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New Directions in Combinatorics >>>

Ka Hin LEUNG (NUS), Bernhard Schmidt (Nanyang Technological University) and Qing XIANG (University of Delaware)

[Editor's note: From 9 to 27 May 2016, the Institute hosted the program "New Directions in Combinatorics". The co-chairs of the organizing committee, Ka Hin Leung (NUS), Bernhard Schmidt (Nanyang Technological University) and Qing Xiang (University of Delaware) contributed this invited article to Imprints.*]*

This program brought together researchers from Design Theory, Finite Geometry, and Additive Combinatorics. These subareas of Combinatorics have seen exciting developments and substantial changes in direction in recent years, due to their connections with areas such as Algebra, Number Theory, Ergodic Theory, and the Probabilistic Method.

Design Theory deals with problems of arranging objects according to certain rules. For example, for which positive integers v and k is it possible to find v distinct k-subsets of $\{1,\ldots,v\}$ such that any two of these subsets intersect in exactly one element? (This innocent looking problem has been the subject of research for decades and is still far from being completely resolved.) Design Theory has important applications in Computer Science, Statistics, and Digital Communication.

Finite Geometry investigates finite incidence structures usually coming from vector spaces over a finite field and can be partially viewed as a finite analogue of analytic geometry in Euclidean Spaces. Objects studied in Finite Geometry include finite projective spaces and polar spaces, as well as arcs, conics, ovals, ovoids, and spreads. Algebraic and number theoretic methods play an important role in this area. In particular, the so-called "polynomial method" has led to numerous outstanding results.

Additive Combinatorics is an area connecting Number Theory and Combinatorics, which has experienced tremendous growth over the past decade. It is concerned with the additive structure of subsets of the integers and subsets of groups in general. For instance, a famous result in Additive Combinatorics is Szemerédi's Theorem: Every subset of the integers of positive upper density contains arbitrarily long arithmetic progressions. Several recent advances in Additive Combinatorics involve employing methods from Combinatorics to attack deep problems in Number Theory. An account of some of these new developments is given in the brilliant book Additive Combinatorics by Terence Tao and Van Vu which appeared in 2009.

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The IMS program included talks by researchers in these fields and in areas closely related to Algebraic Graph Theory and Finite Fields. Remarkably, tools such as Linear Algebra, Polynomials, and Fourier Analysis over Finite Abelian Groups were present as a common theme in almost all talks. Lively discussions arose which will certainly lead to fruitful collaborations.

The following lecture series by leading experts were highlights of the program.

1) Ben Green: Finite Field Models in Additive Combinatorics

Green began his lectures explaining the proof of a sensational result on caps in finite vector spaces over F_3 which had been obtained by Croot, Lev, Pach, Ellenberg and Gijswijt just days before the start of the IMS program: A subset of F_3^n that does not contain distinct elements *a, b, c* with $a + b + c = 0$ asymptotically has cardinality roughly at most $(2.756)^n$. This is a fundamental result which dramatically improves previously known bounds. The proof relies on a beautiful variant of the polynomial method (which perfectly fits the theme of the program). Green also spoke about applications of Fourier Analysis over Finite Abelian Groups and Gowers Norms to Additive Combinatorics, including sumset estimates, Freiman's theorem over finite fields, and the Balog-Szemeredi-Gowers theorem. It became apparent from his lectures that these results are part of a beautiful, well-rounded theory.

2) Peter Keevash: Existence and Enumeration of Designs

Keevash spoke on his breakthrough result in Design Theory: The proof of the existence conjecture on t-designs. This had been one of the most significant open problems in Combinatorics, unsolved since the 19th century. To illustrate his result, consider a special case: For a lottery, 6 numbers are drawn from 1,2,…,n (n > 10). Each lottery ticket contains 10 of the numbers 1,2,…,n. A ticket wins if all 6 drawn numbers are on the ticket. Does there exist a collection of lottery tickets, such that exactly one of the tickets wins, no matter which 6 numbers are drawn? Prior to Keevash's work, not even a single collection like this had been known to exist. His result implies that, in fact, there are infinitely many values of n for which such a collection exists. It is a curious point, however, that his result is non-constructive and therefore it is still impossible to explicitly describe these collections.

3) Simeon Ball and Aart Blokhuis: The Polynomial Method in Finite Geometry

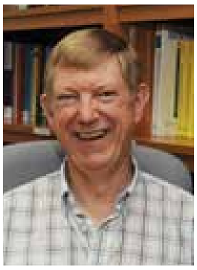
The polynomial method is a powerful algebraic tool which has been used to derive numerous important results in Combinatorics and Finite Geometry. The basic idea is to translate combinatorial or geometric properties of certain sets (often subsets of finite vector spaces) into algebraic properties of polynomials. These properties are exploited by algebraic methods to get more detailed information on the structure of the polynomials, which, in turn, can be re-translated into additional properties of the sets of interest. An outstanding example of the application of the polynomial method is the proof of the non-existence of maximal arcs in desarguesian planes of odd order by Ball, Blokhuis, and Mazzocca.

The speakers described a wealth of applications of the polynomial method, including results on blocking sets, arcs, and Kakeya type sets. It was emphasized that there is a lot of flexibility in this approach: Different kinds of bounds can be obtained by working with polynomials over different fields such as the finite field of the underlying geometry, the complex numbers, or the *p*-adic numbers. Furthermore, various methods are employed to analyse the structure of polynomials, such as Bezout's theorem, resultants, Hasse derivatives, group characters, and the Combinatorial Nullstellensatz.

Ka Hin Leung *(NUS)*,
Bernhard Schmidt *(Nanyang Technological University)*
and Qing Xiang *(University of Delaware)*

New Scientific Advisory Board and Management Board Members >>>

The Institute is pleased to welcome three new members to the Scientific Advisory Board (SAB) and one member to the Management Board (MB).


Iain Johnstone

Professor Iain Johnstone is Marjorie Mhoon Fair Professor at the Departments of Statistics and Biomedical Data Sciences at Stanford University. His research interests include high dimensional data, random matrix methods, decision theory, and wavelet methods. He was a Guggenheim Fellow (1997-1998). He was president of the Institute of Mathematical Statistics (2001-2002). His honors and awards include the Distinguished Alumni Award by the Department of Statistical Science in Cornell University in September 2013. He received the Guy Medal (Silver) in 2010 from the Royal Statistical Society. He is a member of the American Academy of Arts and Sciences and the National Academy of Sciences.


Fang-hua LIN

Professor Fang-hua Lin, is a Julius Silver Professor of Mathematics at the Courant Institute of Mathematical Sciences, New York University. His research interests include classical analysis, partial differential equations and geometric analysis. His honors include a Sloan Fellowship (1989), a Presidential Young Investigator award (1989-1994), the Changjiang Professorship at Zhejiang University (1999), the Bôcher Memorial Prize (2002) by the American Mathematical Society for his contributions on the Ginzburg-Landau (GL) equations, election to the American Academy of Arts and Sciences (2004), Fellow of American Mathematical Society (2015), and the S.S. Chern Prize at the ICCM (2004). Professor Lin was an invited speaker at the International Congress of Mathematics in 1990, an invited speaker at the AMS National Meeting in 2002 and a Plenary speaker at the ICCM 2004 and 2007.

Professor Jill Pipher, is Elisha Benjamin Andrews Professor of Mathematics at Brown University. She was founding director of the Institute for Computational and Experimental Research in Mathematics (ICERM) at Brown University, and served as President of the Association for Women in Mathematics from 2011-2013. Her research interests are in Harmonic analysis; Elliptic PDE; Cryptography. She was elected Fellow of the American Academy of Arts and Sciences in 2015, and a Fellow of the American Mathematical Association, Inaugural class in 2012. Her honors include an NSF Presidential Young Investigator Award, and Alfred P. Sloan Foundation Fellowship, and she was an invited speaker at the International Congress of Mathematicians in 2014.


Jill Pipher

We welcome Professor Mohan S. Kankanhalli to the IMS Management Board. He is the Provost's Chair Professor of Computer Science at the National University of Singapore (NUS), and the Dean of the School of Computing at NUS. His research interests include multimedia computing, information security, image/video processing and social media analysis.


Mohan S Kankanhalli

The Institute would like to thank the outgoing SAB and MB members, Professor Jianqing Fan, Professor Douglas N. Arnold and Professor David S. Rosemblum. Professors Fan and Arnold joined the SAB in 2011 and 2013, and their advice and suggestions have greatly benefited the Institute, and in particular its scientific programs. Professor David S. Rosenblum contributed in overseeing the Institute's operations and activities as an MB member from 1 January 2015 to 30 June 2016.

The Institute looks forward to strengthening its scientific programs further under the new and incumbent members of the SAB and MB.

Kwok Pui Choi
National University of Singapore

News Highlights >>>

Personnel movements at IMS

The Institute takes the opportunity to thank Ms Lim Shi Qing for her service as the Institute's housing officer till March 2016. Ms Lee Jia Ling, who joined IMS on 27 June 2016 will cover her duties.

