IMPRINTS

21 Celebrating years of Mathematical Synergy

NUS National University of Singapore | IMS Institute for Mathematical Sciences

JANUARY– JUNE 2021 ISSUE 37

NEWSLETTER OF THE INSTITUTE FOR MATHEMATICAL SCIENCES, NATIONAL UNIVERSITY OF SINGAPORE

On behalf of the Scientific Advisory Board (SAB), I would like to congratulate IMS on its 21st anniversary (the age of majority in Singapore!). The SAB provides advice and guidance on the scientific development of IMS and in particular assists the Director in evaluating and selecting proposals for the Institute's programs. Each of the members, whether from Singapore, or from the international community, has a long connection with, and affection for, IMS and its further evolution.

Perhaps a personal experience can illustrate how the work of the SAB promotes the success of the IMS and its programs. In 2010, the proposals before the SAB included programs in high dimensional statistics and in random matrix theory (RMT). As a part of its review, the SAB always looks for potential linkages among proposals, and in this case (I was told, as I joined the Board only later) it suggested that the two programs occur one after the other, with the weeks and workshops at the "border" focusing on points of intersection in the two fields. For me, as a regular participant, this was ideal, as my research indeed lay at that intersection. As universally happens, I met many people at the workshops. And, specifically due to the intersection, one of them was Matt McKay, an electrical engineer from Hong Kong working in RMT, and we began an interdisciplinary collaboration that continues to this day.

Congratulations to Chi Tat and all at the Institute!

Iain Johnstone
Stanford University

Chair
Scientific Advisory Board

The establishment and evolution of the Institute of Mathematical Sciences (IMS) at the National University of Singapore is a story of youthful enthusiasm, steadfast dedication and commitment, and forward-thinking leadership. Through the support of Singaporean institutions and the international community, IMS grew from a centre for stimulating, nurturing and sustaining local interests and activities in the mathematical science to an internationally respected focal point of promoting frontier research and collaboration.

On behalf of the IMS Management Board, I wish to thank both the past and present members of the IMS Scientific Advisory Board for their constructive suggestions and insightful guidance. Professors Louis Chen, the inaugural IMS Director, laid the solid foundation for the Institute. Professor Chong Chi Tat fits into Professor Chen's role superbly and fearlessly. The many people, both local and international, who organize to the impactful programmes over the years, contribute in an integral way to the success of the Institute. May the Institute continue to flourish and grow from strength to strength in the coming years.

Lai Choy Heng
National University of Singapore

Chair
Board of Management

When the Institute for Mathematical Sciences (IMS) was established at the turn of the new century, with a start-up grant from the Singapore Ministry of Education, it signaled the beginning of a new chapter in the nation's development of mathematical sciences. From the moment of its inception, the IMS set its mission and vision as providing a platform for a forum on state of the art in mathematics and its applications, facilitating interaction and collaboration between local and overseas researchers, and offering research opportunities to young scientists. These objectives remain true today.

The official opening of the Institute took place on 17 July 2001, almost exactly twenty years ago. IMS follows a mode of operation that is widely adopted among mathematical institutes around the world. Every year, IMS invites submissions of proposals for programs or workshops with specific themes or topics that are of interest to the local scientific community. The proposals are reviewed by the IMS Scientific Advisory Board which meets annually. Selected programs and activities are funded by the Institute, and may be of duration of a week to a month or even a semester. Since its inaugural program ("Coding theory and data integrity") in July 2001, the Institute has hosted 163 programs and workshops, and welcomed around 15,000 visitors. The visitors included senior researchers and leading figures in contemporary mathematical sciences, and graduate students as well as researchers starting their careers. The topics covered in the programs and activities were wide-ranging, from pure mathematics such as "Langland's program, "Complex geometry and dynamical systems", "Computational aspects of infinity", to those at the intersection of physics and mathematics such as "Mathematical horizons of quantum physics", "Interacting particle systems". There were also topics on applications such as "Theories and numerics of inverse problems', "Data sciences: bringing mathematics, physics and biology together", and topics in computer science such as "Program verification". Also there were programs on applications of mathematics/ statistics to medical science, for example "Quantitative methods for drug discovery and development", "Causal inference", as well as applications to economic science, e.g. "Dynamic models in economics", …and the list goes on. It offers a glimpse of the exciting advances one witnesses in contemporary mathematical science, and the transformations it brings to the modern world. A more careful look at the lectures delivered and the research results presented in the programs and workshops show the breadth and depth of contributions by local researchers.

Among them were collaborative works or projects initiated or completed by individuals participating at IMS activities. We are pleased that the Institute is meeting the role of a facilitator for scientific inquiry, contributing to the growth of NUS as a research-intensive university.

At the institute level, IMS began a collaboration with the Vietnam Institute of Advanced Studies in Mathematics on supporting young researchers, and a collaboration with the Institute of Pure and Applied Mathematics at UCLA on the RIPS program (Research on Industry Problems for Students). In the coming year, a workshop on machine learning will be organized jointly with the Simons Institute for the Theory of Computing at Berkeley. IMS hopes to further develop its relationship with other mathematical institutes in the coming decade.

The first 21 years of IMS have been a fulfilling journey. This would not have been possible without the continued strong support, both financial and organizational, that the University has so generously given. We thank President Tan Eng Chye and former President Tan Chorh Chuan, Provost Ho Teck Hua and Deputy President for Research and Technology Chen Tsu Han, for this, and for their trust and encouragement. We are also grateful to the Scientific Advisory Board, led in succession by Professors Roger Howe, Yum Tong Siu and the current chair Iain Johnston, and the Management Board chaired by Professor Lai Choy Heng, for their guidance and advice. To our colleagues in Singapore and abroad who organized IMS activities, and to the staff of the Institute who routinely receive compliments from participants for their dedicated and efficient service, IMS expresses its deep gratitude and appreciation.

Chong Chi Tat
National University of Singapore
Director

COVER ARTICLE

Topics at the Interface of Low Dimensional Group Actions and Geometric Structures

From 4 to 15 January 2021, the Institute hosted a workshop on "Topics at the Interface of Low Dimensional Group Actions and Geometric Structures". The organizers contributed this invited article to Imprints.

BY THOMAS KOBERDA *(University of Virginia)*

In the last decade, the fields of geometric group theory, geometric structures on manifolds, and dynamics in low dimensions have seen a huge amount of progress in diverse research directions. Moreover, these fields have benefited from a large amount of synergy. The program brought together experts in all three fields and in many related topics, and featured extensive interaction between mathematicians from all over the world and from all career stages.

A basic question one can consider about a given group is how to understand its structure, its meaningful actions, and the relationship between the two. For instance this can mean understanding the group as the fundamental group of a space such as a low dimensional manifold, and investigating the various geometric structures with which that space can be endowed via representations of this group into a reductive Lie group.

Another way to frame the basic question is to investigate the geometry that is intrinsic to the group itself. This is the rich subject of geometric group theory. One can also study the orbit structure of actions of the group on various spaces, including ones as basic as the circle. This is the domain of low dimensional dynamics.

These three perspectives on groups and group actions are intimately connected, and new trends in this vein were the primary focus of the program.

The program was completely remote, and all talks were pre-recorded. Discussion was facilitated through a Gathertown platform and Zoom question and answer sessions, with designated time slots that were convenient for participants from various time zones. This way, all participants could have access to each speaker. The Gathertown platform was designed as a digital replica of the IMS, situated within a digital replica of Singapore, complete with a Merlion.

The first week of the program consisted of minicourses aimed at graduate students and early career researchers. These were delivered by Francesco Bonsante (Pavia, anti--de Sitter geometry), François Guéritaud (Strasbourg, Anosov representations), Tullia Dymarz (Wisconsin, Coarse geometry of groups), and Yair Minsky (Yale, Hyperbolicity and mapping class groups).

The second week of the program consisted of research talks and two master courses. The range of topics discussed was diverse indeed: from connections between the curve complex of a hyperbolic surface and model theory to the behavior of generic ordered groups to real projective structures to the interaction between dynamics and diophantine approximation. For the question and answer sessions, the speaker's talk would be summarized briefly by the chairperson of the session, after which participants would be free to ask questions. Participants unable to attend the sessions were able to pose questions in designated fora. In all, twenty speakers delivered a total of twenty two lectures. There were over 250 registered participants, which is far more than would have been able to participate in person.

