of my studies, the big difference being I was working on real-world data," explains Bahar.

"AMSI Intern has given me a better understanding of industry and the capacity of Big Data related jobs. To see how my research can impact outcomes at one of Australia's biggest companies has been invaluable."

Bahar Salehi , The University of Melbourne

It has been a win-win situation with Steve and the team relishing both the opportunity to foster new skills in Bahar and learn from her technical experience, vision and research approaches.

"As well as the satisfaction of exposing students like Bahar to industry and how enterprises work with and adopt new technologies, our team has benefited from the opportunity to pick up new ideas and techniques," says Steve.

AMSI Intern is a welcome opportunity for Telstra, which has a long history of research investment, to strengthen ties with universities, emerging technologies and the community. Citing the program's flexibility and ability to match students to short-term leading-edge opportunities, Steve is quick to encourage others across the organisation to jump on board.

"I'm an advocate for AMSI Intern," says Steve. "We have been able to successfully match interns based upon our short-term special project needs and their interest areas."

With Telstra's AMSI Intern journey only just beginning, it seems likely more students will be wetting their toes in one of industry's biggest pools.

"After the success of the 2015 internships we have another three interns commencing in early 2016 to work with high performing staff in my team and elsewhere in Telstra," Steve says.

4.2 MATHEMATICS IN INDUSTRY STUDY GROUP (MISG)

The University of South Australia, 1–5 February 2016

AMSI partners with ANZIAM to deliver the annual Mathematics in Industry Study Group. Applied mathematicians, statisticians, physical scientists and engineers apply cutting-edge mathematical science to provide practical working solutions to real life industry challenges facing multinational and small to medium businesses within Australia and New Zealand and globally.

The MiSG creates business linkages to high-calibre professionals, tools and technologies to improve capacity and capability in problem solving and decision-making. Each year, 100 world-leading applied mathematicians, statisticians and physical scientists attend, using the opportunity to apply their skills to business participant challenges.

The program receives acclaim from industry partners as a low cost, high yield investment in problem solving. Some partners have implemented MiSG practices directly following the workshops, while others have expanded their investment into collaborative research partnerships to solve even larger business challenges.

Every participating industry partner receives a brief summary report immediately following the MiSG workshop. These reports capture the essence of what was achieved during the workshop and summarise the ongoing work to be discussed in full technical detail in a final report.

MiSG2016 was opened by The University of South Australia's Deputy Vice Chancellor of Research and innovation, Professor Tanya Monro.

Projects

MiSG 2016 tackled four industry problems, delivering a range of challenges for mathematical statistics, operational mathematics, applied and computational mathematics researchers.

Inference in a knowledge base

Knowledge can be represented by a graph of entities (e.g. people, locations, events) and links between entities (e.g. "is related to", "visited"). The attributes of entities and the attributes of links are uncertain, and the probabilities associated with entity attributes and link attributes are generally not independent. How can uncertain attributes be represented? How can inferences generated from the knowledge base be ranked by certainty?
Partner: DST Group

Sequencing ore extraction to control blend quality

Mine scheduling is the task of determining the best material to supply to a processing plant in order to hit production targets, subject to a number of physical, logical, and capacity constraints. This includes determining an excavation sequence for excavators to follow and selecting material to draw from stockpiles to service the processing plant. On extraction, material can either be processed directly or stockpiled for processing at a later time. A geological model specifies quality attributes of material in the ground, but this model has a level of uncertainty associated with it. The problem is to optimise the extraction sequence and processing plant feed in order to maximise the chance of hitting the production quality and tonnage targets. The planning method must be scalable to work with tens of thousands of distinct "blocks" of material in the geological model
Partner: Schneider Electric

Modelling water pollutant density associated with surface water runoff

South Australian Water Corporation sources a significant portion of its raw water from surface water catchments and the River Murray. The raw water is then treated before delivery to customers. Elevated stream flow resulting from rain events is a major driver behind the transport of land-based pollutants to surface water. Ideally, raw water quality should be measured at times of peak flow, but this is not always possible. How can we optimise our sampling to capture a range of runoff events, and then predict pollutant density under a broad range of conditions including peak flow?
Partner: SA Water

Optimisation of household PV and storage

Rooftop solar photovoltaic (PV) panels, household electrical energy storage (batteries), home energy management, interval metering and new tariffs will change the way that households use electricity from the grid. Distributed storage can also give electricity retailers the ability to shift loads in response to changes in the wholesale price of electricity and constraints on the distribution network. What is the ideal mix of PV, storage and tariff for a customer? What is the value of these technologies to customers and to electricity retailers?
Partner: Ergon Energy