Programs & Activities >>>

Semidefinite and Matrix Methods for Optimization and Communication (18 January - 28 February 2016)

Website: http://www2.ims.nus.edu.sg/Programs/016semi/index.php

Organizing Committee
Rahul Jain, *National University of Singapore*
Hartmut Klauck, *Nanyang Technological University and National University of Singapore*
Troy Lee, *Nanyang Technological University*
Miklos Santha, *Université Paris Diderot - Paris 7 and National University of Singapore*

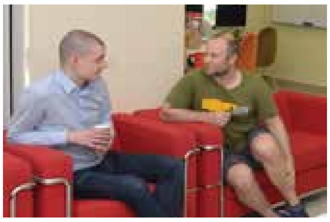
There were three main objectives in this program: to survey the current state of the log rank conjecture; to better understand the recent work on the lower bounds on the size of semidefinite programming relaxations; and to explore connections between approximation algorithms arising from the sum-of-squares method and methods based on epsilon nets. Three workshops were organized during the program.

The first workshop on Log Rank Conjecture (18 - 22 January 2016) consisted of a four-hour tutorial by Shachar Lovett (University of California, San Diego, USA) and 12 invited talks. The second workshop on Positive Semidefinite Rank (1 - 5 February 2016) had 14 talks and a four-hour tutorial by James R. Lee (University of Washington, USA), which was based on a paper which won best paper award at the 47th ACM Symposium on Theory of Computing (STOC 2015), the most prestigious conference in computer science. Last but not least, there were a total of 11 talks delivered at the third workshop on Approximation Algorithms (15 - 19 February 2016).

The program raised the awareness of a wider international theoretical computer science community for the researchers at NUS, and engaged researchers from different fields of computer science and mathematics. For example, researchers from different disciplines in proof complexity and algebraic geometry met during the second workshop. Results from a feedback survey showed that nine research papers/projects were initiated and/or worked on during or after the program. There were a total of 61 participants which included 21 graduate students.


Jakob Nordström: A generalized method for proving polynomial calculus degree lower bounds


Rekha Thomas: PSD-minimal polytopes


Mika Goos and Troy LEE: Performing local measurements


Case analysis in communication complexity

New Developments in Representation Theory (6 - 31 March 2016)

— *Jointly organized with Department of Mathematics, NUS*

Website: http://www2.ims.nus.edu.sg/Programs/016theory/index.php

Co-chairs
Wee Teck Gan, *National University of Singapore*
Chen-Bo Zhu, *National University of Singapore*

The objective of the program was to take stock of recent developments in the representation theory of reductive groups over local fields, especially on the internal approach to representation theory, and to stimulate further research in these directions.

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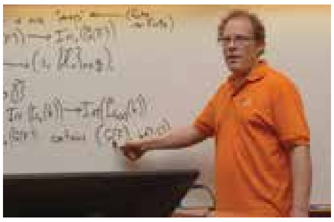
Dan Ciubotaru (University of Oxford, UK) and Zhang Lei (NUS) gave a three-part tutorial (4.5 hours in total) on Hecke algebras and Automorphic descent respectively. There were a total of 47 invited talks which not only reported on many recent breakthroughs, but also aimed to chart future directions (for examples talks by David Vogan, Roger Howe and Toshiyuki Kobayashi). There was also a good mix of talks on finite dimensional representation theory, Hecke algebras, real versus p-adic groups, as well as global applications to automorphic forms.

In Marie-France Vigneras' talk, she reported on the successful complete classification of some mod-p representations in terms of supersingular ones, completing earlier partial results of Bartel-Livne, Herzig and Abe. She had worked on this joint project with Noriyuki Abe and Florian Herzig when they met previously in 2013 at IMS for the program "Modular Representations of Finite and p-adic groups". A joint paper (together with Guy Henniart) is due to appear in JAMS (Journal of the American Mathematical Society). Although it is still early to say, the organizers do hope that this program will bring an impact on other significant research achievements.

NUS has a large group of researchers working in various aspects of representation theory. Students and postdocs from the local community could learn and interact with the world's leading researchers as well as with their peers from other countries. Several graduate students and junior postdocs gave talks during the workshop.

Results from a feedback survey showed that 16 research papers/projects were initiated and/or worked on during or after the program. There were a total of 70 participants and among them 16 were graduate students.

Roger Howe: Small representations of finite groups



Jeffrey Adler: Transferring representations between finite reductive groups

Jing-Song HUANG: A homomorphism of Harish-Chandra for polar representations

Martin Weissman, Dan Ciubotaru and Pavle Pandzic: Uncovering interactions of a tempered representation

Dimensions of representations within a group

Oppenheim Lecture 2016 (16 – 17 March 2016)

— Jointly organized with Department of Mathematics, NUS

Website: http://ww1.math.nus.edu.sg/events/oppenheimlecture2016.html

Emmanuel Candes

The second Oppenheim Lecture "Around the Reproducibility of Scientific Research in the Big Data Era: What Statistics Can Offer" was delivered by Professor Emmanuel Candes of Stanford University on 16 March 2016. There was another talk held in conjunction with Oppenheim Lecture by Professor Candes titled "Modern Optimization Meets Physics: Recent Progress on the Phase Retrieval Problem" on 17 March 2016.

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The Oppenheim Lecture was attended by over 300 participants and the workshop was attended by 60 participants.

Participants of the Oppenheim lecture

New Directions in Combinatorics (9 - 27 May 2016)

Website: http://www2.ims.nus.edu.sg/Programs/016combin/index.php

Co-chairs

Ka Hin Leung, *National University of Singapore*
Bernhard Schmidt, *Nanyang Technological University*
Qing Xiang, *University of Delaware*

This program aimed to nurture multi-disciplinary collaborations among researchers in the fields of Combinatorics, Number Theory, and Algebra which use common mathematical methods such as Probabilistic method, Fourier analysis, inverse theorems, and algebraic constructions. It also provided high-quality training of research students and postdoctoral fellows.

The program consisted of three mini courses by Ben Green (University of Oxford, UK), Peter Keevash (University of Oxford, UK), Simeon Ball (Universitat Politècnica de Catalunya, Spain) and Aart Blokhuis (Eindhoven University of Technology, The Netherlands). A new result on caps in finite vector spaces had been proved by one of the participants (Vsevolod Lev, The University of Haifa at Oranim, Israel) and his co-authors just days before the program started. The proof of the result was explained in detail by Ben Green as part of his mini-course.

A joint event with the Department of Mathematics, NUS, was held on Wednesday, 25 May 2016. It featured a colloquium talk by Ben Green from the University of Oxford, UK and Ameera Chowdhury from Rutgers University, USA.

There were a total of 46 participants and among them eight were graduate students. Results from a feedback survey showed that 14 research papers/projects were initiated and/or worked on during or after the program.

Ben Green: Finite field models in additive combinatorics

Peter Cameron: Combinatorics of transformation semigroups and synchronization

Peter Keevash and Stefaan De Winter discusses on an interesting necessary condition for existence

The existence and construction of Combinatorial Designs

International Workshop on Fluid-Structure Interaction Problems (30 May - 3 June 2016)

Website: http://www2.ims.nus.edu.sg/Programs/016wfluid/index.php

Co-Chairs

Boo Cheong Khoo, *National University of Singapore*
Zhilin Li, *North Carolina State University*
Jie Liu, *National University of Singapore*

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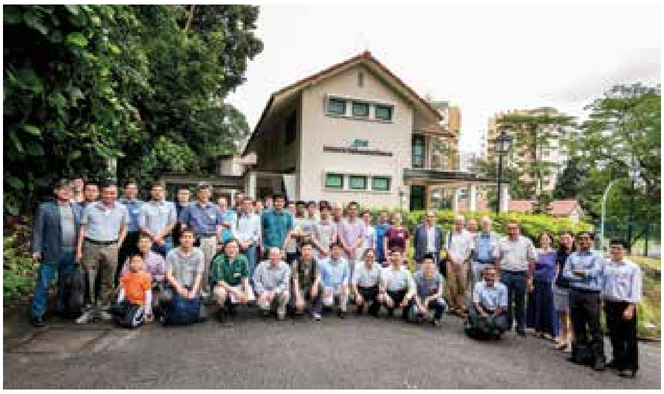
Many problems in applied sciences and engineering involve the motion of geometric objects such as interfaces or filaments interacting with surrounding fluids. These problems are generally called fluid-structure interaction problems (FSI). This workshop reinforced the communication between mathematicians, engineers, numerical analysts of different groups and researchers working on numerical partial differential equation (PDE) and theoretical PDE. Participants learned about recent progress on solving FSI problems, and the recent applications of FSI, for example in parachute simulation, hemodynamic and cardiovascular dynamics. There were in total 51 invited talks in this 5-day workshop which had experts from different groups of FSI, and 18 postdocs/graduate students present their work. There were a total of 75 participants and among them 16 were graduate students.

Olivier Pironneau: A monolithic fluid-structure formulation

James Thomas Beale: Uniform error estimates for finite difference methods applied to fluid motion with interfaces

Gretar Tryggvason and Lisl Weynans: Simulating flows of considerable complexity using a simple motion



Cultivating a common interest in solving fluid-structure interaction problems

Empirical Likelihood Based Methods in Statistics (6 June - 1 July 2016)

Website: http://www2.ims.nus.edu.sg/Programs/016emp/index.php

Organizing Committee

Sanjay Chaudhuri, *National University of Singapore*
Song Xi Chen, *Peking University and Iowa State University*
Malay Ghosh, *University of Florida*
Ian McKeague, *Columbia University*
Art B. Owen, *Stanford University*
Cheng Yong Tang, *Temple University*

Empirical likelihood based methods are becoming more and more popular in current statistics and econometrics. It is a semi-parametric method which allows the user to specify a parameter based model through estimating equations.