NEW MANAGEMENT BOARD MEMBER

The Institute is pleased to welcome Professor Kim Chuan Toh, NUS, as new member to its management board.

Kim Chuan Toh

Professor Toh obtained his PhD at Cornell University. He is Leo Tan Professor in Science and head of the Department of Mathematics. He is also affiliated with the Institute of Operations Research and Analytics, Institute of Data Science, and Department Statistics and Applied Probability at NUS. He received the President's Science Award (2019), Beale-Orchard-Hays Prize (2018), University Research Recognition Award (2018) and Farkas Prize (2017). He has served in the SIAM Fellows Selection Committee and SIAM Journal Committee. He is currently an area editor of Mathematical Programming Computation, and an associate editor of SIAM Journal on Optimization, Mathematical Programming Series B, and ACM Transactions on Mathematical Software. His research interests include algorithms, applications, and theory in matrix optimization such as semidefinite programming, as well as fast algorithms for large scale statistical and machine learning problems.

APPRECIATION

The Institute would like to express its thanks to outgoing members KK Phua and Professor Chengbo Zhu for their contributions in overseeing the Institute's activities since they joined the management board in 2001 and 2014, respectively.

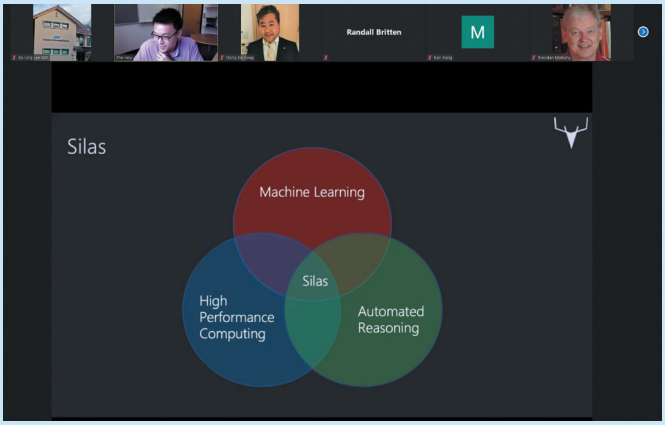
Topics at the Interface of Low Dimensional Group Actions and Geometric Structures

4–15 JANUARY 2021

CO-CHAIRS
Indira Lara Chatterji | Université de Nice - Sophia Antipolis
Thomas Koberda | University of Virginia
François Labourie | Université de Nice - Sophia Antipolis
Sara Maloni | University of Virginia
Tengren Zhang | National University of Singapore

This two-week workshop focused on the interactions between geometric group theory, geometric structures and Anosov representations. There were more than 250 attendees who joined the virtual workshop, which included more than 70 PhD students.

22nd International Conference on Formal Engineering Methods (ICFEM)



Zhe Hou: Tutorial on Silas: Dependable and High Performance Machine Learning


Jun Sun


Rajeev Goré


Sanjit A. Seshia

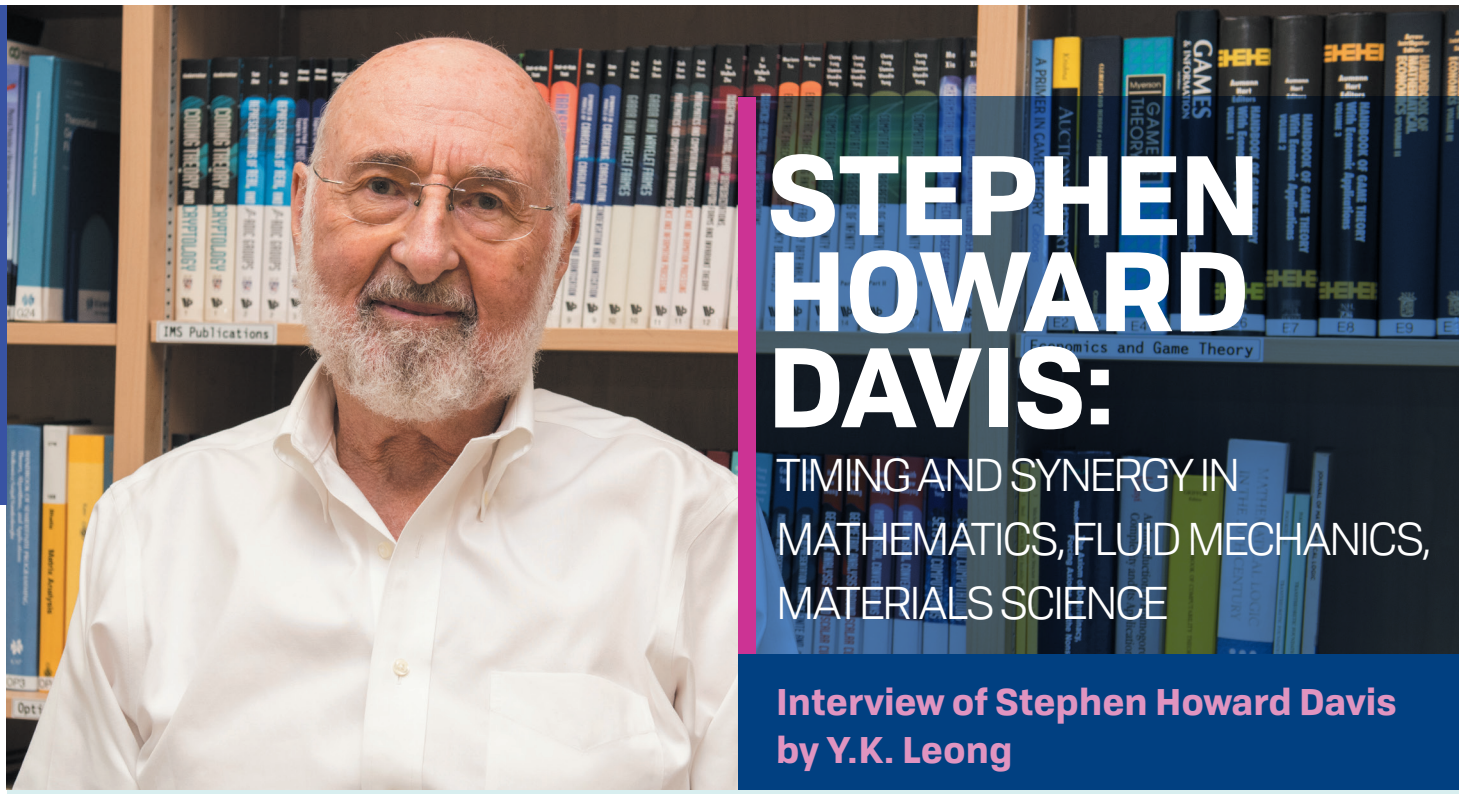
1–3 MARCH 2021

CO-CHAIRS:
Jin Song Dong | National University of Singapore and Griffith University
Jim McCarthy | Defence Science and Technology
Zhe Hou | Griffith University
Shang-Wei Lin | Nanyang Technological University
Brendan Mahony | Defence Science and Technology

The International Conference on Formal Engineering Methods (ICFEM) gathers researchers and practitioners interested in the recent development in the use and development of formal engineering methods for software and system development. There were three keynote speakers; Emeritus Professor Rajeev Goré (Australian National University), Associate Professor Jun Sun (Singapore Management University) and Professor Sanjit A. Seshia (University of California, Berkeley).

Zhe Hou of Griffith University delivered three hours of tutorial lectures titled "Silas: Dependable and High Performance Machine Learning" on the first day of the conference. A doctoral symposium was also planned after his lectures. ICFEM 2020 had one affiliated workshop: the 10th International Workshop on SOFL + MSVL for Reliability and Security (SOFL+MSVL 2020) consisted of 13 talks. The second and third day were planned with 20 research paper presentations. There was an average of 30 participants in the three-day conference.

INTERVIEW



STEPHEN HOWARD DAVIS:

TIMING AND SYNERGY IN MATHEMATICS, FLUID MECHANICS, MATERIALS SCIENCE

Interview of Stephen Howard Davis by Y.K. Leong

Stephen Howard Davis has made fundamental contributions in fluid mechanics and materials science through his pioneering work in hydrodynamic stability, interfacial fluid mechanics and crystal growth.