Weblinks

http://mathsinindustry.com/about/misg-2016-3/2016-program-2/

Other Sponsors

ANZIAM, The University of South Australia

Contact

Assoc. Prof. Peter Pudney, The University of South Australia,
Peter.Pudney@unisa.edu.au

4.3 ACE INDUSTRY LINKAGE FORUM

27 May 2016, AMSI ACE Room (The University of Melbourne)

Maximising Australian productivity through innovation and technical development remains a critical priority for academic research, industry and government alike. There is an increased focus on the societal benefits from research, with the very real possibility research impact measurements will be included in future ERA evaluations. What is the role of mathematical scientists in all of this? This forum brought together a number of academics in the mathematical sciences with current or past ARC Linkage project connections with industry and the public sector. The panel drew from their own experiences with industry collaboration, presenting real-life case studies and sharing insights and strategies for successful partnerships.

Topics included:

- Establishing and fostering collaborations
- Securing funding—ARC Linkage and other sources
- Research benefits

This discussion forum was designed to provide participants with information, and to start a conversation among mathematical scientists about ways to engage with industry.

Advanced Collaborative Environment (ACE) Network

The Advanced Collaborative Environment (ACE) at AMSI member universities enables maths departments to collaborate through advanced video conferencing and desktop sharing facilities. It has been established to facilitate greater collaboration between the mathematical sciences community both within Australia and internationally.

Speakers

Discussion Leader: Prof. Peter Taylor, Professor of Operations Research and Australian Laureate Fellow, The University of Melbourne, and Director of the ARC Centre of Excellence for Mathematical and Statistical Frontiers (ACEMS). Peter has extensive consulting experience with industries such as Defence, mineral resources, and telecommunications

Dr Amie Albrecht, Senior Lecturer at the University of South Australia and researcher within the Centre of Industrial and Applied Mathematics. Amie's research is motivated by practical industry-inspired challenges, mainly in Operations Research with applications to transport problems. She is a collaborator on a recently awarded ARC Linkage Project on improving train flows with connected driver advice systems, with industry partner TTG Transportation Technology Pty Ltd.

Assoc. Prof. Tim Garoni, Associate Professor in the School of Mathematical Sciences at Monash University. His research interests include Mathematical physics and statistical mechanics. Together with Jan de Gier he collaborates on an ARC Linkage project on urban traffic congestion with industry partner VicRoads.

Prof. Jan De Gier, Professor of Mathematics at the School of Mathematics and Statistics at the University of Melbourne. He is interested in solvable lattice models, which aside from the pure maths aspects provide useful frameworks for modelling real world phenomena. With Tim Garoni, he is a collaborator on the urban traffic congestion project with VicRoads.

Assoc. Prof. Yvonne Stokes, Associate Professor in Applied Mathematics at the University of Adelaide. Her research interests are fluid mechanics, mathematical biology and industrial mathematics. She is currently collaborating on a Linkage Project in the area of nano-electrospray ionisation mass spectrometry, an analytical tool for proteomics and synthetic chemistry, with Trajan Scientific And Medical Pty Ltd.

Participation

Number of remote locations connected: 6
Approximate number of participants: 30

Key Contact

Maaike Wienk, AMSI, **ace@amsi.org.au**

4.4 PARKS VICTORIA PARTNERSHIP

Protecting Australia's Iconic Flora and Fauna, Sustained with Statistics

AMSI provides statistical support to Parks Victoria's environmental monitoring, evaluation and reporting processes through a partnership program established in 2010.

Kally Yuen, AMSI Statistician

An accredited statistician, Kally is an experienced biostatistician, having worked at the Peter MacCallum Cancer Centre and Centre for Youth Mental Health at The University of Melbourne. Accredited by the Statistical Society of Australia in 2004, Kally's qualifications include a Master of Science degree in Statistics, Bachelor of Science degree with First Class Honours in Statistics and Computer Science. She received the Maurice Belz First Prize for Statistics while she was an undergraduate at The University of Melbourne.

Kally specialises in survival analysis, generalised linear models and relational database management systems. She is experienced in statistical consulting, research study design, study protocol and research database development, statistical analyses of research data, protocol review for research and ethics committees and grant assessment. Highly published, she has been a co-author in more than 30 research publications, 14 as a senior author. She has nurtured new talent as an instructor in statistics training courses and supervisor for research students.