Under the true model the empirical likelihood based estimates are almost as efficient as their parametric counterparts. However, if the parametric distribution for data generation is misspecified empirical likelihood based estimates are often more efficient. These properties have led to an increased popularity of empirical likelihood based methods in severely constrained problems.

The program started with an eight-hour tutorial on empirical likelihood by Sanjay Chaudhuri from the Department of Statistics and Applied Probability at the National University of Singapore. There were a total of 24 talks in the two workshops: Recent Developments in Empirical Likelihood Methodology (13 – 17 June 2016) and New Applications of Empirical Likelihood (20 – 24 June 2016).

All the activities were well attended by students and fellow researchers. The talks in the workshop were delivered by the eminent experts in the field of empirical likelihood and encompassed many application areas.

Many new ideas in the field of empirical or related likelihoods developed from the talks and research discussions. Results from a feedback survey showed eight research papers/projects initiated and/or worked on during or after the program. There were a total of 68 participants and among them 23 were PhD students.

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Art Owen: Self-concordance for empirical likelihood

Song-Xi CHEN: High dimensional empirical likelihood for general estimating equations with dependent data

Workshop participants engage in a poster session

Stochastic ordering in a selected moment

IMS Graduate Summer School in Logic (27 June - 15 July 2016)

... Jointly organized with Department of Mathematics, NUS

Website: http://www2.ims.nus.edu.sg/Programs/016logicss/index.php

The summer school consisted of 12.5 hours of lectures by Hugh Woodin (Harvard University), 11 hours of lectures by Theodore A. Slaman (The University of California, Berkeley) and 12.5 hours of lectures by Thomas Scanlon (The University of California, Berkeley). There were also four talks by graduate students.

There were a total of 53 participants and among them 27 were graduate students.

Hugh Woodin and Xianghui SHI: Treating the operations of formal logic

Thomas Scanlon: O-minimality and its applications in diophantine geometry

Participants of the 2016 Logic Summer School

Second Melbourne-Singapore Probability and Statistics Forum (4 July 2016)

Website: http://www2.ims.nus.edu.sg/Programs/016wprob/index.php

This activity was organized by the probability and statistics groups at the University of Melbourne and the National University of Singapore. There were a total of six invited talks and 17 participants.

Steven KOU: EM algorithm and Stochastic control

Group embedding a combined interest in probability and statistics

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Mathematics of Shapes and Application (4 - 31 July 2016)

Website: http://www2.ims.nus.edu.sg/Programs/016shape/index.php

Co-Chairs
Ji Hui, *National University of Singapore*
Sergey Kushnarev, *Singapore University of Technology and Design*
Laurent Younes, *Johns Hopkins University*

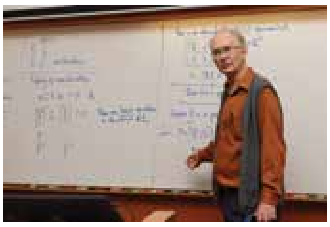
Understanding how a single shape can incur a complex range of transformations, while defining the same perceptually obvious figure, entails a rich and challenging collection of problems, at the interface between applied mathematics, statistics and computer science.

The program started with a summer school from 5 to 15 July 2016, with seven tutorials by Ji Hui (NUS), Sergey Kushnarev (Singapore University of Technology and Design), Joan Alexis Glaunès (Université Paris Descartes, France), Martins Bruveris (Brunel University London, UK), Martin Bauer (University of Vienna, Austria), Tom Fletcher (University of Utah, USA) and Richard Hartley (Australian National University, Australia).

There were a total of 23 talks in the Workshop on State-of-the-Art Shape Research and its Applications from 18 to 22 July 2016. The second Workshop on Applications: Biomedical Imaging and Computer Vision (25 - 29 July 2016) was split into two themes: a Neuroimage Workshop (25 – 27 July 2016) which had 15 talks, and a Computer Vision workshop (28 – 29 July 2016) which had seven talks.

The program was well attended with over 100 self funded/ registered local participants from various disciplines and institutions in Singapore.There were a total of 160 participants and among them 40 were graduate students.

Michael Miller: BrainClouds, high throughput imaging, and geodesic positioning systems



Richard Hartley: Lie group actions

Sergey Kushnarev and Hui JI: Visual data processing between two shapes

Shape optimization on mathematical models

Public lectures:

Nisheeth Vishnoi: Evolution and Computation

Professor Nisheeth Vishnoi of the École Polytechnique Fédérale de Lausanne, Switzerland delivered a public lecture on "Evolution and Computation" in NUS on 17 February 2016. In the lecture, he delineated the interplay between natural life processes, evolution included, and computation. A total of 60 people attended the lecture.

James Davis: Apple vs Samsung: a Mathematical Battle

Professor James Davis of the University of Richmond, USA delivered a public lecture on "Apple vs Samsung: a Mathematical Battle" in NUS on 18 May 2016. After a gentle introduction to error correcting codes used in 3G communication, he described the patent battles between Apple and Samsung. A total of 96 people attended the lecture.

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Current Program

Geometry, Topology and Dynamics of Moduli Spaces (1 - 19 August 2016)

Website: http://www2.ims.nus.edu.sg/Programs/016wgeo/index.php

Co-Chairs

Ser Peow Tan, *National University of Singapore*
Graeme Wilkin, *National University of Singapore*

The subject of this program is the topic of moduli spaces and their connections with different areas of mathematics and physics. Moduli spaces arise naturally from the study of one of the most fundamental problems in mathematics: parametrising mathematical objects up to equivalence. Understanding the moduli space and its local and global structure can often give new information about the underlying geometric problem.

The focus in this program will be on the moduli spaces of geometric structures on Riemann surfaces and moduli spaces of Higgs bundles, for which the geometry, topology and dynamics gives new information about geometric and topological problems in low dimensions.

Activities

- Workshop on New Perspectives on Moduli Spaces in Gauge Theory: 1 - 5 August 2016
- Informal discussions, research collaborations and mini-courses: 8 - 12 August 2016
- Workshop on Moduli spaces of geometric structures: 15 - 19 August 2016

Next Program

Automata, Logic and Games (22 August - 25 September 2016)

Website: http://www2.ims.nus.edu.sg/Programs/016auto/index.php

Co-Chairs

Anthony Widjaja Lin, *Yale-NUS College and National University of Singapore*
Luke Ong, *University of Oxford*

The proposed program is concerned with both the theory and practice of verification. An objective of the program is to promote interactions between researchers working in the theory and foundations of automata, logic and games, and those who build tool implementations of model checking algorithms, perform empirical studies, and work with the verification industry.

Activities

- Summer School on Mathematics of Shapes: 4 - 15 July 2016
- Week 1: 22 - 25 August 2016, Theme: Communicating, Distributed and Parameterized Systems (CDPS)
- INFINITY 2016 Workshop: 26 August 2016
- Week 2: 29 August - 2 September 2016, Theme: Constraints
- Week 3: 5 - 9 September 2016, Theme: Quantitative Model Checking (QMC)
- Week 4: 12 - 16 September 2016, Annual Meeting of IFIP Working Group 2.2
- Week 5: 19 - 23 September 2016, Higher-Order Model Checking (HOMC) + CDPS

Programs & Activities in the Pipeline

Workshop on Mathematics of Information - Theoretic Cryptography (19 - 30 September 2016)

Jointly organized with Nanyang Technological University

Website: http://www2.ims.nus.edu.sg/Programs/016wcrypto/index.php

Organizing Committee:

Ronald Cramer, *Centrum Wiskunde & Informatica and Leiden University*
Venkatesan Guruswami, *Carnegie Mellon University*
Yuval Ishai, *Technion - Israel Institute of Technology*
San Ling, *Nanyang Technological University*
Carles Padró, *Universitat Politècnica de Catalunya*
Chaoping Xing, *Nanyang Technological University*

In recent years, there has been a surge in interactions between information-theoretic cryptography and several areas in mathematics -- algebraic geometry, algebraic number theory, coding theory, combinatorics and probability theory. The primary focus of this program is organized around certain concrete, exciting developments

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that have recently fueled and deepened these particular interactions. The program will further foster and strengthen the emerging international research community on the intersection between cryptography, theory of computation and pure mathematics.

Activities

- Tutorials: 19 - 23 September 2016
- Workshop: 26 - 30 September 2016

Higher Dimensional Algebraic Geometry, Holomorphic Dynamics and Their Interactions (3 - 28 January 2017)

Website: http://www2.ims.nus.edu.sg/Programs/017hidim/index.php

Co-chairs

Tien Cuong Dinh, *National University of Singapore*
Keiji Oguiso, *University of Tokyo*
Wing Keung To, *National University of Singapore*
De-Qi Zhang, *National University of Singapore*

In recent years there have been breakthroughs in the classification theory of higher dimensional compact algebraic varieties and complex manifolds. These results have profound influence on many areas of mathematics – including the study of higher dimensional dynamics and number theoretic dynamics.