Born and bred in New York, Davis received all his degrees (BEE in Electrical Engineering, and MS and PhD in Mathematics) from the Rensselaer Polytechnic Institute, having won scholarships from New York State. He spent two short stints of two years each as a research mathematician at RAND Corporation and as a lecturer in applied mathematics at Imperial College in London. He then moved to Johns Hopkins University first as an assistant professor and quickly moved up the ranks to the position of associate professor and full professor of mechanics. After 10 years at Johns Hopkins, he moved to Northwestern University where he was McCormick School (Institute) Professor and Walter P. Murphy Professor of Applied Mathematics and (by courtesy) professor of Mechanical Engineering and Chemical and Biological Engineering in the McCormick School of Engineering. While at Northwestern, from 1979-1994, he was concurrently president of his own consultancy company (SHD Associates, Inc). He had also been chair of the Department of Engineering Sciences and Applied Mathematics and Director of the Center for Multiphase Fluid Flow and Transport. He retired in December 2019 as Emeritus Professor and continues to be active in research.

Davis is an ISI (Institute for Scientific Information) Highly Cited Researcher in Engineering. His research output numbers more than 250 papers and reports, both single and joint authored, and his attraction as advisor and mentor can be seen in the work of some of his 40 doctoral students. The legacy that is spanned by his prodigious collaboration is clearly reflected in the setting up of the inaugural Stephen H. Davis Symposium at Northwestern University, which was held on 15 October 2019 in his honor (on his retirement) and to celebrate his fundamental contributions to fluid mechanics and materials science. (The Second Stephen H. Davis Symposium will be held on 4 October 2021.) Indeed, a decade earlier, Davis' work was sufficiently impactful in his field that a whole volume (No. 647) of the *Journal of Fluid Mechanics* (one of the leading journals in his field) was, unbeknownst to him, dedicated by the other members of the editorial board of that journal to him on the occasion of his 70th birthday.

The tremendous success of Davis in his research is not only due to his ability to use mathematics to solve problems in applied mathematics but also to his uncanny sense of timing in research, as G. Paul Neitzel wrote in his essay[1] on the personal life and research contributions of Davis in the 70th birthday celebrative volume of the journal.

"Steve not only has been at the right place at the right time geographically – from RPI to California, Hopkins to Northwestern – but he has chosen to enter research areas at defining moments, producing fundamental, enlightening work that has enabled others to also advance the respective areas."

Davis' research involves modelling and asymptotic and numerical methods. His pioneering work in interfacial dynamics and hydrodynamic stability, which are of both intrinsic and practical interest, has given impetus to advances in other areas of fluid mechanics and materials science. Among other things, he was the first to have

[1] G. Paul Neitzel "Stephen H. Davis – 70, and counting", *Journal of Fluid Mechanics* 647 (2010), 3–12

studied the following: the instability of time-dependent flows including Stokes Layers, the dynamic instabilities driven by variations in surface tension along interfaces, the nonlinear theory of film rupture by instabilities driven by van der Waals attractions, the coupling of evaporation and thin film instabilities, the analytic theory of moving contact lines leading to the understanding of the dynamics and instabilities of droplet spreading, the dynamics of metallic foams and devising a unique numerical simulation based on a network model that can be used to follow in time a regular foam as it becomes disorganized. His review article RMP[2] laid out how long-wave asymptotic theory would be the basis of research worldwide in the analysis of thin- films, droplet spreading, and micro/nano -science flows.

In material science, Davis pioneered the coupling of morphological instabilities and material anisotropy, and first gave a theory of rapid solidification in which thermodynamic disequilibrium generates banding. He was the first to use long-wave theories to describe the destabilization of deposited solid films and their evolution to quantum dots through coarsening via the derivation of convective Cahn-Hilliard equations. He has also pioneered the study of the interaction of fluid and solidification, finding ways of using imposed motion to delay morphological instability and showing how freezing can modify the modes of convection. He has recently outlined a method of freezing a metallic foam so as to produce a porous solid with uniform permeability.

Well-known for his book *The Theory of Solidification,* he has co-edited the following monographs: *Frontiers of Fluid Mechanics* (with L. Lumley), *Interactive Dynamics of Convection and Solidification* (with H. E. Huppert, U. Müller and M. G. Worster) and *Free Boundaries in Viscous Flows* (with R. A. Brown). Davis has served on the editorial boards of numerous leading publications such as Cambridge University Press Monographs in Mechanics, SIAM Monographs on Mathematical Modeling and Computation, International Review of Mathematics (UK), Proceedings of the Royal Society (London). Notably, he was on the editorial board of the Journal of Fluid Mechanics as Assistant and Associate Editor from 1969–1989 and then Editor from 2000–2010. He has been the Editor of the *Annual Review of Fluid Mechanics* since 1999.

Davis is a Fellow of the American Physical Society and a member of the United States National Academy of Sciences, the United States National Academy of Engineering, the American Academy of Arts and Sciences and the Johns Hopkins Society of Scholars. He received the prestigious Fluid Dynamics Prize of the American Physical Society and the G. I. Taylor Medal of the Society of Engineering Science.

He has twice been Chairman of the Division of Fluid Dynamics of the American Physical Society. In his extensive professional services, he has worn the hats of member, chairman and advisor in committees of the following scientific bodies, such as the U.S. National Academy of Sciences, Institute of Mathematical Sciences, Imperial College, London, U.S. National Aeronautics and Space Administration (NASA), U.S. National Committee on Theoretical and Applied Mechanics, Society for Industrial and Applied Mathematics (SIAM), U.S. National Science Foundation, Discipline Working Group on Fluid Dynamics and Transport Phenomena, Microgravity Science and Applications, U.S. National Academy of Engineering.

Throughout his illustrious career, Davis has been invited outside the U.S. as distinguished professor and to give numerous talks in Australia, France, Germany, Singapore, Switzerland and U.K. and, in particular, the following special lectures in US and UK : the Prince Distinguished Lecture, Stewartson Memorial L, Westinghouse Distinguished L, Richard C. DiPrima L, L.S.G. Kovasznay Distinguished L, Ascher H. Shapiro L, S. S. Penner L, George K. Batchelor L, John Laufer Keynote L, Boelter L, Arthur Newell Talbot L, and Lighthill (Inaugural) Lecture.

Davis was invited to the Institute for Mathematical Sciences (IMS) of the National University of Singapore (NUS) from 1–31 May 2018 as Distinguished Visitor for the Institute's program "Modeling and Simulation of Interface Dynamics in Fluids/Solids and Their Applications" (23 April–25 May 2018), in which he gave a tutorial on his specialty "Thin-domain asymptotics in fluid mechanics".

He also gave a fascinating talk "A history of moving contact lines" in the Ng Kong Beng Public Lecture Series on 10 May 2018. What is not so well-known is the fact that Davis' work has been influential on the research of some faculty in the Department of Mathematics of NUS such as Weiqing Ren. In fact, Davis had written a joint paper with one of the co-organizers of this IMS program, David Srolovitz of the City University of Hong Kong. During Davis' visit to IMS, Y.K. Leong took the opportunity to interview him on behalf of the IMS newsletter Imprints on 28 May 2018. The following is an edited and vetted version of the transcript of the interview, in which he gave a glimpse of some intriguing aspects of interfacial dynamics and materials science, and of applied mathematics, in general.

Acknowledgement. Y.K. Leong would like to thank Von Bing Yap of the Department of Statistics and Applied Probability, National University of Singapore for preparing a raw draft of the transcript of the interview.

[2] Alexander Oron, Stephen H. Davis and S. George Bankoff, Long-scale evolution of thin liquid films, *Reviews of Modern Physics* **69** (1997), 931-980

IMPRINTS I **Your undergraduate and graduate education was all taken at Rensselaer Polytechnic Institute (RPI) which is the oldest technological institute in the English-speaking world. Could you tell us how and why you chose to go to RPI?**

STEPHEN H. DAVIS D Well, there are really two reasons. One is that I lived in New York State which gave scholarships to people who went to universities in New York State. And that amount of money was nontrivial. I couldn't have gone to RPI without that. The other [reason] why I picked RPI is that one of my neighbors at home had gone there and I was familiar with the name. So, it wasn't a very deep reason.

I **I believe you actually did your education almost completely there: your undergraduate as well as your graduate. Normally, American undergraduates do not go to the same university for their graduate study; is that correct? It's very unusual for you to continue at the same university.**

D That's correct. Well, I went to a different department. I was in Electrical Engineering and then I went to Mathematics. So it was like a going to a different university.