Projects

Sallow Wattle Control Monitoring Project In The Grampians National Park

A native plant, Sallow Wattle is also an environmental weed in many areas of Australia. Widespread invasion of Sallow Wattle in the Grampians National Park has become a major concern for Parks Victoria following the January 2014 bushfire. The Victorian Government post-fire recovery fund enabled the establishment of an experimental monitoring program to ascertain the most effective technique to control the notorious weed. Dr Marie Keatley, Parks Victoria flora scientist, and Kally Yuen worked with park rangers to develop the program, which will trial five control techniques. This commenced in November 2015 with baseline monitoring resulting in detection of Mediterranean Linseed, an uncommon weed in Victoria. This has since been removed from the site and a specimen collected for the National Herbarium of Victoria.

Fox Control and Remote Camera Monitoring At The Great Otway National Park

The introduced Red Fox preys on a wide range of native fauna and poses a serious threat to the conservation of many species at the Great Otway National Park. A fox-baiting program is helping to address this threat, with rangers monitoring effectiveness through annual remote camera monitoring of fox and native prey species. In 2015, an analysis was undertaken of the data collected from 2009 to 2014. Results were presented to Dr Mark Antos, Parks Victoria fauna scientist, as well as local and regional staff. This will assist planning of a proposed large-scale fox control program in the park. In December 2015, the team presented a poster on the evaluation of monitoring and analysis approaches used in this program at the Eco-Stats Conference in Sydney. This received positive feedback from attendees.

AMSI Intern Program

Parks Victoria is a long-term AMSI Intern industry partner, providing opportunities for postgraduate students to gain industry experience and apply their research in the context of real-world projects. In 2015, Deakin University postgraduate student, Yongqing Jiang, commenced a three- month internship under the supervision of Dr John Wright and Dr Mark Antos. In recent years, motion or heat-triggered remote cameras have proven to be an efficient and reliable tool for animal surveys. While this approach offers many benefits over other methods, such as trapping, it has high data management and curation demands. Yongqing's project aims to develop an efficient data management system to capture the camera data and generate basic summary outputs. Engagement with AMSI commenced in October 2015 with a detailed briefing of the project. Having commenced in December 2015, it is anticipated that the project will be completed in March 2016.

AMSI acknowledges Parks Victoria for their continuing support of this important research collaboration.