Activities

- Informal discussion: 4-6, 9, 20-27 January 2017
- Workshop: 10-13, 16-19 January 2017

Complex Geometry, Dynamical Systems and Foliation Theory (1 – 26 May 2017)

Website: http://www2.ims.nus.edu.sg/Programs/017geo/index.php

Organizing committee

Tien Cuong Dinh, *National University of Singapore*
George Marinescu, *University of Cologne*
Xiaonan Ma, *Université Paris Diderot - Paris 7*
De-Q Zhang, *National University of Singapore*

This program concerns the recent developments in complex analysis and its applications. The aim of this program is to bring together experts working in these topics with interest in pluripotential theory. Pluripotential Theory, a branch of Complex Analysis, is a very important tool with connections with many mathematical theories: Complex Analysis, Complex Differential Geometry, Complex Algebraic Geometry, Dynamics, Foliations and Mathematical Physics.

Activities

- Informal Discussions and Seminars: 2 - 5 May 2017 and 22 - 26 May 2017
- Mini Courses: 8 - 12 May 2017
- Conference: 15 - 19 May 2017

Data Sciences: Bridging Mathematics, Physics and Biology (29 May - 16 June 2017 and 30 November - 8 December 2017)

IMS Graduate Summer School in Logic (19 June - 7 July 2017)

Quantitative Methods for Drug Discovery and Development (19 June - 14 July 2017)

Genealogies of Interacting Particle Systems (17 July - 18 August 2017)

Beyond I.I.D. in Information Theory (24 - 28 July 2017)

For full list of upcoming events, visit our webpage at http://www2.ims.nus.edu.sg/

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Mathematical Conversations

Peter Gavin Hall: From Probability to Statistics – Martingales. Percolation, Bootstrap and Beyond >>>


Peter Hall

Interview of the late Peter Gavin Hall (1951-2016) by Y.K. Leong

To the memory of Professor Peter Gavin Hall (1951-2016)

The late Peter Gavin Hall was one of the world's foremost probabilists and statisticians who dedicated his life to his chosen fields of research and to the development of the mathematical sciences in Australia. He made important contributions to a wide range of areas in probability and statistics and to numerous applications in science, engineering, economics and industry.

Hall had mutual interests with Louis Chen, the recently retired and founding director of the Institute for Mathematical Sciences (IMS) of the National University of Singapore (NUS) and emeritus professor of NUS, not only in mathematics but also in their active involvement in international statistical organisations (Bernoulli Society and Institute of Mathematical Statistics) as well as national research centres and institutes. He was invited to the IMS program in honour of Charles Stein in August 2003 and was back in NUS as an organiser in the Scientific Program Committee for the 7th World Congress in Probability and Statistics held in Singapore from 14 - 19 July 2008. Subsequently, he was invited as Saw Swee Hock Professor of Statistics at NUS's Department of Statistics and Applied Probability (DSAP) for two brief periods 3 September - 2 November 2011 and 13 August - 10 October 2012. He was also co-chair of the organizing committee of the Institute program *Meeting the Challenges of High Dimension: Statistical Methodology, Theory and Applications* (13 August - 26 October 2012). He gave a tutorial on 25, 27 September 2012 on "Some methodology and theory for functional data analysis". During this visit, Y.K. Leong took the opportunity to interview him on behalf of *Imprints* at DSAP on 20 September 2012. The following is an edited version of the transcript of this interview in which he talked about his personal roots, mathematical research centres in Australia and the two different worldviews of statistics and mathematics.

Note and Acknowledgments. It is with deep regret that the transcript of this interview has not been read by Professor Hall. We have retained the original spirit of frankness and openness with which he shared his views and experiences. We would like to thank Jeannie Hall for vetting the edited transcript and for her helpful comments on the interview article, and Terence Speed (Walter and Eliza Hall Institute of Medical Research, University of California, Berkeley, University of Sheffield) for corrections and clarifications in the transcript. Any inaccuracy in transcription or interpretation is solely due to the interviewer. This interview was given in NUS three years before Professor Hall's last interview conducted by Aurore Delaigle and Matt P. Wand and published in *Statistical Science* Vol 31, No. 2 (2016), 275-304.

Imprints (I): May I start with something less mathematical and perhaps closer to your heart? Your mother Ruby Payne-Scott was a pioneer in radiophysics and radio astronomy and had made significant discoveries in solar radio astronomy. How much influence did she have on your education and choice of career?

Peter Hall (H): She had a very large influence on me. She stayed working for the Division of Radiophysics up until she was pregnant with me, and only because, I guess, in mid-1951, the year I was born, she was obviously carrying a child. At that time she wasn't supposed to be married while working for a government organisation at the level she was. So she had either been living in sin or she had married and disobeyed the law. She left CSIRO [Commonwealth Scientific and Industrial Research Organization] shortly before I was born, but the chief of the organisation was very keen to have her back if she wanted to return after I was born. I remember that my mother made quite a few visits to research facilities (radio-telescopes) when I was very young. And I used to be minded by two of the secretaries in the

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division, Sally and Sylvia, while my mother went off to look at the telescopes. So I have a strong recollection in my fairly young years of strong connections to physics. That stayed with me throughout my life. It led me to want to do a degree in physics and go on to become a theoretical physicist. But I found that as an undergraduate in the University of Sydney I was put off a little by the teaching there. I remember that Bob May (Sir Robert May), who probably had visited IMS [Institute for Mathematical Sciences] here, gave the first lecture. But he was extremely busy and only gave the first lecture in my undergraduate physics course in first year and he didn't give any more lectures, unfortunately. From that point, things went downhill, at least as far as I was concerned. Despite my mother's influence, which was really very benign, [there was] never any pressure. I determined in second, third and fourth year that I would just do as much mathematics as I could, and I dropped physics, chemistry and biology at the end of first year.

I: Was she disappointed you didn't follow up with physics?

H: No, both my parents (you couldn't wish to have better parents) were very encouraging of me and my sister, but they never put any pressure on us in any way except perhaps I remember … my sister became an artist, but in order to get into technical college she had to pass mathematics and science at a reasonable level. She's extremely intelligent and got through these subjects just on this basis. I think that she did almost no work. My mother was a bit concerned that she pushed Fiona (my sister) a little harder than she would normally do, simply to ensure that she got the passes at the level needed in order to go to college to study art, which is what she did.

I: You did your BSc in University of Sydney but you went to ANU for your MSc. Was there much research in probability and statistics done in Sydney at that time? What motivated you to choose probability for your MSc?

H: First of all, there was a reasonable amount of research in the University of Sydney in those days, but in the 1970s and also much in the 1960s too, I think ANU was the strongest place in Australia to do research in probability and statistics. I remember my professor at the University of Sydney recommended that I go there if I could. I was motivated to work in probability largely because of a course I had at the University of Sydney in my fourth year. I was one of only two people who started off in the honors program in statistics. There was a young woman who started with me, but my memory is that she dropped out at the end of the first term. I didn't see her any more after that. I was really by myself. With the exception of only one professor I had no lectures. He insisted in giving me an ordinary lecture with me sitting in the classroom by myself. The others I worked with only in terms of a reading program. There was a young man, a logician from pure mathematics, who was interested in learning probability for various reasons. He and I and Malcolm Quine, who was my lecturer, took turns each to give one of 3 lectures every week from Kai Lai Chung's book *A course in probability theory*. I was really taken by that book; I loved it. He wrote that book in a very personal way; many of his own passions show through. I was infected by that but I think other people who perhaps don't see things the way that he or I do probably find it a bit of a nuisance that his book is so personal and so passionate, which is not usual in an undergraduate text book like that. But for me it really was an eye-opener. It enthused me tremendously about probability and that book is the main reason that I went on to do postgraduate work in probability.

I: I notice that you obtained your Master's (from Australian National University) and DPhil (from Oxford University) practically at the same time. How did that come about?

H: I guess that in about the middle of 1973 when I was halfway through my fourth year as undergraduate, I decided I wanted to go on to do research in probability theory. That meant getting a scholarship to do a PhD. I used to go up to an office in the University of Sydney and go through the files they had on various scholarships you could apply for. I went up there once a week because throughout the second part of the year they were getting more and more notices. So I used to write to some of these places to apply for scholarships. I applied for entry into several US universities; I remember Berkeley was one of them. I applied for a Commonwealth scholarship to take me to the United Kingdom. I applied for a CSIRO scholarship, I applied for a scholarship to Brasenose College, Oxford, not knowing what I might do if I got it. I applied to lots of places and I remember writing lots of letters. To the US ones I had to get a lawyer to notarize my bank accounts so that I was seen as not being a complete pauper, and I sat for the Graduate