I **Can you tell me why you chose mathematics instead of engineering?**

D My PhD thesis was on pattern selection. How patterns form in physical systems. I was looking at Bénard convection[3] and I was looking at how hexagonal cells form and how two-dimensional cells form.

I **Where do Bénard cells occur?**

D Well, they occur on the [surface of the] sun, for example. There are also convection cells in the atmosphere of the earth – in a lot of natural situations. They occur in laboratories, of course.

I **Do they involve a lot of mathematical modeling?**

D Yes. And it involves nonlinear stability theory.

I **Who was your PhD advisor?**

D It was Lee [Aaron] Segel[4]. He was a new professor in the Department [of Applied Mathematics], and he was working on nonlinear fluid mechanics which I thought was an interesting subject.

I **You studied Electrical Engineering as an undergraduate. Didn't you?**

D Yes. Only as an undergraduate.

I **And then you switched to mathematics, ultimately connecting to engineering.**

D Well, fluid dynamics was completely different from electrical engineering. It had nothing to do with electrical engineering.

I **You worked for two years at the RAND Corporation after your PhD, and then you went back to academia in Imperial College, in London for two years, before continuing your academic career in the United States. Did your initial years in industry have any influence on the direction of your subsequent career development?**

D Not in a useful way because the RAND Corporation doesn't manufacture anything. It's an organization that writes studies of policy for the government. So, what I learned though, when I was there, is that even though it was a wonderful place (it was one block from the beach) I could work on anything I wanted, but I missed having students and supervising students. And that's what I really liked.

I **Is the atmosphere at RAND Corporation research-oriented?**

D It's research but it's not research into science. It's research into economic and political policy.

I **So then, it didn't have any influence on your thinking subsequently?**

D Not very much.

I **But then you went to London, right?**

D Yes, to Imperial College.

I **Which is not within United States.**

D What happened was that Imperial College hired a new professor whom I knew and who invited me to go there as a lecturer. He had been a very well-known professor at a government laboratory in the U.K.

I **Who was that?**

D John Trevor Stuart.

I **Was he in fluid dynamics?**

D Right. He also did pattern selection and nonlinear stability problems. He was one of the pioneers.

I **What do you see yourself as first and foremost: mathematician, physicist or engineer?**

D I can't pick one because where I work is a neighborhood of all three. So, where the three

[3] Henri Bénard (1874-1939)

[4] Lee Aaron Segel (1932-2005)

intersect is where I live. So, physicists think I'm a physicist; engineers think I'm an engineer and mathematicians think I'm a mathematician.

I **So, you have a lot of collaborators.**

D Yes, I do. From all different fields.

I **Interfacial fluid dynamics is a multidisciplinary field at the interface of physics, chemistry, engineering, and mathematics. How did you get interested in it?**

D When I was a graduate student, my advisor gave me a little problem to do on interfacial fluid mechanics which I thought was an interesting subject. It wasn't my thesis topic, but it still remained there a few years later. And then, I got into this area when I was at Imperial College, and I did a lot of research in it afterwards. My first job after Imperial was at Johns Hopkins University. And so, that was where I started to work in it seriously.

I **Did the people at Johns Hopkins University do a lot of interfacial fluid mechanics?**

D Not before I came. They did a lot of fluid mechanics. And, also, Johns Hopkins is known for medicine. The medical school is very well known.

I **Did you have any interaction with the medical people?**

D Well, I worked with them a little bit, but I haven't done so recently.

I **Are there some real-life products that have resulted from research in interfacial fluid dynamics?**

D Rather than talk about products, I would like to talk about processes. So, for example, if one wants to coat a solid surface with a liquid, whether it coats well or air gets sucked underneath depends on the mechanics of the front. In other words, the tip of the liquid has to satisfy certain conditions. This has been very well studied by a lot of people and it has revolutionized the industry of coating because they now have numerical codes that answer most of their questions. And all of it came from the theory.

I **Is coating something like applying a liquid on a surface?**

D When you paint a solid with a brush, the paint film sometimes adheres well while other time air bubbles grow. Theory tells us which case will emerge.

I **That seems to involve a lot of physics.**

D It does, but it's both mathematics and physics. I'll give you another example. In the oil industry, most of the oil is contained in a porous rock, and so, you have little droplets of oil in the crevices, in the holes. If you try to force water through the holes to capture the oil; you force water in, and you just get water out. You don't get any oil, so you have to do something more technical. And so, you have to put in some polymers in the water or use boiling water. There are various interfacial interactions between the oil, the water and the polymer. The theory turns out to be very well developed.

I **This seems to be a very complicated process.**

D It's very complicated because it's very hard to look into a rock. I mean, the holes are like nanometers in diameter. And I'll give you one more example. Sometimes infants are born prematurely, and they do not develop the ability to make surfactants. You know what a surfactant is? It's a material that lowers the surface tension of an interface between a liquid lining and air. There's a mechanism for producing it. And if you produce it, it lowers the surface tension. There's a liquid lining in the lungs, and it allows the lungs to open. For the babies who do not produce surfactants, they cannot open the lung and they would normally die. And so, what physicians do is that they try to inject some of the surfactants through the mouth into the lungs, like a bolus. A bolus is a small volume of surfactant and they want to push it into the lung, get it down into the lung so that the lung can open. And to do that properly, you have to know a lot about interfacial dynamics. In fact, one of my students [James Bernard Grotberg] worked on this and he's become very famous for doing this.

I **That's fantastic.**

D It is. Interfaces are everywhere.

I **Do you have any patents?**

D I think I have just one, nothing very interesting.

I **What do you consider to be the most satisfying piece for mathematical research you've done?**

D You know, that's like asking, "Which child do you like the best?"

I **Especially if you're a favourite father of too many.**

D So I'll pick one. There was a student of mine named Elizabeth Dussan[5], and for her PhD, she studied the motion of contact lines. A contact line is a line common to say liquid, solid and gas. If this is liquid spreading on a solid, that line there, is the contact line. And she was able to do the most general kinematics and good

[5] Elizabeth B. Dussan V

experiments that have shown everything there is to know about the general features of contact lines. So, that work is a very famous piece of work, and before that nobody had done anything really.

I **You collaborated in this?**

D Of course, yes. Let me tell you how I discovered moving contact lines. I was in London with a professor from Imperial [College] at a bar. We were drinking. I was drinking a martini. And, you know, if you take the glass and you tilt it, the interface moves up the wall and down the wall. So I asked, how is that possible with the no-slip condition, which is usually what fluid dynamicist uses: that there's no relative velocity between the liquid and the solid right at the wall. He had no idea, of course, but I realized that was a real problem. And that was the problem that she [Elizabeth Dussan] discussed.

I **It is very serendipitous.**

D Exactly. So that work has led to a whole industry of people working on contact lines, including people here like Weiqing Ren who works on contact lines.

I **Doesn't this involve some boundary value problems?**

D Yes, but they're boundary value problems problems of modified type.

I **But the contact lines move, do they?**

D They do move. And so, what happens is if you do a standard analysis using a no-slip condition between the liquid and the solid, it takes an infinite force to move the front, which is not good. So, you have to use a different boundary condition which allows the contact line to move.

I **In the history of materials science, was there any new material that was anticipated, or at least inspired by mathematics?**

D Well, the work I do doesn't involve this. But, for example, there was a group in Materials Science at Northwestern, where I come from, that is trying to answer the following problem. If I tell you, "I need a material with all these different properties, how do I get the material? "They have a computer program that, for a class of materials and prescribed properties, predicts one or several materials that satisfy all the conditions.

I **Those materials are already existing?**

D Not necessarily. What they do is they are really taking all the different properties they know of materials and putting them together in such a way that they get one material or several materials compatible with all those properties.

I **And this is done with a computer?**

D Well, it used to be done in experimental laboratories and it is still done in experimental laboratories, but it takes years to do that. On a computer, it takes seconds.

I **You mean they actually produce a material with the required molecular structure and everything?**

D Yes. Well, they don't produce the material, but they tell you what the material is. So, you produce it later.

I **Who is able to do that?**

D Well, they have all the molecular structures, all the dynamics built in there. It's a huge program, and so, they put in everything they know. It's not perfect yet, but they are getting to a stage where they can get exactly what they want. It's remarkable.

I **This is like alchemy.**

D It is like alchemy; that's right.

I **I can't believe it. It means, in principle, you can produce almost anything that you want.**

D Well, I guess if you ask for too many properties and they contradict each other, you can't get anything. So, there has to be at least one material that satisfies all of those properties.