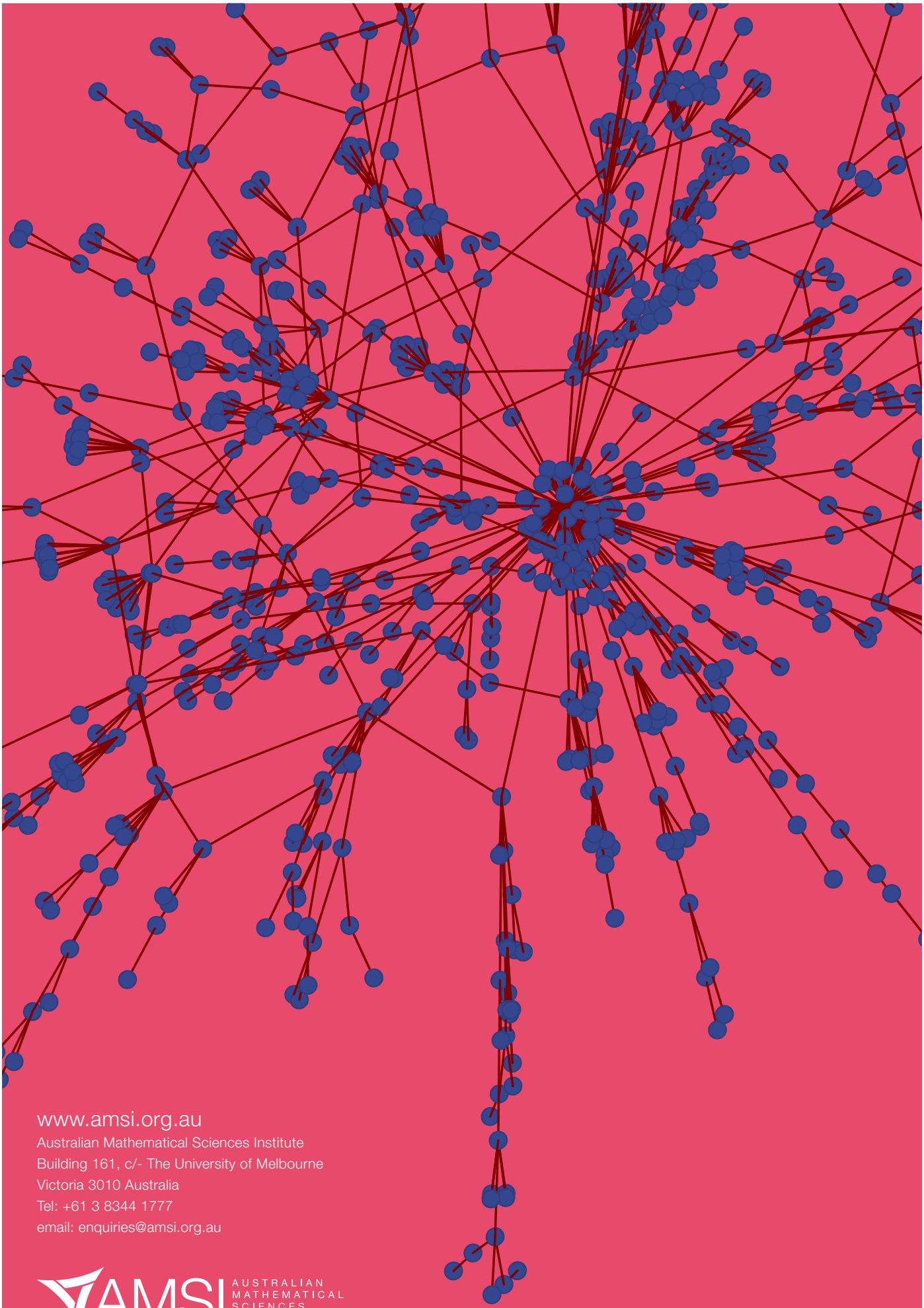
ACRONYMS

ABACBS	Australian Bioinformatics and Computational Biology Society
ACE	Advanced Collaborative Network
ACEMS	ARC Centre of Excellence for Mathematical and Statistical Frontiers
ACOLA	Australian Council of Learned Academies
AGR	Access Grid Room
AMSI	Australian Mathematical Sciences Institute
AMSSC	Australian Mathematical Sciences Student Conference
ANU	The Australian National University
ANZAMP	Australian and New Zealand Association of Mathematical Physics
ANZIAM	Australian and New Zealand Industrial and Applied Mathematics
ARC	Australian Research Council
AustMS	Australian Mathematical Society
BIS	BioInfoSummer
CARMA	The Priority Research Centre in Computer Assisted Mathematics and Applications, The University of Newcastle
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DST Group	Defence Science Technology Group
ECR	Early Career Researchers
EMBL Australia	European Molecular Biology Laboratory Australia
ERA	Excellence in Research for Australia
FAA	Fellow to the Australian Academy of Science
FAAAS	Fellow of the American Association for the Advancement of Science
FAMS	Fellow of the American Mathematical Society
FAustMS	Fellow of the Australian Mathematical Society
FRSC	Fellow of the Royal Society of Canada
HDR	Higher Degrees by Research
IMPA	Instituto Nacional de Mathemática Pura e Applicada
ISI	The Institute for Scientific Information
MASCOS	Centre of Excellence for Mathematics and Statistics of Complex Systems
MathSciNet	Mathematical Reviews Database, maintained by the American Mathematical Society
MiSG	Mathematics in Industry Study Group
MSI	Mathematical Sciences Institute, The Australian National University
OECD	Organisation for Economic Co-operation and Development
ONR Global	Office of Naval Research Global
PIMS	Pacific Institute for the Mathematical Sciences
QCIF	The Queensland Cyber Infrastructure Foundation
QUT	Queensland University of Technology
SAGE	Science in Australia Gender Equity
SPCM	South Pacific Conferences in Mathematics
SSA	Statistical Society of Australia
STEM	Science, Technology, Engineering and Mathematics
UCLA	University of California, Los Angeles
UNE	The University of New England
UniSA	University of South Australia
UNSW	University of New South Wales
UoM	The University of Melbourne
UoN	The University of Newcastle
UOW	University of Wollongong
UQ	The University of Queensland
USQ	University of Southern Queensland
USYD	The University of Sydney
UTas	University of Tasmania
UTS	University of Technology Sydney
UWA	The University of Western Australia
UWS	Western Sydney University
VRS	Vacation Research Scholarships
WEHI	The Walter and Eliza Hall Institute of Medical Research
WiMSIG	Women in Mathematics Special Interest Group

AMSI MISSION

The radical improvement of mathematical sciences capacity and capability in the Australian community through:

- The support of high quality mathematics education for all young Australians.
- Improving the supply of mathematically well-prepared students entering tertiary education by direct involvement with schools.
- The support of mathematical sciences research and its applications including cross-disciplinary areas and public and private sectors.
- The enhancement of the undergraduate and postgraduate experience of students in the mathematical sciences and related disciplines.



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