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Record Exams to get into US programs. It was a major undertaking to apply to all these places and sitting for the exams over the weekends. And then I went to the ANU in December 1973 on a vacation scholarship. You appreciate that December through February is the summer holiday in Australia and it's possible to get a very low level scholarship as a student to work with somebody and see whether you would like to do research or not. So I went down to the ANU. I worked with Roger Miles [Roger Edmund Miles] and Pat Moran [Patrick Alfred Pierce Moran (1917-1988)] for a little while, and then I met Chris Heyde [Christopher Charles Heyde (1939-2008)] and went on to problems in martingale limit theory. I quite like that experience; I made a lot of friends in Canberra and I thought I might stay there for my PhD. I know that my mother particularly didn't want me to go overseas. I used to call her up once a week and talked to her, sometimes to my father. I told her at one point that I decided I would stay in Australia to do my PhD and that I was going to write to all the places that I had made applications to and I would tell them that I wouldn't accept any offers that came and that they should not consider me any further. Because I had applied to so many places I had a lot of letters to write. I hadn't had any offers because it was something like March 1974 and none of these places in the northern hemisphere had made any decision, and I had been offered a CSIRO scholarship to do a PhD at the ANU. I decided to stay. So I wrote all those letters. And then in about April or May or a bit later I had a phone call from my mother one evening, and she said, "I thought you told me that you had decided to stay in Australia to do your PhD", and I said, "Yes". She said, "I thought you told me you had written to all these places to withdraw". And I said, "Yes." She said, "Well I received a letter from Brasenose College in Oxford offering you a scholarship." In fact, I had not told my mother the complete truth. Because I didn't have much money in those days to pay for the postage, I thought I would save myself the trouble – I thought I would never get these scholarships open to people in all fields from Australia and New Zealand. I don't even know whether there is a mathematician in that college at all. I hadn't even bothered to tell my mother. She was a little bit annoyed, but in a very nice way. By that time my research wasn't going on quite as well as I had been doing earlier. I was still doing ok but it wasn't sailing along completely blissfully. So I decided I would go to Oxford after all. I spoke to Chris Heyde, my PhD advisor and he was very good about it. He must have been a bit put out because I said I would work with him and I changed my mind. But he was very good about that. I really must give him credit. Then he said, "You've already got a fair number of results. Why don't you write them up and submit it as a Master's thesis. You'd better check up on the rules, but I think it's possible." So I checked up on the rules, and it was clear that from the time when I enrolled in my Master's program until the time I left Canberra to go to England, I had enough residency. The university requirements for residency were very weak because many students went overseas or left Canberra anyway to do field work for their Master's and PhD degree. But the university was very strict in that I couldn't submit my Master's thesis until two years after I had enrolled. Chris said, "Don't worry, write it up and I'll submit it for you in two years' time." So he submitted it for me in two years' time, and that was also the same time I submitted my Oxford DPhil thesis.

I: Before you went to Oxford did you have any particular person in mind to work with?

H: During my time as a PhD student in Canberra I met many people, and I decided that I wanted to go abroad at some point. It wasn't going to be during my PhD, it was going to be afterwards as a postdoc or something like that. When I sent the application I didn't have a clue who was at Oxford. I later found out that there was a probabilist there, Chris Preston. He was at Oxford and he had pushed for me at the committee meeting. That's what he told me afterwards. I am forever grateful to him for doing that. I got to quite like him. He moved to Germany while I was a student.

I: Was he your advisor?

H: No, he wasn't my advisor. My advisor was John Kingman, later Sir John Kingman. He went on to be the Vice-Chancellor of Bristol University and then the Director of the Isaac Newton Institute [for Mathematical Sciences]. I met John Kingman when he visited Canberra in 1974. He must have come out in May or June or something like that. People said, "Look, he is a great probabilist. Did you ever talk to him and see whether you could work with him?" So I did and he said, "Oh, yes, I would be happy to supervise you." But I hadn't heard of him before. I lived a very quiet and monastic life. I met him in the department of Professor Pat Moran. He was visiting Pat, I think. Maurice Bartlett

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[Maurice Stevenson Bartlett (1910-2002)] was also visiting at that time. So Kingman agreed to be my supervisor but in the end I didn't work on a problem that he gave me. I worked on generalizations of the problem that I started to work on for my Master's degree in Canberra. He was my formal advisor, but I actually found my own research problem. That's good training for a student as long as he can do it. He has to fall back on his own resources.

I: Apparently you are very independent in your research. Was it from the days of Sydney University?

H: Maybe, it may also be a family trait. My mother was a very independent woman. My father, I guess, was too, but not obviously so. People would probably say that my sister and I had picked up that trait from my mother. We both have a tendency to decide what we think we would like to do, or think what should be done and then try to do it.

I: After your doctorate, your entire scientific career was developed in Australia – at the University of Melbourne and a larger part in ANU. Is this due to a kind of patriotic feeling you have towards Australia?

H: I think it is a cultural thing rather than a matter of patriotism. From my parents, who were very keen on hiking (called "bushwalking" in Australia), I had acquired a strong love of the Australian environment, and also of the "Australian system", for example, a strong interest in Australian history, government and politics. I recall that when I was at Oxford, my father used to enclose eucalyptus leaves in the aerogrammes he sent me, and I was always emotionally affected by that. It's more a feeling of a strong tie to the culture and that tie is not without a degree of ambivalence and conflict sometimes. One of the aspects of Australian culture goes back to the roots of European civilization, I should say, as a dumping ground for convicts from the United Kingdom and Ireland. One of the consequences of those roots still persists somewhat in the anti-intellectual environment in the country as the country has become what it has become, largely on the basis of what it can hew from the ground, what it can grow and what it can mine. At the same time this is associated with a strong ethic of not taking yourself particularly seriously, and also very little by way of a class society. There is some degree of class in any culture, I suppose. Some people have more wealth than others, and this leads to a degree of inequality. In Australia, particularly at the time of my youth, and also today (the pattern is not quite as clear today), in my contact with people through my family, my parents, and so on, there were very few barriers to doing anything. In those days, I won a scholarship to go to the university. I didn't have to pay any fees, for example. That is not true if I were a student today. I will have to pay substantial fees although I would only pay them later – it comes out of my taxes. Students these days have to eventually pay back much of the cost of their tuition. When I was a student I was able to win a scholarship to pay those fees. You know, I think that in a way education is more accessible today. In many ways there are more opportunities for sources of funding. I always like this about Australia. When I got to the United Kingdom (of course, this was in Oxford) I found, more to my amusement than anything else, a lot of, not just relics but the present day practices of class division. It made me, I think, even more convinced that Australia is the place I wanted to make my career. I think I have always felt like that. My mother and father were very politically active and I have always been interested in politics and international affairs and things like that.

I: Were they born in Australia?

H: Yes, my mother and father were born in Australia but all my grandparents were born in the United Kingdom, three in England and one in Glasgow in Scotland, and that was my father's mother who was born in Glasgow to Irish parents.

I: Are you yourself politically active?

H: Not in the way my mother and father were. I've never been a member of a political party. I'm a significant contributor to reviews and things like that of the mathematical sciences in Australia. For example, I'm currently the Chair of the steering committee that's developing a decadal plan for the mathematical sciences in Australia. We have to finish our work by the end of 2014. I've always had a strong feeling that when things are not right you should try to fix them. But, of course, there are people who do that more effectively than I do. So I don't want to create the impression that I'm the best person for this. This is something that I picked up from both of my parents. My earliest political recollection (voting is compulsory in Australia, just as it is in Singapore)

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is that in one election, my mother had to go to the polling booth which was in my primary school. She asked me if I would come with her, so I said, "Sure". So we walked – 15 minutes' walk and on the way back, I asked her, "Who did you vote for?" And she said "Oh, I voted communist." I said, "Why did you vote communist?" And she said, "Well, they are the only party with a decent education policy." *[Laughs]* At that time, that was probably true. My parents were very keen on changing things when they thought that they needed changing. I inherited that.

I: Can I come back to ANU? I believe there is some kind of centre of mathematics at ANU. Were you ever involved in it?

H: Oh, yeah. It goes back to 1981. The Australian government announced in 1981, I think, a competition for people to get funding for special research centres (they later change the name to centres of excellence, but I'm not completely sure I've got it the right way around). It was the first time we had a competition like this. Neil Trudinger, along with some other people (Neil was the intellectual leader of the bid), applied and much to the surprise of the senior management of the ANU, they were successful. They never thought that a bunch of mathematicians would get this sort of thing. They thought it might go to physicists who wanted a particle accelerator or something like that. Of course, Neil wasn't surprised, and he got it – this was the Centre for Mathematical Analysis (CMA). It opened its doors in 1982 which was also the year MSRI opened its doors in Berkeley. In those days (it is an enormous credit to Neil Trudinger) Australia was up there with the first countries in the world; we were behind Germany, but we were ahead of Singapore. We were ahead of United Kingdom. I think MSRI was the first of the NSF funded research institutes in mathematics in the US although there is always the Institute for Advanced Study in Princeton and so on. It's actually quite extraordinary what Neil did. This centre continued until the end of 1990. I think Neil got a new offer. Neil and I applied together in 1994 for a new centre, also to be funded by the Australian Research Council which was to be called the Centre for Mathematics and its Applications (again the same three letters, CMA) and this was again Neil's doing. He decided to keep the acronym and have a centre doing new things. The centre didn't just involve classical applied mathematics but it involved statistics as well as computing and computational mathematics. I remember we went for an interview at the University of Sydney and we were not successful. Anyway we managed to get funding from the Australian National University and they agreed to pay my salary for a certain number of years and Neil's as well. We were both from the teaching part of the university. In those days there was a research part; it's not clear nowadays, things have changed since I left. We persuaded the university to put in some money for our salaries and the administration. We persuaded most of the people in the old department of mathematics in the Institute [of Advanced Studies], where Bernhard Neumann [Bernhard Hermann Neumann (1909-2002)] had been, and also most of the people in the old department of statistics which was where Pat Moran was. We cobbled together the Centre for Mathematics and its Applications even though our application for funding from the ARC was not successful. Over the next 10 year or so, Neil and I put in, I think, at least one further bid and it too was not successful. Basically there were two problems which had not been problems back in the early '80s when Neil had first applied. One of them was that there was a lower level of funding to be asked for and even this lower level was quite high. It was designed to pay for large pieces of equipment and things like that. You would appreciate that for a group of mathematicians you don't have too many expenses except people's salaries. So in order to get above that threshold we had to have a lot of people, and particularly in a "small" country like Australia, you are paying a lot of people. The institute becomes very diverse in terms of its character. It didn't make any sense for Australia to have everybody working on partial differential equations, for example, or everybody working in statistics. Because we have to spend at least a certain amount of money and it's just so many people, and so scientifically it is only credible if you are fairly broad in your outlook. That was one of the considerations that led Neil to broaden it out. But to be fair to him he always saw the importance of applications of mathematics. He himself works in partial differential equations, and in much of Europe partial differential equations will be regarded as a part of applied mathematics, not a part of pure mathematics. Neil always had a strong affinity for and appreciation of applications of mathematics and that was what led him to broaden out and include me, which was very nice of him to do. This thing went on and the CMA still exists today but it has a different character, significantly more focused on pure mathematics and mathematical physics.