I **NASA would be interested in this sort of thing.**

D Well, they do work with NASA.

I **I believe you said you've started a company in industry and you are actively engaged in it for about 15 years. What kind of company was it?**

D It was a consulting company. So, I was the consultant and I hired other people as consultants and we solved industrial problems that different companies wanted. See, I learned much more from this than working at the RAND Corporation because, you know, you find that the real-world problems have things that you can reduce to something simple, which are good scientific problems. And so, that was a very good experience.

I **It's quite computational, right?**

D Well, we did some computation, but most of what we did was modeling and analysis. So, I worked with a company that makes fiberglass fibers, one that drills for oil, and two oil companies. So, there were a lot of different kinds of companies that I worked with.

I **So, it's quite profitable, isn't it?**

D It was profitable, yeah. but, of course, I'm not a billionaire.

I **I think some of your activity in the industry overlaps with your academic career, right?**

D Well, they were done at the same time, simultaneously. So, I was still a professor, but I had a company as well.

I **This is really quite unusual in the sense that you're solving real-life problems whereas people always think that people in the university are not doing real-life problems.**

D Well, there's like a whole spectrum, going from very applied to very pure, and everything in between is possible.

I **Breakthroughs in pure mathematics, such as the solution of the four-color theorem, the Poincaré conjecture, and Fermat's Last Theorem are often projected to the general public as great intellectual achievements. but advances in applied mathematics are rarely highlighted to the public. Do you think that more should be done to foster awareness in advances in applied mathematics?**

D Absolutely, yes. The trouble with applied mathematicians is that they are not good politicians. So, you know, in pure mathematics, they identify a problem like Fermat's Last Theorem, and they say, "If we solve this, the world will change." And it was solved and the world didn't change, but they're very good at publicity. We should do a lot better job because what we do has more influence on the world than what they do.

I **I think the physicists are very good in this.**

D And physicists are very good at that. You see, when you review a proposal from pure mathematicians or a proposal by physicists, all the reviews say that this person is a genius whereas the applied people never say that.

I **I thought applied mathematicians are very good at getting grants rather than the pure mathematicans.**

D Yeah, that's right. exactly. So, in Northwestern, the pure mathematicians don't get very much in grants and we [applied mathematicians] do get a lot.

I **But then the pure mathematicians get enough publicity when difficult problems are solved.**

D So, they do that better than we do. We should do better.

I **What about SIAM? They do a lot of publicity for applied mathematics.**

D Uh, not as well as the pure mathematicians. See, in applied mathematics, it's very hard to pick something that needs solution, like Fermat's Last Theorem because in applied mathematics, it's very broad in terms of physics, mathematics and engineering. And so, the real hard things to do are the modeling. And after you have a model, we can find a way to solve it. But we do not prove a theorem; we solve it either numerically or analytically. See, they [the pure mathematicians] want to prove theorems and proving theorems is harder, but it's also narrower.

I **But if you can produce a model that works for a lot of things, that will be worth publicizing.**

D We should do that.

I **What about your students? You have a lot of students, right?**

D I've had 40 PhD students.

I **It is a very large number.**

D It is. And so, actually, several of my students have retired already, but I haven't.

I **Really remarkable. And you're still traveling around the world.**

D Yes.

Watch a recording of our public lectures

Indra's Pearls: A Mathematical Adventure
Caroline Series, *University of Warwick, UK*

The Importance of Quantum Mechanics to Saving Our Planet
Kieron Burke, *University of California, Irvine, USA*

Can Every Mathematical Problem Be Solved?
Menachem Magidor, *The Hebrew University of Jerusalem, Israel*

Mobile Health Intervention Optimization
Susan A. Murphy, *Harvard University, USA*

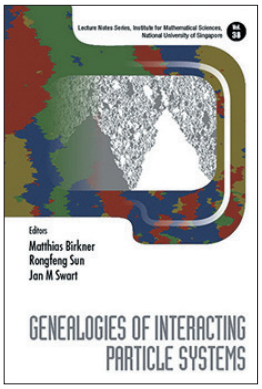
YouTube

Available on our webpage and YouTube channel
tinyurl.com/imsnus

LECTURE NOTE SERIES

VOLUME 38

Genealogies of Interacting Particle Systems



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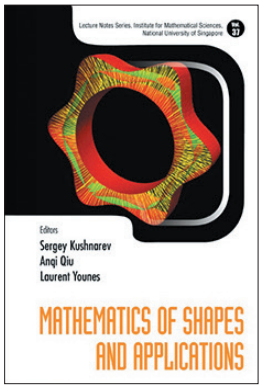
VOLUME 37

Mathematics of Shapes and Applications



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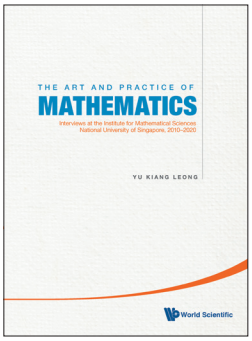
INTERVIEW VOLUME

The Art and Practice of Mathematics

AUTHORED BY:

- **Yu Kiang Leong**



This book constitutes the second volume of interviews with prominent mathematicians and mathematical scientists who visited the Institute for Mathematical Sciences, National University of Singapore. First published in the Institute's newsletter Imprints during the period 2010–2020, they offer glimpses of an esoteric universe as viewed and experienced by some of the leading and creative practitioners of the craft of mathematics.

The topics covered in this volume are wide-ranging, running from pure mathematics (logic, number theory, algebraic geometry) to applied mathematics (mathematical modeling, fluid dynamics) through probability and statistics, mathematical physics, theoretical computer science and financial mathematics. This eclectic mix of the abstract and the concrete should interest those who are enthralled by the mystique and power of mathematics, whether they are students, researchers or the non-specialists.

For more information, visit ims.nus.edu.sg >> Publications

CALL FOR PROPOSALS

The Institute for Mathematical Sciences (IMS) of the National University of Singapore (NUS) invites submissions of proposals from researchers in academia and industry. The proposals are for organizing thematic programs or workshops to be held at IMS.

The IMS is particularly interested in receiving proposals of programs/workshops that focus on exciting new developments in the mathematical sciences. Proposals of interdisciplinary nature in areas that interface mathematics with science, social science or engineering are welcome.

A soft copy of the proposal, for the period of funding from **1 July 2023 to March 2024**, should be sent to the Director of the Institute at imsdir@nus.edu.sg by **31 May 2021**.

The exposition of a proposal should be aimed at the non-specialist and will be evaluated by a scientific panel. Proposals of interdisciplinary programs/workshops should describe how the activity would benefit the intended audience with diverse backgrounds and facilitate research collaboration.

Information on the Institute and its activities, as well as a detailed format for the proposal are available on the IMS website ims.nus.edu.sg. Enquiries may be directed to imssec@nus.edu.sg.

NUS National University of Singapore | IMS Institute for Mathematical Sciences

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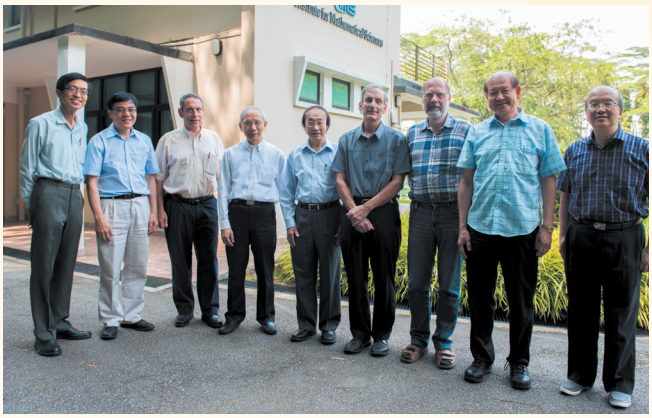
21 Celebrating years of Mathematical Synergy

2011 Visit to TMSI



2015 SAB

Committee members

Current SAB members
- Iain Johnstone (Chair)
- Louis Chen
- Chi Tat Chong
- Choy Heng Lai
- Fang-Hua Lin
- Ngô Bảo Châu
- Benoît Perthame
- Gim Pew Quek
- Adrian Röllin
- Emmanuel Ullmo

Former SAB members
- Douglas N. Arnold
- Jianqing Fan
- Hans Föllmer
- Avner Friedman
- Wolfgang Hackbusch
- Roger Howe (Chair, 2000–2010)
- Jacques-Louis Lions (1928 - 2001)
- Pao Chuen Lui
- Keith Moffatt
- David Mumford
- Jill Pipher
- Olivier Pironneau
- Tong Boon Quek
- David Siegmund
- Yum-Tong Siu (Chair, 2011–2018)
- Hugh Woodin

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- Yue Khei Lau, William
- Seng Luan Lee
- Tong Heng Lee
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- Mong King Lim
- Andrew Lim
- Paul Matsudaira
- Andrew Nee
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- Beng Chin Ooi
- K K Phua
- Seeram Ramakrishna
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- Denny Leung
- Ka Hin Leung
- Yeneng Sun
- Ser Peow Tan
- Wing Keung To

Outreach

As part of its outreach program, the Institute organizes several lectures delivered by prominent mathematical scientists each year. These lectures raise public awareness and the role of mathematics in science, engineering, technology and industry. Some of them have attracted over 200 participants!

Persi Diaconis: The Search for Randomness

Shing-Tung Yau: The Shape of Inner Space

The Search for Randomness

Persi Diaconis, Stanford University
19 August 2003, 6pm

Numbers and Code, Behind the Magic of Visual Effects

Jointly organized with NUS High School of Mathematics and Science
Jiayi Chong, Pixar Animation Studios
7 Jul 2010, 3.30pm

The Shape of Inner Space

Jointly organized with Department of Mathematics
Shing-Tung Yau, Harvard University
4 Jan 2011, 6pm

What's Math Got to Do with It? Mathematics at the Frontiers of Sciences and Technology

Jointly organized with Singapore Mathematical Society and Department of Mathematics, NUS
Tony Chan, University of California
15 Dec 2003, 6pm

2015: IMS Receives a Gift in Memory of Mr Ng Kong Beng

Mr Ng Kok Lip and Mr Ng Kok Koon have endowed a gift of S$250,000 to the Institute for Mathematical Sciences (IMS) in memory of their late father, Mr Ng Kong Beng. The Ng Kong Beng Memorial Fund 黄光明纪念基金 thus established will provide funding support to the Institute's graduate summer/winter school programs and public lectures, and the latter have been named the Ng Kong Beng Public Lecture Series 黄光明公开讲座. The inaugural Ng Kong Beng Public Lecture "Magic Pictures About Higgs Bundles" was presented by Professor Tamás Hausel (École Polytechnique Fédérale de Lausanne, Switzerland) at NUS on 7 August 2014.

IMS has also hosted lectures outside of the university campus, including the National Library Board.

Bubbles-Foams, Grains-Metals: Curvature Flow in Cellular Materials

David J. Srolovitz, University of Pennsylvania and Penn Institute for Computational Science
9 Feb 2015, 6.30pm

David J. Srolovitz: Bubbles-Foams, Grains-Metals: Curvature Flow in Cellular Materials

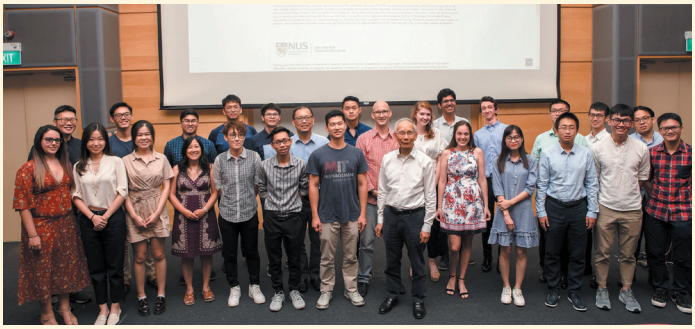
Past events

Programs organized by IMS brought members of the international scientific community to Singapore to share ideas and collaborate with local scientists.

Researchers and non-researchers (i.e. computational chemists, engineers, numerical analysts, biologists, material scientists and mechanical engineers) discuss interesting fundamental problems, explore possible solutions/ applications related to specific fields of interest (i.e. engineering, social science, computer science, informatics, finance, economics, statistics, physicals, chemical science, computational chemistry and biology, homotopy theory).

Workshop on Living Analytics: Analyzing High-Dimensional Behavioral and Other Data from Dynamic Network Environments 1 (26–28 February 2014)

The workshop broadened the statistical research underpinnings of models and computational algorithms for living analytics research and other research activities involving the analysis of large high-dimensional databases. The workshop has provided a forum for scientists to interact and develop methodology for "big data" problems using living analytics as a focal point.



RIPS 2019

Workshop on Living Analytics: poster and demo session

Summer school of the Econometric Society 2018

Training

Programs also had a strong educational component and provided mentoring to students and young scientists, through summer schools, tutorials, and informal discussions.

Asian Initiative for Infinity (AII) Graduate Summer School (2010-2012)

The AII Graduate Summer School (jointly funded by the John Templeton Foundation) consisted of a set of intensive short courses conducted by leaders in the field. It provided an important opportunity for graduate students and young researchers in Singapore and the region to learn about the latest research developments in the fundamental area of mathematical logic.

Combinatorial and Toric Homotopy (1–31 August 2015)

This program started a Young Topologist Seminar (11–19 August 2015), which consisted of tutorials on advanced topics in algebraic topology, seminars on toric topology, combinatorial and applied topology and geometric groups. This seminar, which aimed to train junior topologists, focused on various applications of topology to computer sciences and robotics.

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

Many participants expressed appreciation for the learning sessions planned during this program, stating that they had benefitted from the sessions more than conventional talks.

Dynamic Models in Economics (4–22 June 2018 & 2 July–3 August 2018)

The summer school of the Econometric Society (15 - 19 June 2018) was held in Singapore as part of this program.

Research in Industrial Projects for Students (RIPS) 2019 – Singapore (17 June–9 August 2019)

The Research in Industrial Projects for Students Program in Singapore (RIPS-SG) was run by IMS in collaboration with Institute for Pure and Applied Mathematics at the University of California, Los Angeles.

RIPS 2019

This project, which started in 2019, provides an opportunity for undergraduate students to work in international teams on a real-world research project proposed by sponsors. Projects vary, but all involve mathematics, statistics, data science and computer science to some degree.

Density Functionals for Many-Particle Systems: Mathematical Theory and Physical Applications of Effective Equations (2–27 September 2019)

The workshop was an integral part of the NUS module 'QT5201R: Density Functional for Many-Particle Systems' aimed at graduate students from the university; Centre for Quantum Technologies, Physics, Mathematics, and Chemistry.

Collaborations

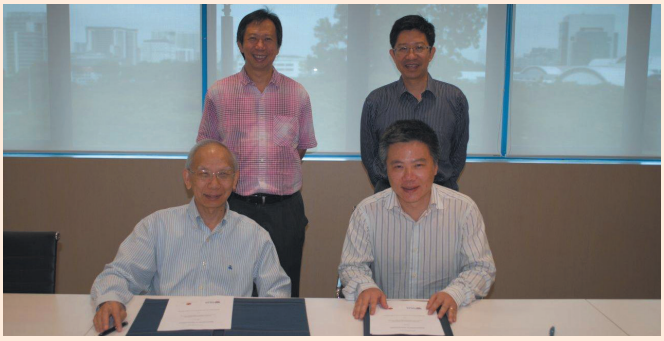
IMS established ties with two mathematics institutes in the Asia Pacific region for research collaboration and joint organization of programs and activities.

Joint research and academic exchange agreement with the National Institute for Mathematical Sciences

On 16 August 2014, an agreement on joint research and academic exchange was signed by Professor Dongsu Kim, President of the National Institute for Mathematical Sciences, and Professor Chong Chi Tat, Director of IMS. The agreement includes funding visiting researchers and graduate students to participate in research programs of the host institute.

Memorandum of Understanding with the Vietnam Institute for Advanced Study in Mathematics

On 30 January 2015, a memorandum of understanding (MOU) between the Institute for Mathematical Sciences (IMS), NUS and the Vietnam Institute for Advanced Study in Mathematics was signed by Professor Chong Chi Tat, Director of IMS, and Professor Ngô Bảo Châu, Scientific Director of VIASM. Both institutes agree to promote joint research, develop areas of Mathematical Sciences of mutual interests, and to cooperate on the exchange of scientific academic, and technical information.