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I: You also have a long-standing joint appointment at University of California at Davis. How did that come about?

H: Over a reasonable period, starting in the 1980s, I was on sabbatical leave in the US. I visited Davis to give a talk and spent a little time there. Not long after that time I began working jointly with Hans-Georg Muller and Jane-Ling Wang (husband and wife team) at the department there. Hans had actually just become the head of department. We worked a bit together, and they asked me if I would be interested in taking a position there and moving there. I previously have been asked by a couple of places in the US, one of them was Berkeley. I did give them my cv and I was offered a position, but in the end for the reasons I gave you before, I didn't really want to leave Australia. And I didn't want to leave Australia to go to Davis either. So I declined it as graciously as I could. They were rather constructive about this and they said, "Look, why don't you come and give us a course and see whether you like it here, maybe some sort of fractional appointment." So I did and went over there and gave a course and I really like it. I go there every year. I must admit when I started [the actual appointment began in 2005] I wasn't sure how long it would last for. I go over there every spring. I only teach in even number years. So I taught this year. I give graduate courses and undergraduate courses. In odd number years I don't teach. I travel a bit and work with people and give talks. So I really enjoy it, I have to say. I think one of the fortunate things I feel is that they are very accommodating to me. You parachute in and helicopter out. Because you are only there for a quarter there is a lot of stuff you would expect a member of faculty to do which I can't do. I can't serve on too many committees, for example. Sometimes when a colleague there is on leave when I'm there in spring, I will take over his committee responsibilities. But then when I leave I pass it on to somebody else. It requires a bit of generosity on their part to put up with this. I'm really grateful to them for this.

In statistics today, the US is preeminent like it has never been before in my career. When I was a student in the United Kingdom, the UK was then very strong in probability – people like David Kendall [David George Kendall (1918–2007)] and Peter Whittle and others at Cambridge and Kingman in Oxford and many others around the country. Also, there were two tremendously strong groups in statistics as well (I wasn't fully aware of this because I was working in probability), particularly the one looked after by David Cox [David Roxbee Cox] at Imperial College. Some of the people I have just mentioned, like Kendall and Whittle, had very strong interests in statistics as well as probability. In the 1970s when I was in the UK and certainly before that time too, these people weren't young then; the UK was still giving the US a run for its money. It's a much smaller country, but nevertheless in statistics, it had some remarkable people like Galton [Francis Galton (1822 -1911)], Fisher [Ronald Aylmer Fisher (1890-1962)], and others as the foundation for their excellence in statistics. But somehow during the 1980s, for one reason or another (maybe because David Cox retired, and so did David Kendall, and the group at Cambridge focused less on statistics), statistics became less strong in the UK, and after ... out of this, emerged a very powerful US group in statistics today. I think it is just amazing how influential it is. I must say it is very well funded. My colleagues in the US wouldn't say it's well funded. They would have good reasons for being concerned about the level of funding, but nevertheless it's better funded than in other places. It's extremely successful. Those activities are really the basis for the billions of dollars' worth of industry in the US. It has given us Google and Yahoo and things like that and, of course, the strengths that were created by the statistics environment in the US then help to feedback positively into that environment: many of the graduates are joining these companies today. It's just going on from strength to strength. Being in the US and working there is very beneficial.

I: It's quite surprising that the scientific pull from the US is not as strong as the cultural pull from Australia.

H: I never thought of it that way before. I think it's true for a number of others particularly the Chinese community in the US. This is something that is very striking to me. The statistics community in the US has been significantly influenced by the young Chinese men and women who moved there, starting really from the late 80's. This is starting to taper off a bit today and we are seeing perhaps more people from India and Eastern Europe as a proportion of graduate students. Many of those young men and women have had extraordinary influence not just on the US direction but throughout international directions. Of course, there were more differences between the US culture and the ones they came from than the differences between the US and mine.

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So they try earnestly to bridge that culture. They feel very strongly the scientific pull of the US but also the strong personal cultural links to their own country, such as China. I think I probably share with them a sense of this conflict.

I: Which discovery or result in your theoretical work has given you the greatest sense of accomplishment?

H: I still remember very fondly my work on the rates of convergence in the central limit theorem which I did in the late '70s and early '80s. But this turned out to be an area that not many people are interested in today. Although I still feel quite warm about my own work there, it's largely not known because people have gone on to other things. I think my work on continuum percolation has been a little more influential. My work on martingales, at least through the book with Chris Heyde, has been influential with my own personal results on martingales as really just bricks in the wall. I took a job at the ANU in 1978 and the condition on taking the job was that I move into a relatively applied area, particularly I should move into statistics. I had applied for a job as a biometrician because I only had a contract job at the University of Melbourne and I needed a permanent position. Chip Heathcote [Christopher Robin Heathcote (1931-2016)] was the head of the department of statistics in the Faculties in those days. He was very kind and generous to me. He told me over the phone when he made the offer to me that was what they wanted me to do. They didn't have any time limit on this. I could just try and do it if I could and make the move [to statistics]. Pretty much after I arrived there, I started reading statistics papers and I really enjoyed it. There is a period through the 1980s when my work in probability and statistics was really quite blurred. I looked at a number of problems in extreme value theory, and depending on how you view those problems they can be seen as problems either in statistics or in probability. That was part of my transition from probability to statistics. I think my best work in statistics is about properties of bootstrap methods, explaining why some approaches are to be preferred to others. Probably my work on fractal properties of surface roughness has pleased me the most.

I: You mentioned percolation. That's related to physics, isn't it?

H: Yes.

I: Has your work been applied in physics?

H: Whether they actually apply my work in physics, I don't know. I wrote two papers on the subject [continuum percolation]. I didn't do it any more after that. Percolation is very much part of probability. I also had a fractional appointment for a short time with CSIRO which is a government research organization. I kept that up for only a year because I was warned that I might lose my research grant if I kept it. Because CSIRO was not available for research grants, I became a consultant. That was my official title, I think. So I did work with people there and that led me into the study of fractal properties of surfaces. I used to go to Sydney for a week, here and there during the year and work with people there. I had one CSIRO colleague who was my PhD student, Steve Davies. He was very good and still is, I'm sure. He works in the government sector now.

I: You mentioned your work on fractals. Is it applied in industry?

H: That's where it came from, in CSIRO. They had several problems, at least two, which came from other divisions. The main one that got us going was a problem in the manufacture of plastic wraps. There was a division of chemicals and polymers, the same division that developed the process of plastic banknotes (Singapore is issuing plastic banknotes and Australia too). That division of CSIRO was also responsible for producing this newly designed plastic wrap, and the idea was that the wrap would allow gases that promote the longevity of food to pass one way and gases that the food produces which would hasten its decay to go the other way. So if you wrap food or, more particularly, cut flowers for export, take it on a plane and send it off to Europe, they will be fresh for an extra day in the European market. But the important thing about this is that the side of the wrap which is in touch with the thing you are wrapping (the flowers, for example) should be very smooth because if it is rough there is a lot of opportunity for molds and so on to stick on there and therefore the advantages can be lost. So we had to develop ways of quantifying the roughness of the surface of this plastic wrap and they analyzed the plastic wrap under an electron microscope and gave us samples and we measured the fractal dimensions of the membrane. We also looked at similar problems in soil surface roughness related to the absorption of water by soil and also at some

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point in connection with the roughness of aluminium sheet that is used to make a can. If you take a coca cola can and cut it open and fold it out, you can imagine that the surface of the can is not very shiny and the reason is that it is quite rough at the microscopic level. This is all related to the characteristics of the rolling operation that produces that sheet. This was something which the division of CSIRO was very active in. We played a role in that.

I: One of your papers on the bootstrap method ("Theoretical comparison of bootstrap confidence intervals") is reprinted in the *Breakthroughs in Statistics* collection. Could you give us some idea of what the bootstrap method is about?

H: This paper that you mentioned was one of the contributions I made in the 1980s. The bootstrap method is actually quite simple. The study of statistics can, to a large extent, be formulated in terms of trying to get information about the population from data drawn from that population. Basically what you are trying to do is to describe the relationship between the population and the data. If you can't do that accurately then you would really need a statistician. The statistician's task is to try to do that as well as he can. Of course, it is obviously fraught with a lot of difficulties particularly if you don't know much about the distribution from which you drew the data. The bootstrap method attempts to model that by drawing a sample from your data itself. So you have your dataset, and you draw a new sample of the same size by sampling randomly with replacement, that is, after you take data value out you put it back again. Obviously if you are sampling randomly without replacement you will just get the sample back. If you put it back, you get a reasonable number of ties. In most contemporary problems where the bootstrap is used you actually do the sampling on a computer. There is a small number of problems which are so simple that you can do it mathematically – you don't need to actually do the sampling. In a sentence, the bootstrap is a way of modelling the relationship between the sample and the population it came from by the relationship between the resample and the sample you drew it from. The first of these two is exactly what a statistician is trying to learn about, and the latter is something about which the statistician can learn as much as he or she wishes, for example, by experimentation.