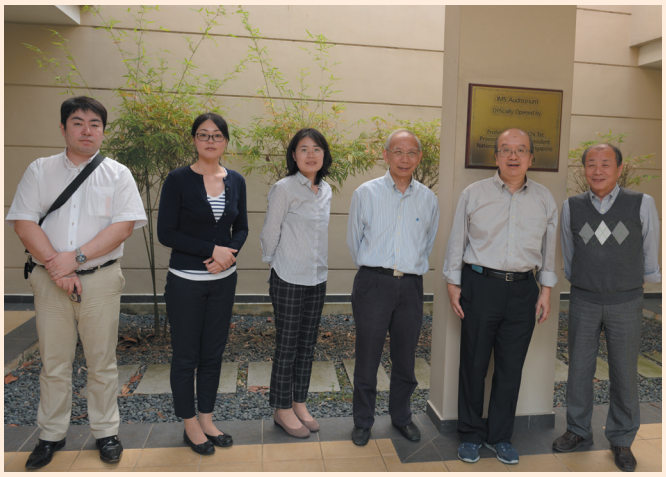


2015 MOU signing

Visit from Tohoku Forum for Creativity, Japan

On January 2015, the Institute hosted Professor Yoshiaki Maeda and his colleagues from the Tohoku Forum for Creativity. Professor Chi-tat Chong, Director of IMS, gave a brief presentation of our institute's mission, organizational structure, and highlighted some of our past and upcoming programs. During the visit, Professors Maeda and Chong exchanged ideas to foster further collaboration in research/programs.

Some programs were hosted at venues outside IMS; within NUS (Yong Siew Toh Conservatory of Music) or other instituitions (Nanyang Technological University, Singapore Management University).



2015 Visit from Tohoku Forum for Creativity

Mathemusical Conversations: Mathematics and Computation in Music Performance and Composition (13–15 February 2015)

This workshop, which was jointly organized with Yong Siew Toh Conservatory of Music at NUS, brought together world experts and emerging scholars in and across mathematics, with a special emphasis on mathematical and computational research in music performance and composition that serve as the foundation for understanding and enabling human creativity and for future music technologies.

This workshop with her exclusive focus on mathematics and music was first of its kind in Asia. The workshop was also jointly organized with the Centre for Digital Music, Queen Mary University of London, UK, Science and Technology of Music and Sound Lab, IRCAM, CNRS, UPMC, France.

Performance by Kam Ning, Eran Egozy and Elaine Chew

Panel discussion during the workshop on Mathematics for Defence (April 2012)

Industry/ Applications

Speakers presented in their talks various interesting and impactful examples on how mathematics is applied and created to solve challenging problems arising from industries. The wide spectrum of industry-related problems described in the talks had widened the perspectives of local researchers and students from various research institutes such as A*STAR (Institute for Infocomm Research, Bioinformatics Institute, Data Storage Institute) and DSO; industries (PSA, AIMMS, Robert Bosch, and Khoo Teck Puat Hospital); and instituitions (Ministry of Education, National Institute of Education, Singapore; School of the Arts Singapore (SOTA), Singapore Institute of Management (SIM).

Workshop on Mathematics for Defence (13 April 2012)

The one-day workshop brought together defence scientists and mathematicians to discuss and exchange ideas. There was also a panel discussion on enhancing collaboration between the two groups of researchers.

Joint Workshop of IMS and IMI on Mathematics for Industry: Biology and Climate Prospects (3–7 September 2012)

The workshop was the first collaboration between IMS and the Institute of Mathematics for Industry at Kyushu University, Japan.

IMS-JSPS Joint Workshop in Mathematical Logic and Foundations of Mathematics (1–5 September 2014 and 15–16 January 2016)

In recent years, interaction among researchers in East Asia, particularly in Japan, China and Singapore in foundations and other areas of mathematical logic has increased significantly. This workshop, jointly sponsored by the Japan Society for the Promotion of Science and the National University of Singapore, provide participants a venue for continued interaction and explore new research collaborations in three broad areas of common interest: reverse mathematics (involving both standard and nonstandard models of arithmetic), algorithmic randomness (in both classical and higher setting), and set theory (particularly cardinal characters of the continuum). It was a great opportunity for graduate students and young researchers, especially from Japan, to give talks and meet many international scientists.

Networks in Biological Sciences (1 June–31 July 2015)

This program focused on the mathematics for network models (both cellular protein networks and network models in evolution) in Biology. This was the first program on network models in biology held in Asia.

Mathematics of Shapes and Applications (4–31 July 2016)

This program provided a systematic and comprehensive program in the study of shapes. The workshop on biomedical imaging and computer vision (25 - 29 July 2016) was divided into two themes: a Neuroimage Workshop (25 – 27 July 2016) and a Computer Vision workshop (28 – 29 July 2016). The program was able to attract a diverse audience from various disciplines and institutions such as Clinical Imaging Research Center, NUS-A*STAR, Duke-NUS Medical School, Singapore Institute for Neurotechnology (SINAPSE), NTU, SUTD, Singapore Bioimaging Consortium (SBIC), Bioinformatics Institute, Singapore Institute for Clinical Sciences, Institute

for Infocomm Research, National Neuroscience Institute, DSO National Laboratories, Bureau Veritas Singapore and Advanced Digital Sciences Center in Singapore

Data Sciences: Bridging Mathematics, Physics and Biology (29 May–16 June 2017 and 4–12 January 2018)

This program in data science was designed to promote the development of science-driven mathematical and computational methods to mine and utilize large datasets in science and engineering. During the workshop "Frame Theory and Sparse Representation of Complex Data", several speakers presented mathematical results towards the understanding of deep neural networks from different perspectives.

The inaugural validation task force for X-ray Free-electron Laser (XFEL) based single particle imaging (SPI) was initiated in the second half of this program. To date, XFEL-SPI has been regarded as one of the most ambitious bio-imaging project of biomolecules in their native state. This project requires the collection and processing of very large amounts of noisy, sparse, and complex data, which tends to involve many computational steps that are currently controlled by ad-hoc parameters. The complexity of this workflow makes it challenging to check the validity of the intermediate steps as well as the results at the end of the workflow. Represented at this workshop were key experts in various parts of the XFEL-SPI data processing pipeline, who unanimously acknowledged the importance of setting up this validation task force. Participants extensively discussed the potential pitfalls and safeguarding measures, and whether the latter were already present or had to be invented.

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

The scientific community has witnessed an increased interest in quantitative methods for discovering new treatments for personalized medicine. The program has brought together international experts from academia and the pharmaceutical industry to share their knowledge and discuss research ideas. There is already a U.S. industry working group called "Quantitative Sciences in the Pharmaceutical Industry" dedicated to sharing information on exploratory and confirmatory techniques for subgroup identification and analysis. It attracted health and medical professionals in the pharmaceutical and biotechnology community in Singapore.

Statistical Methods for Developing Personalized Mobile Health Interventions (4 February–1 March 2019)

The program aimed to focus on the theme of quantitative methods for developing personalized mHealth interventions, bring together perspectives from statisticians, computer scientists, as well as health/behavioural scientists working in the area of mHealth. The goal was to provide a platform for intellectual exchange between statisticians, computer scientists and quantitatively oriented public health/clinical/behavioural/health services researchers on the theme of mHealth, so that they all can learn from each other about the cutting–edge study design and analyze techniques in mHealth, as well as practical lessons from real studies. The primary application area of focus was on the management of chronic diseases and conditions, and thus broadly of interest to scientists based in Singapore.

Quantitative Finance (18–22 March 2019 & 22 July–31 August 2019)

Quantitative finance is an interdisciplinary research area related to finance, mathematics, and statistics, and requires advanced quantitative techniques. Increased interest in this field–in academia and industry–has led to breakthroughs and an explosion of research activity. Participants were encouraged to present their recent works including theories, methods and applications in several aspects of quantitative finance, which include but are not limited to stochastic control in finance, FinTech and machine learning, and asset pricing and risk management.

Computational Approaches to the Analysis of Biomolecular Sequences, Structures and Their Functions and Applications to Biotechnology and Clinical Data Studies (23–27 March 2020)

The workshop aimed to cover topics on theoretical modelling and simulations of biomolecular evolution, protein sequence and 3D structure, and the dynamical relationship with biomolecular function and how to use them to bridge the gap to phenotype and clinical application.

Celebrations

Combinatorial and Toric Homotopy (1–31 August 2015)

Frederick R. Cohen, Professor of Mathematics at the University of Rochester, has made major contributions in homotopy theory, particularly in the study of loop spaces, and configuration spaces, with connections to braid groups, modular forms and cohomology of groups. This program was organized to honor his achievements as a scholar and a teacher and to celebrate his 70th birthday. Although he was not able to attend the program at IMS, the organizers connected with him through a half-hour Skype session on 27 August 2015.

Skype session with Frederick R. Cohen

Aspects of Computation (21 August–15 September 2017)

in celebration of the research work of Professor Rod Downey This four-week program focused on recent developments in parametric complexity theory, computability theory with applications in algebra, algorithmic randomness, model theory. Computation theory has received a lot of attention by mathematicians and theoretical computer scientists during the last few decades.

Conference on 60 Years of Yang-Mills Gauge Field Theories (25–28 May 2015)

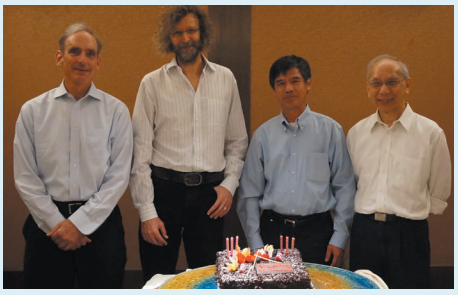
The co-chairs were Lars Brink (Chalmers University of Technology) and Phua Kok Khoo (IAS, Nanyang Technological University). There were a total of 51 talks and a public lecture on "Personal Perspectives on Physics" which included talks delivered by Nobel laureates Yang Chen Ning and David Gross.

Workshop on Spline Approximation and its Applications (4–6 December 2017)

Carl de Boor's contributions to splines, approximation theory, scientific computing, mathematics, and science have not gone unnoticed. At the occasion of Carl de Boor's 80th birthday, the workshop brought together a group of mathematicians from many generations who have worked on spline functions and applications. The workshop not only reviewed the glorious history of the development of spline functions, but has also provided an opportunity to inspire future directions of spline functions in both theory and applications.

Higher Recursion Theory and Set Theory (20 May–14 June 2019)

This program was held in celebration of the research work of Professors Theodore A. Slaman and W. Hugh Woodin.



Birthday celebrations with Professors Hugh Woodin, Theodore Slaman, Feng Qi and Chi-tat Chong

Symposium in Memory of Charles Stein [1920–2016] (17–28 Jun 2019)

The objective of the symposium was to bring together leading international experts in statistics and probability to pay tribute to Charles Stein. The symposium comprised two parts, one on statistics and the other on probability. The topics of the talks included historical perspectives on Charles Stein, his influence on various areas in statistics, in particular shrinkage estimation, and probability theory, in particular Stein's method. There is a long history of meetings at IMS related to his work, in particular to what is now called Stein's method. What started with a successful and very influential five-week program in 2003, was followed by smaller, but equally important workshops at IMS in 2009, 2010 and 2015, and these meetings had a high, measurable impact on the field. While a part of this year's symposium was similar in spirit to these previous meetings, widening the range of topics by including Stein's contributions to statistics and bringing together researchers from otherwise rather separate communities has undoubtedly expanded each community's horizon and will foster new interaction between the fields.

Birthday celebrations for Professor Carl de Boor

Continuation of existing conferences

Algorithmic Randomness (2–30 June 2014)

Activities involved the 2014 "Computability, Complexity and Randomness Conference" (CCR 2014), a regular and yet important meeting devoted generally to the mathematics of computation and complexity, but tends to primarily focus on algorithmic randomness/algorithmic information theory and its impact on mathematics.

Workshop on Computability Theory and the Foundations of Mathematics (8–12 September 2017)

The scope involves Computability Theory, Reverse Mathematics, Nonstandard Analysis, Proof Theory, Constructive Mathematics, Theory of Randomness and Computational Complexity Theory. The CTFM series has been headed by Kazuyuki Tanaka (Tohoku University). Meetings were usually held in Japan. It was the first time the workshop was held in Singapore.

Pan Asia Number Theory Conference 2018 (25–29 June 2018)

The Pan Asia Number Theory Conference is an annual conference focused on exciting recent developments in number theory and related subjects, especially those occurring in the greater Asian regions or by mathematicians of Asian origin.

Theories and Numerics of Inverse Problems (6–17 August 2018 & 24–28 September 2018)

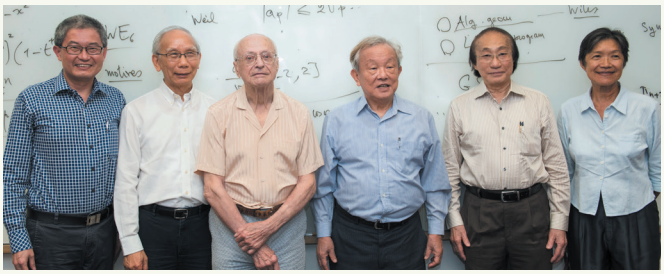
The 9th International Conference on Inverse Problems and Related Topics (13–17 August 2018) was held in Singapore as part of the program.

Statistical Data Integration (5–16 August 2019)

The program consisted of a three-day conference, which was a satellite to the 62nd ISI World Statistics Congress, held in Kuala Lumpur from 18–23 August 2019.

Distinguished Visitor Lecture Series

This program started in 2015. Under this program, the Institute has enjoyed visits from a stellar array of distinguished scientists. The list of distinguished visitors can be found on our website.



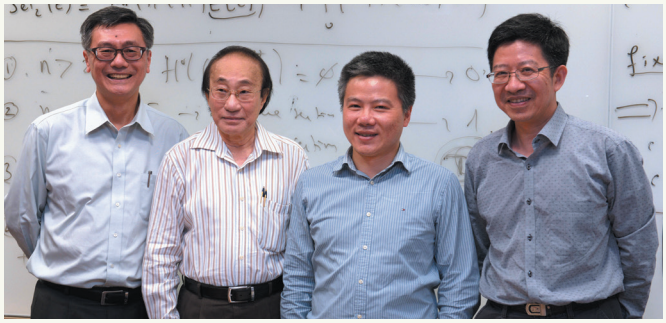
Oppenheim lecture by Jean-Pierre Serre (2018)

Conversation with Professor Elon Lindenstrauss (2017)

Oppenheim Lecture by Emmanuel Candes (2016)

Oppenheim Lecture

The Oppenheim Lectures is a distinguished lecture series jointly organized by the Department of Mathematics, and the Institute. It is held annually beginning from 2015, and is in honour of Sir Alexander Oppenheim. The inaugural Oppenheim Lecture was delivered by a Field medalist, Professor Ngô Bảo Châu of the University of Chicago and the Vietnam Institute for Advanced Study in Mathematics on 28 January 2015.



Oppenheim Lecture by Ngô Bảo Châu (2015)

Supplementary funding

The Geometry, Topology and Physics of Moduli Spaces of Higgs Bundles (7 July–29 August 2014)

National Science Foundation, GEAR and the European Research Council

Workshop on Stochastic Processes in Random Media (4–15 May 2015)

Office of Naval Research Global

Density Functionals for Many-Particle Systems: Mathematical Theory and Physical Applications of Effective Equations (2–27 September 2019)

Julian Schwinger Foundation

Testimonials/Voices

- I have presented some work that is already finished, but I am working on some extensions, and the questions at IMS also gave some ideas
- Whenever I visit IMS, It is a valuable time for me. People in IMS are fantastic. I enjoy very much and learn a lot. Certainly, IMS provides the best meetings.
- The environment was very welcoming, and the various whiteboards and snacks in the lounge were conducive to productive discussions!
- The information received in advance are very useful. The rooms for discussions are very useful.
- This was a very stimulating conference. Thanks a lot!
- The conference was extremely well organized, with a very good mix of the young generation and well known leading experts in the area.
- The learning sessions were really helpful. Presentations and open discussions format help me to get an overview of some of the important modern research areas.
- I met people that could create potential collaboration done the road and I have learned a lot in the advancement of statistical methods for classification that is an important step to achieve personalized medicine. Attending this workshop has opened my mind for how to lead statisticians in my company to broaden and enhance our statistical knowledge and tools in subgroup identification. I appreciated the organized group outing events, a lot fun and great opportunity for team building. Thanks to IMS for the efforts in organizing such workshop and for your generous financial support for us to attend the workshop.
- Full of different topics and perspectives, but in a relaxed, interactive environment.
- Renewing old contacts, making new ones, learning about new work.