I: Why is it called the bootstrap?

H: I've always been interested in the history and origin of the bootstrap. It has a very interesting origin. Arguably, the origin of this idea goes back to an Englishman who was in the Indian Civil Service in the 1920s. He was asked as a senior civil servant in the government of one of the Indian states to make forecasts of the yields of various crops, hemp which was made into ropes by the British and rice and things like that. In order to make those forecasts to describe the accuracy, he had to estimate the variance variability. To do that, to cut a long story short, he invented a precursor of the bootstrap and he published a little tract on it in1927. He went on to be very influential in the government of India and he was an advisor to [Lord] Mountbatten [(1900-1979)] in 1947 when Britain gave India its independence.

I: What is his name?

H: John Hubback [(1878-1968)], Sir John later. His ideas were later picked up by the Indian statistician Mahalanobis [Prasanta Chandra Mahalanobis (1893-1972)]. He was trained in Cambridge. There was a bit of interest in his work in the '50s, '60s and until the early '70s. [Bradley] Efron came in and saw the whole thing fairly freshly and he made two contributions which were responsible for the field really exploding. One of them, of course, was recognizing that the sort of sampling you need to do can be done very quickly on a computer. When Efron wrote his paper in the late '70s it was just at the right time. The other thing that Efron saw which nobody else had seen before him was that you could use the bootstrap for almost anything. In the past it had been used mainly for variance estimation but Efron saw that it could be used for distribution estimation and it could be used for estimating the error rate of classifiers. Almost any statistical problem has a potential bootstrap solution and that insight as much as anything else is instrumental in the field becoming so significantly influential. And the name – I think there is a little explanation in a footnote in Efron's 1978 paper. In fact, many people thought the whole thing was crazy at that time – the idea of trying to get something useful by drawing data out of your sample. People thought this is like pulling yourself up by your bootstraps. That's something you can't do and hence the name.

I: I believe you also wrote a book on the bootstrap, isn't it?

H: Yes. The book is really about the theory of the bootstrap.

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It's hard to imagine today that the bootstrap could be controversial.

I: Is it still controversial?

H: No, but in some places it might be. However, in the 1980s there was still a level of controversy, partly due to people not understanding the process of re-sampling from your sample – people thought this was a crazy idea. Of course, the best way to show that it is not crazy is to develop a theory to show that you can get useful information in this way. The book that you refer to is an attempt to establish that theory. The book came out in1992.

I: You have the distinction of being one of the most prolific and highly-cited researcher in probability and statistics. Do you work on multiple problems within a given period of time? If so, how do you manage to do that?

H: I do work on multiple problems within a given period of time and, in fact, I'm struggling with several of them now. I think many people do that, maybe more common in statistics than it is in mathematics. I think it tends to be a function of the fact that you are aware that you are relying on other people to bring something to the table with all their weapons and they do. Defining when your research has ended under those circumstances is quite difficult because other people revising the paper sometimes come back and say, "I've started work on …" So I think the whole idea of beginning and ending a problem is less well defined today. When I was younger, for most of my career up until the mid-80s and even after that point, most of my papers were written by me alone. You're not waiting on anybody. You can start something, stop it and start something else at any point and go on. But today when there are several co-authors it doesn't work like that. Many people are working on several topics at the same time.

I: Do you enjoy collaborating with people?

H: Oh, yeah, very much so, whether they enjoy collaborating with me, I don't know. I certainly enjoy collaborating with people. You should put this question to Terry Tao [Fields Medal 2006] because he is extraordinary. I know him a little. He collaborates tremendously. One of the indications of his extraordinary intelligence and capacity is the fact that he can collaborate with so many people around the world at the same time, and this is in pure mathematics, not in statistics.

I: He works in probability too.

H: Yeah. He works in probability. He had a paper in the *Annals of Statistics*. He and I had a paper in the *Journal of the Royal Statistical Society* ["Relative Efficiencies of Kernel and Local Likelihood Density Estimators", *Journal of the Royal Statistical Society. Series B (Statistical Methodology)*, Vol. 64, No. 3 (2002), pp. 537-547]. He is simply an extraordinary man. We are very proud of him. If we can produce somebody like Terry every 20 years or so we would be fine *[laughs]*, but I'm afraid there is no hope of that.

I: Most people have the perception that statistics is concerned mostly about testing of hypothesis and interval estimation. What kind of problems do statistics generally address nowadays? Are there any central problems in statistics whose resolution will have immense impact on the field?

H: I think your question probably comes from your experience as a mathematician because in pure mathematics if you solve a problem that has baffled people for a few hundred years that is a great achievement and your fame is assured, whereas in statistics if people haven't solved it for decades it's probably not relevant any longer. People just move on. The whole way of describing what are the road blocks in statistics is quite different from mathematics. Statistics is not really its own master as mathematics is. Pure mathematics, particularly, has a life of its own, and so do the other classical disciplines like physics and chemistry. Physicists decide whether they want to find a new particle or not. This is not influenced by anybody in industry or medicine or anything like that, whereas statistics is not like that at all. An excellent and obvious example of this is the work of statisticians on high-dimensional problems related to genomics. The medical technology for recording genomic data is changing quickly and changing frequently. Every time that happens the nature of statistical tools that are needed also has to be revised. A statistician doesn't have much control over this. It's simply laid on their doorsteps and because they enjoy solving problems they get to work on it. There have been a number of exceptions to this where the statistical tools remain robust despite the development

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of new technology. The bootstrap is one of them and is applicable to a great many different problems, including many that have not motivated it directly. Another of those has been David Cox's contributions to survival analysis. From time to time somebody gets a really good idea which does have a really significant impact, but in my lifetime, although we like to think that something we have done is like that, it's probably not so for most of us. By and large we are bobbing around on the surface of the water trying to solve the problems that are often due much more to people outside statistics than to people within statistics. It's not like there is some big road block, some core problem that once we have solved it will change the way things are done. That does happen from time to time but usually progress is made in quite a different way.

Epilogue

Peter Gavin Hall was born in Sydney on 20 November 1951. His mother Ruby Violet Payne-Scott (1912-1981) was a pioneer in radar during World War II and in radio astronomy, as well as being the world's first woman radio astronomer. His father William ("Bill") Holmen Hall (1911-1999) was a telephone technician. They were both keen bushwalkers and met through their avid participation in the activities of a bushwalking club (Sydney Bush Walkers). His sister Fiona Margaret Hall is one of Australia's leading contemporary artists. Hall did his school and undergraduate education in Sydney. He obtained a BSc with First Class Honours from the University of Sydney in 1974, followed by an MSc from the Australian National University (ANU) and a DPhil from the University of Oxford, both in 1976. He met his wife Jeannie Jean Chien Lo in Oxford. Jeannie was a civil servant from the British Colonial Civil Service in Hong Kong, studying at Oxford. They married in Hong Kong in 1977. Jeannie went on to have a distinguished career in the Australian Federal Public Service.

Hall returned to Australia in 1976 from Oxford to take up what he believed to be a tenure-track appointment at the University of Melbourne. When he found out that it was only a three-year appointment, he applied to go to the ANU. Chip Heathcote, then the head of the statistics department of ANU offered him the job – if he agreed to move into statistics. This proved to be a gain not only for ANU and Hall himself but also for the international statistical and scientific community. He was at the ANU for 28 years (1978-2006), but moved back to the University of Melbourne in 2006 as an Australian Research Council (ARC) Federation Fellow, becoming an ARC Laureate Fellow from 2012.

It is obvious from his interview that Hall had a strong attachment to his home country. He was, however, aware of the relative scientific isolation of Australia, and sought to maintain personal research links with other researchers around the world, often making use of his personal research grants. He was proud of the fact that Australia was one of the first countries to establish a mathematical research centre (Centre for Mathematical Analysis in Canberra) – in the same year as the Mathematical Sciences Research Institute (MSRI) in Berkeley and ahead of the Isaac Newton Institute for Mathematical Sciences in Cambridge. Yet he felt that Australia might have lost this initiative and that other countries in the region could overtake Australia. Although Australia had the edge in establishing a mathematical research centre well before Singapore did, he lamented at some point, in a good natured and half-joking manner, that "Singapore had stolen the march on Australia". He was always active in promoting the awareness and interests of mathematics in the general scheme of things, especially in the Australian Academy of Science (AAS) of which he was a council member during the years 2003-2006, 2008-2013. He was totally committed to his home country and wanted the best for Australia in mathematics and the mathematical sciences and was supportive of regional efforts in promoting mathematics. He would voice his concerns, both in academia and in the public media, on the need and urgency to upgrade the level of mathematical teaching in schools and universities and to ensure a sufficient supply of local university faculty of the highest calibre.

What is perhaps not so well-known is that he took time off from more serious research work to interview four of his Australian colleagues (Anthony John Guttmann, Gustav Isaac Lehrer, Hyam Rubinstein and Ian Hugh Sloan). These interviews were published in World Scientific's *Asia Pacific Mathematics Newsletter* in 2011-2013.

His views were sought after by policy makers; for example, he was the first chair of the Scientific Advisory Committee of the Australian Mathematical Sciences Institute established in 2002 and located at the University of Melbourne. He was one of the leading members of the first national strategic

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review of the mathematical sciences in Australia in 2006. The outcome of the review was the setting up of government funded Centres of Excellence in specific strategic areas; in particular, a Centre of Excellence for Mathematical and Statistical Frontiers of Big Data, Big Models, New Insights (renamed Centre of Excellence for Mathematical and Statistical Frontiers) to be funded to the tune of A$20 million over 7 years. In 2014 he was appointed as the inaugural director of this Centre of Excellence, which is based at University of Melbourne and which will foster and facilitate collaboration among five specific Australian universities and seven industrial and public organisations. This was the high point of an illustrious career that started from a fixed-term lecturer position in Melbourne to the directorship of arguably the most ambitious organization for the mathematical sciences in Australia. But, tragically, his career was cut short by the sudden onset of a series of illnesses, and he passed away on 9 January 2016, at the age of 64. He had, however, bequeathed a rich legacy in the mathematical sciences. In recognition of his leadership, the decadal plan of the AAS, "The mathematical sciences in Australia: A vision for 2025" was dedicated to his memory. The extent and impact of his contributions to mathematics and statistics are evident from the obituaries published by major scientific bodies and universities throughout the world. The indelible impressions of his personality on people who are fortunate enough to have met and known him can be unequivocally seen in the feelings expressed in the open website http://www.statcenter.pku.edu.cn/Peter_Gavin_Hall/.

The list of awards for Hall's contributions to mathematics and statistics seems endless: the Australian Mathematical Society Medal, Rollo Davidson Prize, Edgeworth David Medal, Lyle Medal, Committee of Presidents of Statistical Societies (COPSS) Award, Pitman Medal, Hannan Medal, American Statistical Association award for outstanding paper on statistical applications, Matthew Flinders Medal and Lecture, American Statistical Association Gottfried E. Noether Senior Researcher Award for outstanding contributions to nonparametric statistics, Distinguished Achievement Award (International Chinese Statistical Association), Moyal Medal, Challis Award and Lectures, Szekeres Medal, and Guy Medal in Silver. He was honoured with fellowships in scientific bodies like the Australian Academy of Science, the Royal Society of London, the Royal Society of Edinburgh, and the Academy of Social Sciences in Australia. He was made a foreign associate of the US National Academy of Sciences, and an Officer of the Order of Australia. He received honorary doctorates from the Université catholique de Louvain, the University of Glasgow, the University of Sydney and the Universidad de Cantabria (Spain). The COPSS Award, which has been awarded since 1981 to statisticians below the age of 41, is generally regarded by statisticians as the equivalent of the Nobel Prize in statistics. In fact, only 5 of its recipients were based outside North America, and of these only 3 were not from the US, and Hall was one of them.

Hall's penchant for rigour (in theory) was partly responsible for his choosing mathematics (probability in particular) over his initial interest in physics in his undergraduate studies. When Hall started his graduate research work on rates of convergence in the central limit theorem, it was done solely for its own mathematical sake and it gave him immense personal satisfaction. Though he had agreed to turn his attention to problems in statistics when he took up the position in ANU, he published in the early years two books on theoretical questions in probability: *Martingale Limit Theory and its Application* (with C.C. Heyde in 1980) and *Rates of Convergence in the Central Limit Theorem* (in 1982). Little did he suspect that some years later, it would provide the theoretical basis for the revival of a class of somewhat ad hoc and non-rigorous methods, collectively referred to as the "bootstrap method", used by statisticians in drawing information from a sample of data collected. His ground-breaking paper "Theoretical comparison of bootstrap confidence intervals" (*Annals of Statistics*, 1988) was reprinted in the *Breakthroughs in Statistics* collection. This was followed by a book *The Bootstrap and Edgeworth Expansion* published in 1992. Earlier in 1988, he published a widely cited monograph *Introduction to the Theory of Coverage Processes*, which develops the mathematical theory of models for random coverage patterns that are used in many areas such as queueing theory, ballistics and physical chemistry. Not only did he make good his promise to move into statistics, the move produced spectacular results. Perhaps it was his "fondness for problem solving" and his eclectic research interests that generated the driving force.

The speed and capacity with which Hall worked on

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problems are legendary. In 2016, Mathscinet credited him with 606 publications and 240 distinct co-authors. This amazing prodigious output of work and collaboration inspired someone to define the "Hall number" of a statistician as the statistical equivalent of the famous Erdös number in mathematics. In a study "Worldwide institutional and individual rankings in statistical theory by journal publications over the period 1980-1986" by P.C.B. Phillips, I. Choi and P.Z. Schochet *(Econometric Theory 4, 1988, 1-34)*, Hall was overall ranked first (leading by a large margin over the second-ranked Bradley Efron) as well as for publications in *Annals of Statistics*. Interestingly, in the same study, if Hall's score had been compared with the overall score of institutions and universities, he would have ranked as the 17th top ranking institution in the world. Apparently, in the 1980s, the large number of papers written under the name of "Peter Hall" gave statisticians in the "Eastern Bloc" behind the "Iron Curtain" the impression that "Peter Hall" must be a pseudonym for a consortium of authors. This information and a vivid first hand account of Hall's passion for photographing trains are provided by S. Marron of the University of North Carolina at Chapel Hill in a personal "Peter Hall Memorial Page" at http://marron.web.unc.edu/sample-page/peter-hall-memorial-page/.

The impact of Hall's work may be gauged by the fact that he was an ISI highly cited researcher with over 6,750 citations. Also, Scopus citation statistics credits him with 3,500 citations for his book on martingale limit theory, 2,500 citations for his bootstrap book and over 8,000 citations for his published articles. He had the knack of looking at concrete problems and turning them into mathematical ones to which his skills and expertise could be effectively applied. His contributions often broke new ground in other areas in the physical sciences, engineering, biological sciences, economics and technology, and more specifically in limit theory, stochastic geometry, spatial processes, continuum percolation, nonparametric density estimation, regression and classification, extreme value theory, deconvolution and measurement error problems, nonparametric inference for mixture distributions, functional data analysis, empirical likelihood, bootstrap method, curve estimation, smoothing methodologies, density estimation, bandwidth selection and surface roughness measurement using fractals.

Hall had been invited to give numerous prestigious lectures: Belz Lecture (Statistical Society of Australia), S.S. Wilks Lecture (Princeton University), G.W. Snedecor Lecture (Iowa State University), Knibbs Lecture (Statistical Society of Australia), Mahalanobis Memorial Lectures (Indian Statistical Institute), Pitcher Lectures (Lehigh University), Kolmogorov Lecture (Bernoulli Society), Invited Lecture (International Congress of Mathematicians), Distinguished Lecture Series in Statistical Science (Fields Institute), H.O. Hartley Lectures (Texas A&M University), Stephen Corcoran Memorial Lectures (Oxford University), Hoeffding Lectures (University of North Carolina), Richard Tweedie Memorial Lectures (University of New South Wales), Utah State University "Prospects in Statistics" Lectures, Wald Lectures (Institute of Mathematical Statistics), Ilsong Lecture (Korean Statistical Society), Bernard Flury Memorial Lecture in Statistics (Indiana University), Distinguished Lecture Series (National Taiwan University), Bahadur Lectures (University of Chicago), Saw Swee Hock Public Lecture in Statistics (University of Hong Kong), G.S. Watson Lecture (La Trobe University).

Besides his annual commitments at University of California at Davis, Hall held visiting positions in many universities: Aisenstadt Chair (Université de Montréal), Centennial Professorship (London School of Economics), Distinguished Applied Mathematics Lecturer (Hong Kong Baptist University), Carnegie Centenary Professorship (UK), Distinguished Applied Mathematics Lecturer (Hong Kong Polytechnic University), Distinguished Lecturer in Mathematics and Applications (University of South Australia) and Saw Swee Hock Professorship (National University of Singapore).

He also served in Australian and overseas scientific committees in the following capacity: Secretary, Physical Sciences, and Vice-President (Australian Academy of Science), President of Bernoulli Society for Mathematical Statistics and Probability, KAUST Institute for Applied Mathematics and Computational Science Advisory Board, Member of Australian Mathematics Trust Board, President of Institute of Mathematical Statistics, Member of International Advisory Committee for Department of Business Statistics and Econometrics (Peking University), Member of Reference Committee, Group of Eight Universities' Review of Education in Mathematics, Data Science and Quantitative Disciplines (Australia), Member of Fields Medal Committee

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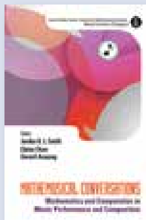
(International Mathematical Union), Committee Member and Deputy Chair of International Review of Mathematics (UK Engineering and Physical Sciences Research Council), Member of Working Party, National Strategic Review of the Mathematical Sciences (Australian Academy of Science). He supervised some 30 PhD students and trained 38 postdocs. He served on the editorial boards of numerous leading journals, notably *Annals of Statistics, Annals of Probability, Journal of the American Statistical Association, Journal of Multivariate Analysis, Journal of Statistical Planning and Inference, Probability Theory and Related Fields, Stochastic Processes and Their Applications, Bernoulli and Econometric Theory*.



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